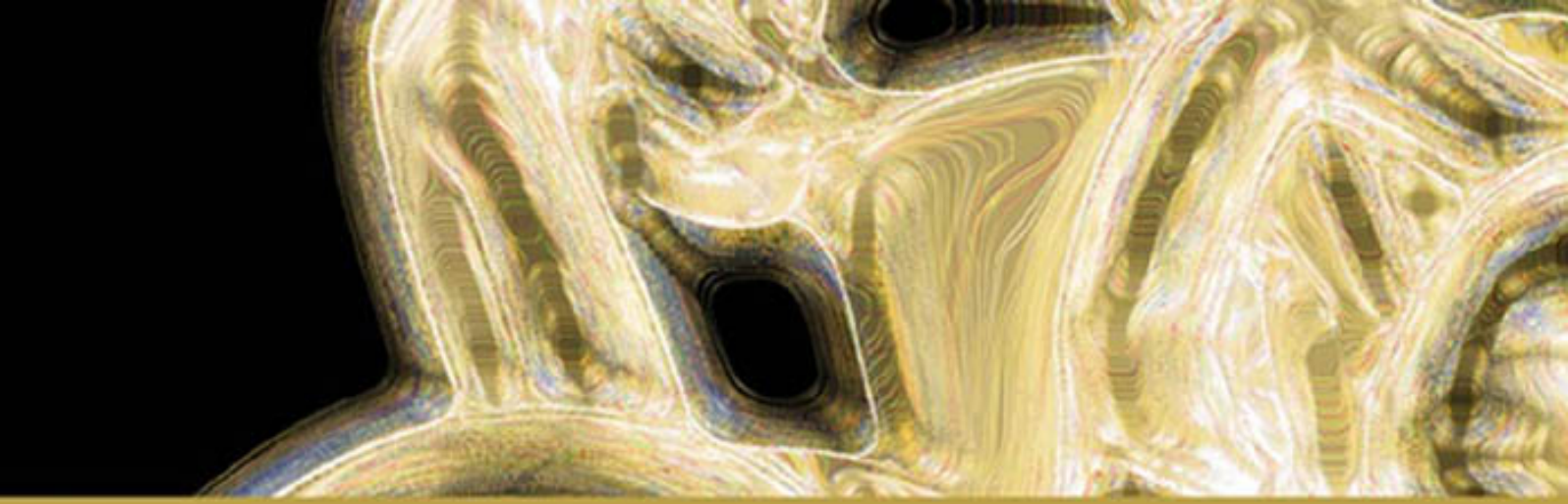


Clinical Audiology

An Introduction

SECOND EDITION



Brad A. Stach

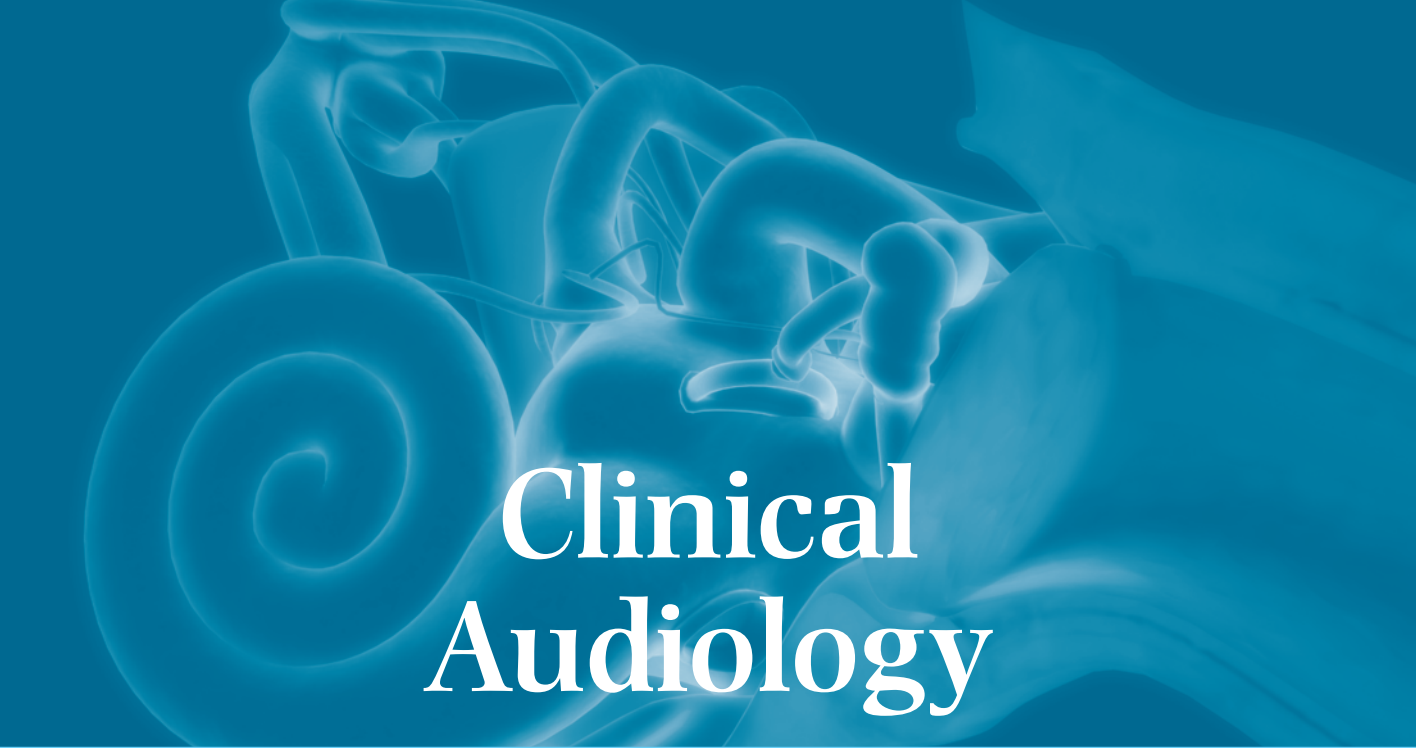
Clinical Audiology

An Introduction

SECOND EDITION

For my daughters,

Madeline Elizabeth and Rachael Hanoven Stach



Clinical Audiology

An Introduction

SECOND EDITION

Brad A. Stach, Ph.D.

Division of Audiology
Department of Otolaryngology—Head & Neck Surgery
Henry Ford Hospital
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Contents

Preface / xix
About the Author / xxiii
Acknowledgments / xxv

1
THE PROFESSION OF AUDIOLOGY IN THE UNITED STATES

Learning Objectives 2
What Is an Audiologist? 3
What Is an Audiologist's Role? 4
- Identification / 5
- Assessment and Diagnosis / 5
- Treatment / 5
- Education / 7
- Prevention / 7
- Research / 8
- Related Activities / 8
- Scope of Practice / 8

Where Do Audiologists Practice? 10
- Private Practice / 11
- Physician's Practices / 13
- Hospitals and Medical Centers / 14
- Hearing and Speech Clinics / 15
- Schools / 15
- Universities / 16
- Hearing Instrument Manufacturers / 17
- Industry / 18

Relation to Other Professions 19
Otolaryngology / 19
Other Medical Specialties / 21
Speech-Language Pathology / 22
Nonaudiologist Hearing Aid Dispensers / 24
Other Professionals / 24
The Evolution of Audiology 25
The Professional Heritage of Audiology / 25
From Academic Discipline to Health-care Profession / 25
From Communication Disorders to the Hearing Profession / 26
From Teacher-Training Model of Education to Health-Care Model / 27
From Certification to Licensure Model / 27
The Clinical Heritage of Audiology / 28
Audiology's Beginnings (Before 1950) / 29
Audiology as an Academic Discipline (1950s and 1960s) / 30
Audiology as a Clinical Profession (1970s and Beyond) / 31
Professional Requirements 33
Becoming an Audiologist / 33
Academic and Clinical Requirements / 34
Summary 35
Short Answer Questions 37
Discussion Questions 38
Information Sources 38
Organizations / 38
Resources / 39

2
THE NATURE OF HEARING

Learning Objectives 41
The Nature of Sound 42
What Is Sound? / 42
Properties of Sound / 45
Intensity / 46
Frequency / 51
Phase / 51
Spectrum / 52
The Auditory System 55
Outer Ear / 56
Middle Ear / 59
Anatomy / 59
Physiology / 60

Inner Ear / 61
Anatomy / 62
Physiology / 66
Auditory Nervous System / 71
The VIIIth Cranial Nerve / 71
The Central Auditory Nervous System / 72
The Vestibular System 76
Anatomy / 77
Physiology / 79
How We Hear 81
Absolute Sensitivity of Hearing / 81
The Nature of Hearing Sensitivity / 82
The Audiogram / 84
Differential Sensitivity / 89
Properties of Pitch and Loudness / 92
Measurement of Sound / 93
Summary 96
Short Answer Questions 97
Discussion Questions 99
Resources 99

3
THE NATURE OF HEARING LOSS

Learning Objectives 101
Types of Hearing Disorder 101
Hearing Sensitivity Loss / 102
Conductive Hearing Loss / 103
Sensorineural Hearing Loss / 105
Mixed Hearing Loss / 109
Suprathreshold Hearing Disorder / 110
Retrocochlear Hearing Disorder / 111
Auditory Processing Disorder / 113
Functional Hearing Loss / 116
Impact of Hearing Disorder 117
Patient Factors / 118
Degree and Configuration of Hearing Sensitivity Loss / 119
Type of Hearing Loss / 126
Conductive Hearing Loss / 126
Sensorineural Hearing Loss / 127
Retrocochlear Hearing Loss / 128
Auditory Processing Disorder / 129

Summary 130
Short Answer Questions 131
Discussion Questions 133
Resources 134

4
CAUSES OF HEARING DISORDER

Learning Objectives 136
Auditory Pathology 136
Conductive Hearing Disorders 138
- Congenital Outer- and Middle-Ear Anomalies / 138
- Impacted Cerumen / 141
- Other Outer-Ear Disorders / 143
- Otitis Media with Effusion / 143
- Complications of OME / 147
  - *Tympanic-Membrane Perforation / 147*
  - *Cholesteatoma / 149*
  - *Tympanosclerosis / 150*
- Otosclerosis / 150
- Other Middle-Ear Disorders / 151

Sensory Hearing Disorders 153
- Congenital and Inherited Sensory Hearing Disorders / 153
  - *Inner-Ear Anomalies / 153*
  - *Teratogenic Factors / 155*
  - *Syndromic Hereditary Hearing Disorder / 156*
  - *Nonsyndromic Hereditary Hearing Disorder / 158*
- Acquired Sensory Hearing Disorders / 159
  - *Perinatal Factors / 159*
  - *Noise-Induced Hearing Loss / 160*
  - *Trauma / 164*
  - *Infections / 165*
  - *Ototoxicity / 167*
  - *Ménière's Disease / 170*
  - *Presbyacusis / 171*
  - *Autoimmune Inner-Ear Disease / 175*
  - *Cochlear Otosclerosis / 176*
  - *Idiopathic Sudden Sensorineural Hearing Loss / 177*

Neural Hearing Disorders 177
- Auditory Neuropathy / 178
- VIIIth Nerve Tumors and Disorders / 179
- Brainstem Disorders / 181

Temporal-Lobe Disorder / 182
Other Nervous System Disorders / 182
Vestibular Disorders 183
Benign Paroxysmal Positional Vertigo / 184
Superior Canal Dehiscence / 185
Vestibulotoxicity / 185
Vestibular Neuritis / 186
Ménière's Disease / 186
Summary 186
Short Answer Questions 188
Discussion Questions 191
Resources 191
Articles and Books / 194
Web Sites / 195

5
INTRODUCTION TO HEARING ASSESSMENT

Learning Objectives 197
The First Question 199
Referral-Source Perspective / 199
Importance of the Case History / 201
The Audiologist's Challenges 207
Evaluating Outer- and Middle-Ear Function / 208
Estimating Hearing Sensitivity / 212
Determining Type of Hearing Loss / 214
Measuring Speech Recognition / 217
Measuring Auditory Processing / 218
Measuring the Impact of Hearing Loss / 219
Screening Hearing Function / 221
Newborn Hearing Screening / 224
School-Age Screening / 227
Workplace Screening / 228
Summary 228
Short Answer Questions 230
Discussion Questions 232
Resources 232
Articles and Books / 232
Web Sites / 234

6
THE AUDIOLOGIST'S ASSESSMENT TOOLS: PURE-TONE AUDIOMETRY

Learning Objectives 236
Equipment and Test Environment 236
The Audiometer / 236
Transducers / 238
Test Environment / 242
The Audiogram 242
Threshold of Hearing Sensitivity / 242
The Audiogram / 243
Modes of Testing / 244
Audiometric Symbols / 246
Audiometric Descriptions / 247
Establishing the Pure-Tone Audiogram 252
Patient Preparation / 253
Audiometric Test Technique / 254
Air Conduction / 256
Bone Conduction / 256
Masking / 258
Air-Conduction Masking / 261
Bone-Conduction Masking / 262
Masking Strategies / 262
The Masking Dilemma / 264
Audiometry Unplugged: Tuning Fork Tests / 265
Summary 267
Short Answer Questions 268
Discussion Questions 271
Resources 271

7
THE AUDIOLOGIST'S ASSESSMENT TOOLS: SPEECH AUDIOMETRY AND OTHER BEHAVIORAL MEASURES

Learning Objectives 274
Speech Audiometry 274
Uses of Speech Audiometry / 275
Speech Thresholds / 275
Pure-Tone Cross-Check / 276

Speech Recognition / 276
Differential Diagnosis / 277
Auditory Processing / 277
Estimating Communicative Function / 278
Speech Audiometry Materials / 278
Types of Materials / 279
Redundancy in Hearing / 280
Other Considerations / 283
Clinical Applications of Speech Audiometery / 285
Speech-Recognition Threshold / 285
Speech Detection Threshold / 288
Word Recognition / 290
Sensitized Speech Measures / 295
Speech Recognition and Site of Lesion / 298
Predicting Speech Recognition / 300
Other Behavioral Measures 302
Traditional Site-of-Lesion Measures / 303
Masking Level Difference / 306
Summary 307
Short Answer Questions 307
Discussion Questions 310
Resources 310

8
THE AUDIOLOGIST'S ASSESSMENT TOOLS: IMMITTANCE MEASURES

Learning Objectives 314
Immittance Audiometry 314
Instrumentation 315
Measurement Technique 317
Basic Immittance Measures 318
Tympanometry / 318
Static Immittance / 325
Acoustic Reflexes / 327
Threshold Measures / 328
Suprathreshold Measures / 330
Principles of Interpretation 331
Clinical Applications 333
Middle-Ear Disorder / 333
Principles of Clinical Application / 333
Normal Middle-Ear Function / 334

Increased Mass / 334
Increased Stiffness / 334
Excessive Immittance / 334
Tympanic-Membrane Perforation / 336
Negative Middle-Ear Pressure / 338
Cochlear Disorder / 339
Retrocochlear Disorder / 345
Cochlear Hearing Loss / 346
Afferent Abnormality / 346
Efferent Abnormality / 346
Central Pathway Abnormality / 349
Summary 351
Short Answer Questions 351
Discussion Questions 354
Resources 354

9
THE AUDIOLOGIST'S ASSESSMENT TOOLS: PHYSIOLOGIC MEASURES

Learning Objectives 357
Auditory Evoked Potentials 357
Measurement Techniques / 359
Recording EEG Activity / 359
Signal Averaging / 362
The Family of Auditory Evoked Potentials / 364
Electrocochleogram / 365
Auditory Brainstem Response / 366
Middle Latency Response / 367
Late Latency Response / 368
Auditory Steady-State Response / 368
Clinical Applications / 370
Prediction of Hearing Sensitivity / 371
Infant Hearing Screening / 376
Diagnostic Applications / 378
Surgical Monitoring / 381
Summary 382
Otoacoustic Emissions 383
Types of Otoacoustic Emissions / 384
Spontaneous Otoacoustic Emissions / 384
Evoked Otoacoustic Emissions / 384
Relation to Hearing Sensitivity / 388

Clinical Applications / 389
Infant Screening / 389
Pediatric Assessment / 390
Cochlear Function Monitoring / 391
Diagnostic Applications / 392
Summary 392
Short Answer Questions 393
Discussion Questions 395
Resources 396

10
DIFFERENT ASSESSMENT APPROACHES FOR DIFFERENT POPULATIONS

Learning Objectives 399
Otologic Referrals 400
Outer- and Middle-Ear Disorders / 400
Evaluative Goals / 400
Test Strategies / 401
Illustrative Cases / 403
Cochlear Disorder / 408
Evaluative Goals / 408
Test Strategies / 408
Illustrative Cases / 410
Retrocochlear Disorder / 415
Evaluative Goals / 415
Test Strategies / 417
Illustrative Cases / 419
Adult Audiologic Referrals 427
Younger Adults / 428
Evaluative Goals / 428
Test Strategies / 428
Illustrative Case / 430
Older Adults / 431
Evaluative Goals / 431
Test Strategies / 432
Illustrative Case / 434
Pediatric Audiologic Referrals 437
Infant Screening / 438
Evaluative Goals / 438
Test Strategies / 438
Illustrative Case / 442

Pediatric Evaluation / 444
Evaluative Goals / 444
Test Strategies / 444
Illustrative Case / 452
Auditory Processing Assessment / 454
Evaluative Goals / 454
Test Strategies / 456
Illustrative Case / 460
Functional Hearing Loss 463
Indicators of Functional Hearing Loss / 465
Nonaudiometric Indicators / 465
Audiometric Indicators / 466
Assessment of Functional Hearing Loss / 467
Strategies to Detect Exaggeration / 467
Strategies to Determine "True" Thresholds / 468
Illustrative Case / 472
Summary 475
Short Answer Questions 476
Discussion Questions 477
Resources 478

11
COMMUNICATING AUDIOMETRIC RESULTS

Learning Objectives 482
Talking to Patients 482
Goal of the Encounter / 482
Information to Convey / 483
Matching Patient and Provider Perspectives / 486
Writing Reports 488
Documenting and Reporting / 488
Report Destination / 490
Nature of the Referral / 491
Information to Convey / 492
The Report / 494
The Audiogram and Other Forms / 504
Supplemental Material / 509
Sample Reporting Strategy / 509
Making Referrals 516
Lines and Ethics of Referral / 516
When to Refer / 520
Summary 523

Short Answer Questions 525
Discussion Questions 527
Resources 528

12
INTRODUCTION TO AUDIOLOGIC MANAGEMENT

Learning Objectives 530
The First Questions 532
- The Importance of Asking Why / 534
- Assessment of Treatment Candidacy / 538
  - *Audiologic Assessment / 538*
  - *Treatment Assessment / 540*

The Audiologist's Challenge 545
- Amplification—Yes or No? / 546
- Amplification Strategies / 550
- Approaches to Fitting Hearing Instruments / 554
- Approaches to Defining Success / 556
- Treatment Planning / 557

Summary 557
Short Answer Questions 558
Discussion Questions 560
Resources 560

13
THE AUDIOLOGIST'S TREATMENT TOOLS: HEARING INSTRUMENTS

Learning Objectives 563
Hearing Instrument Components 566
- Microphone and Other Input Technology / 566
- Amplifier / 568
- Receiver / 573
- Controls / 573
  - *Manual Control / 574*
  - *Programmable Control / 576*

Electroacoustic Characteristics 577
- Frequency Gain Characteristics / 577
- Input-Output Characteristics / 579
  - *Linear Amplification / 580*
  - *Nonlinear Amplification / 581*

Output Limiting / 584
Peak Clipping / 584
Compression Limiting / 584
Signal Processing / 585
Other Processing Features / 588
Hearing Instrument Systems ... 589
Conventional Hearing Aids / 590
Behind-the-Ear / 591
In-the-Ear / 594
Style Considerations / 597
Hearing Assistive Technology / 600
Assistive Listening Devices / 600
Other Assistive Technologies / 604
Implantable Hearing Technology / 606
Cochlear Implants / 606
Bone-Anchored Hearing Aids / 612
Middle-Ear Implants / 613
Summary ... 615
Short Answer Questions ... 616
Discussion Questions ... 618
Resources ... 619

14
THE AUDIOLOGIC TREATMENT PROCESS

Learning Objectives ... 621
Hearing Aid Selection and Fitting ... 621
The Prescription of Gain / 622
Hearing Instrument Selection / 626
Hearing Instrument Fitting and Verification / 627
Ear Impressions / 628
Quality Control / 630
Fitting and Verification / 631
Orientation, Counseling, and Follow-up ... 642
Assessing Outcomes ... 645
Post-Fitting Rehabilitation ... 647
Auditory Training and Speechreading / 647
Educational Programming / 648
Summary ... 649
Short Answer Questions ... 650
Discussion Questions ... 652
Resources ... 653

15
DIFFERENT TREATMENT APPROACHES FOR DIFFERENT POPULATIONS

Learning Objectives 656
Adult Populations 657
Adult Sensorineural Hearing Loss / 657
Treatment Goals / 657
Treatment Strategies / 657
Illustrative Case / 659
Geriatric Sensorineural Hearing Loss / 661
Treatment Goals / 661
Treatment Strategies / 662
Illustrative Case / 664
Pediatric Populations 666
Pediatric Sensorineural Hearing Loss / 666
Treatment Goals / 666
Treatment Strategies / 667
Illustrative Case / 670
Auditory Processing Disorder / 673
Treatment Goals / 673
Treatment Strategies / 674
Illustrative Case / 675
Other Populations 679
Conductive Hearing Loss / 679
Treatment Goals / 679
Treatment Strategies / 679
Illustrative Case / 681
Severe and Profound Sensorineural Hearing Loss / 684
Treatment Goals / 684
Treatment Strategies / 684
Illustrative Cases / 688
Summary 693
Short Answer Questions 694
Discussion Questions 696
Resources 696
Appendix A: Scope of Practice in Audiology / 698
Appendix B: Audiology: Scope of Practice 2004 / 702
Appendix C: Answers to Short Answer and Discussion Questions / 707
Glossary / 734
Index / 771

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Preface

THIS introductory textbook provides an overview of the broad field of audiology, a clinical profession devoted to the diagnosis and treatment of communication disorders that result from hearing impairment. The aim of the book is to provide general familiarization with the many different assessment and treatment technologies and to demonstrate how these technologies are integrated into answering the many challenging clinical questions facing an audiologist.

It is the intention of this book to introduce audiology as a clinical profession, to introduce the clinical questions and challenges that an audiologist faces, and to provide an overview of the various technologies that the audiologist can bring to bear on these questions and challenges. It is hoped that this type of approach will be of benefit to all students who might take an introductory course. For those students who will not pursue a career in audiology, the book will provide an understanding of the nature of hearing impairment, the challenges in its assessment and treatment, and an appreciation of the existing and emerging technologies related to hearing. For those who will be pursuing the profession, the book will also provide a basis for more advanced classes in each of the various areas, with the added advantage of a clinical perspective on why and how such information fits into the overall scheme of their professional challenge.

Rather than writing another introductory textbook focused on rudimentary details, I have attempted in this book to provide a big picture of the field of audiology. My assumptions were: (1) that the basics of hearing and speech sciences are covered in other textbooks and in other classes; (2) that teaching a basic skill in one of the audiometries is not as useful as a broader perspective; (3) that each of the topic areas in the book will be covered in significant depth in advanced classes; and (4) that by introducing young students to the broad scope of the field, they will be better prepared to understand the relevance of what they learn later.

For the nonaudiology major, this will promote an understanding of the clinical usefulness of audiology, without undue attention to the details of implementation.

In some of the clinical areas, I have included clinical notes that give descriptions of particular techniques that the student might consider using. Knowing that there are as many ways to establish a speech threshold as there are people teaching the technique, for example, I was reluctant to burden the beginning student with arguments about the merits of the various methods. Rather, I used the notes to express an opinion about clinical strategies that I have used successfully. I would expect that the contrary opinions of a professor would serve as an excellent teaching opportunity.

This publication is intended primarily for beginning-level students in the fields of audiology and speech-language pathology. It is intended for the first major course in audiology, whether it be at the undergraduate or graduate level. Both intentions challenged the depth and scope of the content, and I can only hope that I reached an appropriate balance.

Ten years have passed since the first edition of this textbook. Revising it gave me an inspiring view of the progress made in hearing health care over those years. When the book was first written, the profession of audiology was just beginning its transition to the doctoral level. Newborn hearing screening had not yet been fully implemented, and we did not yet have clear insight into the diagnosis of auditory neuropathy and similar disorders. All of that has changed. Advances on the treatment side have been even more stunning, from the dramatic changes in hearing aid technology to the remarkable impact of early cochlear implantation. I am impressed, as I look back, that the questions an audiologist faces have not really changed much over the years, but the ability to address those questions has changed substantially. I hope that the second edition conveys this progress effectively.

NEW TO SECOND EDITION

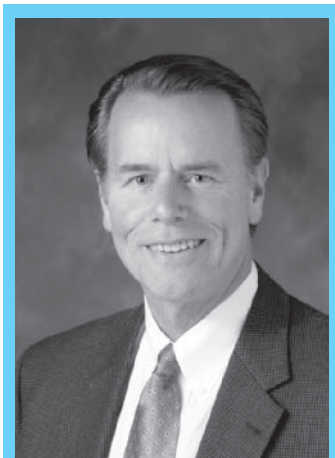
New features and additional content include:

- *Chapter objectives* begin each chapter to preview the concepts to be discussed.
- End of chapter *short answer questions* and *discussion questions* aid the student in applying concepts learned.
- *Bolded key terms* throughout the textbook help the student easily identify important terms.

- *Audiologist profiles* describe the various roles of audiologists in the profession to pique a student's interest and personalize topics discussed.
- Expanded content on topics, including: pure-tone audiometry, physiologic assessment measures, communicating audiometric results, and latest advances in hearing aid and implant technologies.

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About the Author



BRAD A. STACH, PH.D. is Director of the Division of Audiology, Department of Otolaryngology-Head and Neck Surgery, of the Henry Ford Medical Group and Henry Ford Hospital in Detroit, Michigan.

Dr. Stach has served in audiology leadership and clinical positions at The Methodist Hospital of Houston, Texas, Georgetown University Medical Center in Washington, D.C., the California Ear Institute at Stanford University School of Medicine in Palo Alto, California, the Nova Scotia Hearing and Speech Clinic in Halifax, and the Central Institute for the Deaf in St. Louis. He has also held faculty appointments at the Baylor College of Medicine, Georgetown University, Stanford University, Dalhousie University, Washington University of Saint Louis, New Mexico State University, The University of Texas School of Public Health, The University of Maryland at College Park, San Jose State University, Nova Southeastern University, and Wayne State University.

Dr. Stach is the author of a number of scientific articles and book chapters and is an editorial consultant for several professional journals. He was a founding board member of the American Academy of Audiology and has served as its President and the Chair of its Foundation Board of Trustees.

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DR. JAMES JERGER has had the biggest single influence on my career. He has the best clinical mind that I have ever known. The historical perspective in Chapter 1 is his, and his influence permeates the remainder of the book.

Sadanand Singh and Jeff Danhauer talked me into this project a decade ago. I have always appreciated them for the opportunity and for their friendship.

I have worked with a number of remarkably talented clinicians, clinical supervisors, and professors in my career. Each has contributed in some way to the knowledge base necessary to write a textbook of this breadth. I am grateful to all of them.

Gus Mueller contributed substantially to the first edition of this project by providing suggestions for the organization and content of the hearing aid chapters. He tolerated a lot of questions for the second edition as well. I appreciate his insight and friendship.

I am also grateful to my colleagues at the Henry Ford Hospital who assisted in one way or another in the preparation of the second edition. Christine Paul, Adrianne Fazel, and Melanie Shelburg were particularly helpful in providing clinical perspective. Lynn Alvord and two groups of externs, including Elizabeth Gray, Tiffany Harvey, Allison Ivey, Jordan Kotrba, Mori Plackman, Virginia Ramachandran, Michelle Vogel, and Kate Wagner, tolerated numerous discussions of the book's content and covered for me whenever asked. The others, Patty Aldridge, Noreen Gibbens, Kristen Huizdos Graham, Nancy Maranto, Wendy Rizzo, Heidi Sedaros, and Karrie Slominski, were always generous in their support.

Virginia Ramachandran, a rather capable student at Wayne State University, wrote the learning objectives and study questions for each

chapter. She also provided invaluable insight about level and depth of content from a student perspective. I am grateful to her for her willingness to help.

Delmar Cengage enlisted the help of five reviewers to provide perspective on the second edition. Jackie Clark, Thomas Froelich, Elaine Mormer, Greg Noel, and Lauren Shaffer provided excellent reviews of the manuscript. This book is a better one because of their thoughtful comments and suggestions.

A number of friends in industry were called upon to find me pictures of equipment and hearing instruments. They did, and I appreciate their efforts.

Juliet Steiner at Delmar Cengage was responsible for the initial orchestration of the project. Her encouragement and patience were remarkable. Laura Wood aptly saw it to its completion.

Casey Stach contributed to this project in a number of ways. She generated the original margin notes, tried to update my knowledge about cochlear implants, and made innumerable suggestions that improved this textbook. She also provided the support necessary for completion of the project and understood its value, despite the considerable toll it took on early mornings, late evenings, and weekends. Thanks Casey.

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1

THE PROFESSION OF AUDIOLOGY IN THE UNITED STATES

Learning Objectives

What Is an Audiologist?

What Is an Audiologist's Role?
- Identification
- Assessment and Diagnosis
- Treatment
- Education
- Prevention
- Research
- Related Activities
- Scope of Practice

Where Do Audiologists Practice?
- Private Practice
- Physician's Practices
- Hospitals and Medical Centers
- Hearing and Speech Clinics
- Schools
- Universities
- Hearing Instrument Manufacturers
- Industry

Relation to Other Professions
- Otolaryngology
- Other Medical Specialties
- Speech-Language Pathology
- Nonaudiologist Hearing Aid Dispensers
- Other Professionals

The Evolution of Audiology
- The Professional Heritage of Audiology
- The Clinical Heritage of Audiology

Professional Requirements
- Becoming an Audiologist
- Academic and Clinical Requirements

Summary

Short Answer Questions

Discussion Questions

Resources
- Organizations

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- Define the profession of audiology.
- Describe the numerous roles and activities that are included in the scope of practice for audiologists.
- Describe the various environments in which audiologists typically practice.
- Explain how audiology relates to other professions and medical specialties.
- Describe how the field of audiology has changed and evolved since its inception.
- Identify and explain the qualifications audiologists possess that demonstrate competence to practice.
- Describe the components of audiologic academic and clinical education.

A **hearing disorder** is a disturbance of the function of hearing.

A **communication disorder** is an impairment resulting from a speech, language, or hearing disorder.

AUDIOLOGY is the health-care profession devoted to hearing. It is a clinical profession that has as its unique mission the evaluation of hearing ability and the amelioration of impairment that results from **hearing disorders**. Most practitioners in the field of audiology practice their profession in health-care settings or in private practice. Others practice in educational settings, rehabilitation settings, and industry. Regardless of setting, the mission of the audiologist is the prevention of hearing loss, diagnosis of hearing loss, and treatment of **communication disorders** that may result from hearing loss. Specifically, audiologists play a crucial role in early identification of hearing impairment in infants, evaluation of hearing ability in people of all ages, and assessment of communication disorders that may result from hearing impairment. In addition, audiologists evaluate the need for hearing devices and assess, fit, and dispense hearing aids and other assistive listening devices. Audiologists are also involved in postfitting treatment and in educational programming and facilitation. Many audiologists also carry out testing designed to quantify balance function.

Relative to many health professions, audiology is a young profession. Its roots took hold following World War II, when clinics were developed to test the hearing of soldiers returning from the front lines who developed hearing loss as a result of exposure to excessively loud sounds. In those days, audiologic services consisted of measuring how much hearing impairment was present

and instruction in lipreading and auditory rehabilitation. Hearing aid technology was in its early stages of development. If we fast-forward to today, the profession's challenges remain the same, but its ability to meet them has changed dramatically.

Today, using **physiologic** techniques, audiologists screen the hearing of infants on their first day of life. Today audiologists routinely assess **middle ear** function, **inner ear** function, and **central auditory nervous system** function with ever-evolving precision. Questions about hearing aid amplification now go well beyond that of yes or no. Audiologists can measure, with great precision, the amount of amplification delivered to an eardrum. And they can alter that amplification in a number of ways to tailor it to the degree and nature of an individual's hearing loss.

Physiologic refers to measuring the electrical activity of the brain and body.

The portion of the ear from the tympanic membrane (or eardrum) to the oval window is called the **middle ear**.

The **inner ear** contains the sensory organs of hearing.

The portion of the hearing mechanism from the auditory nerve to the auditory cortex is called the **central auditory nervous system**.

But the main questions remain the same:

- Does a hearing loss exist?
- What is the extent of the hearing loss?
- Is the loss causing impairment in communication ability?
- Can the impairment be overcome to some extent with hearing aid amplification?
- What are the amplification needs of the patient?
- How can success with this amplification be verified?
- How much additional treatment is necessary?

These questions form the basis for the profession of audiology. They encompass the issues that represent the unique purview of the profession.

WHAT IS AN AUDIOLOGIST?

An audiologist is a professional who, by virtue of academic degree, clinical education, and appropriate licensure or other credential, is uniquely qualified to provide a comprehensive array of professional services relating to the prevention of hearing loss and the audiologic identification, diagnosis, and treatment of patients with impairments in hearing and balance function.

According to the American Academy of Audiology (AAA) Scope of Practice, "*An audiologist is a person who, by virtue of academic degree, clinical training, and license to practice and/or professional credential, is uniquely qualified to provide a comprehensive array of professional services related to the prevention of hearing loss and the audiologic identification, assessment, diagnosis, and treatment of persons with impairment of auditory and vestibular function, and to the prevention of impairments associated with them.*"

According to the American Speech-Language-Hearing Association (ASHA) Scope of Practice, "*Audiologists are professionals engaged in autonomous practice to promote healthy hearing, communication competency, and quality of life for persons of all ages through the prevention, identification, assessment, and rehabilitation of hearing, auditory function, balance, and other related systems.*"

The audiologist may play a number of different roles:

- clinician,
- teacher,
- research investigator,
- administrator, and
- consultant.

The audiologist provides clinical and academic training in all aspects of hearing impairment and its treatment to students of audiology and personnel in medicine, nursing, and other related professions.

WHAT IS AN AUDIOLOGIST'S ROLE?

The central focus of audiology is auditory impairment and its relationship to disordered communication. The audiologist identifies, assesses, diagnoses, and treats individuals with impairments of hearing and/or **vestibular** function. The audiologist also evaluates and fits hearing aids, and assists in the implementation of hearing loss treatment.

The **vestibular** system is a biological system that, in conjunction with vision and proprioception, functions to maintain balance and equilibrium.

Identification

The audiologist develops and oversees hearing screening programs designed to detect hearing loss in patients. Although identification programs are used in patients of all ages, they are most commonly used to identify hearing loss in infants, children entering school, and in aging patients. An audiologist may also screen for speech and language disorders to identify and refer patients with other communication disorders.

Assessment and Diagnosis

The audiologist serves as the primary expert in the assessment and audiologic diagnosis of auditory impairment. Assessment includes, but is not limited to, the administration and interpretation of **behavioral**, electroacoustic, and electrophysiologic measures of the status of the **peripheral** and central **auditory nervous systems**. Evaluation typically involves assessment of both the type of hearing loss and the extent or degree of hearing loss. The evaluation process reveals whether a hearing loss is of a type that can be medically treated with surgery or drugs or of a more permanent type that can be treated with personal amplification. Once the nature of the loss is determined, the extent of the impairment is evaluated in terms of both **hearing sensitivity** and the ability to use hearing for the perception of speech. Results of this evaluation are then placed into the context of the patient's lifestyle and communication demands to determine the extent to which a loss of hearing has become an impairment and might impact communication function.

Behavioral measures pertain to the observation of the activity of a person in response to some stimuli.

Nerve endings in the inner ear and the VIIIth nerve constitute the **peripheral auditory nervous system**.

Hearing sensitivity is the ability of the ear to detect faint sound.

Assessment of the vestibular system includes administration and interpretation of behavioral and electrophysiologic tests of balance function.

Treatment

Academic preparation and clinical experience qualify the audiologist to provide a full range of auditory treatment services to patients of all ages. Treatment services include those relating to hearing aids, **cochlear implants**, audiologic rehabilitation, cerumen removal, and tinnitus management.

A **cochlear implant** is a device that is implanted in the inner ear to provide hearing for individuals with profound deafness.

The audiologist is the primary individual responsible for the evaluation and fitting of all types of amplification devices, including hearing aids and assistive listening devices. The audiologist determines whether the patient is a suitable candidate for amplification devices, evaluates the benefit that the patient may expect to derive, and recommends an appropriate system to the patient. In conjunction with these recommendations, the audiologist will take ear impressions, fit the hearing-aid devices, provide counseling regarding their use, dispense the devices, and monitor progress with the hearing aids.

The audiologist is also the primary individual responsible for the audiologic evaluation of candidates for cochlear implants. Cochlear implants provide direct electrical stimulation to the inner ear of hearing, or the **cochlea**, and to the **neural system** of hearing. They are used for individuals with **severe-to-profound hearing loss**. Prior to implant surgery, the audiologist carries out audiologic testing to determine patient candidacy and provides counseling to the candidate and family members about appropriateness of implantation and viability of other amplification options. After implant surgery, the audiologist is responsible for programming implant devices, providing **auditory training** and other treatment services, troubleshooting and maintaining implant hardware, and counseling implant users, their families, and other professionals such as teachers.

The portion of the inner ear that consists of a fluid-filled shell-like structure is called the **cochlea**.

A **neural system** is a system containing nerve cells, in this case the VIIIth cranial nerve or auditory nerve.

A hearing loss of 70 dB HL or greater, typically considered deaf, is called a **severe-to-profound hearing loss**.

Auditory training is a rehabilitation method designed to train people to use their remaining hearing.

A device that assists or replaces a missing or dysfunctional system is called a **prosthetic device**.

The audiologist also provides treatment services and education to individuals with hearing impairment, family members, and the public. The audiologist provides information pertaining to hearing and hearing loss, the use of **prosthetic devices**, and strategies for improving speech recognition by exploiting auditory, visual, and tactile avenues for information processing. The audiologist also counsels patients regarding the effects of auditory disorder on communicative and psychosocial status in the personal, social, and vocational arenas.

In addition, the audiologist may be involved in the treatment of patients with vestibular disorders as a participant in a balance-treatment team that recommends and carries out treatment and rehabilitation of impairments of vestibular function.

Education

Audiologists may provide clinical and academic education in audiology. Audiologists teach audiology students, physicians, medical students, medical residents, fellows, and other students about the auditory and vestibular systems and their disorders. They may also be involved in educating the public, the business community, and related industries about hearing and balance, hearing loss and disability, prevention of hearing loss, and treatment strategies, particularly those pertaining to hearing aids and other assistive devices. In the field often referred to as forensic audiology, audiologists may also serve as expert witnesses in court cases, which usually involve issues pertaining to the nature and extent of hearing loss caused by some compensable action.

Audiologists involved in educational settings administer screening and evaluative programs in schools to identify hearing impairment and ensure that all students receive appropriate follow-up and **referral** services. The audiologist also trains and supervises nonaudiologists who perform hearing screening in educational settings. The audiologist serves as the resource for school personnel in matters pertaining to classroom acoustics, assistive listening systems, and communicative strategies. The audiologist maintains both classroom assistive systems and personal hearing devices. The audiologist serves on the team that makes decisions concerning an individual child's educational setting and special requirements. The audiologist also participates actively in the management of all children with hearing disorders of all varieties in the educational setting.

Referral means to direct someone for additional services.

Prevention

The audiologist designs, implements, and coordinates industrial and military hearing conservation programs in an effort to prevent hearing loss that may occur from exposure to excessively loud noises. These programs include identification and amelioration of hazardous noise conditions, identification of hearing loss, employee education, fitting personal hearing protection, and training and supervision of nonaudiologists performing hearing screening in the industrial setting.

Research

The audiologist may be actively involved in the design, implementation, and measurement of the effectiveness of clinical research activity relating to hearing loss assessment and treatment.

Related Activities

Some audiologists, by virtue of employment setting, education, experience, and personal choice, may engage in other health-care activities related to the profession. For example, some audiologists practice in hospital operating rooms, where **multimodality sensory evoked potentials** are used to monitor the function of sensory systems during surgery. In such settings, an audiologist administers and interprets electrophysiologic measures of the integrity of sensory and motor neural function, typically during neurosurgery.

Multimodality sensory evoked potentials is a collective term used to describe the measurement of electrical activity of the ears, eyes, and other systems of the body.

Scope of Practice

It is incumbent on all professions to define their boundaries. They must delineate the professional activities that lie within their education and training and, by exclusion, the activities outside their territory. Two examples of the audiology scope of practice, one from the American Academy of Audiology and the other from the American Speech-Language-Hearing Association, are included in Appendix A.

It is important to understand scope of practice issues. Audiology is an autonomous profession. As long as audiologists are practicing within their boundaries, they are acting as experts in their field. Decisions about diagnostic approaches and about hearing aids and other treatment strategies are theirs to make. A patient with a hearing loss can choose to enter the health-care door through the audiologist, without referral from a physician or other health-care provider. This is a very important responsibility to have and to uphold. Audiologists should be very familiar with their scope of practice along with their code of ethics.

Approximately 85% of all audiologists today in the U.S. **dispense hearing aids**.

Defining the scope of practice for any profession remains a fairly dynamic process. Not so very long ago, in the 1970s, official scope of practice guidelines for the profession of audiology did not delineate the **dispensing of hearing aids** as being within the scope of

the profession. Because the dispensing of hearing aids was such a natural extension of the central theme of the profession, audiologists began expanding their practices into this area as a routine matter of course. Soon, it became a common part of professional practice, and today dispensing hearing aids is considered an integral part of an audiologist's responsibilities.

Professional practices have also expanded in other ways. One example of an expanding activity is in the area of ear canal inspection and **cerumen** management. In order to evaluate hearing, make **ear impressions**, and fit hearing protection devices and hearing aids, the ear canals of patients need to be relatively free of debris and excessive cerumen. **Otoscopic** examination and external ear canal management for cerumen removal have become a routine part of many audiologists' practices.

Another example is in the assessment of vestibular function. The most common type of testing is called **electronystagmography**, or ENG. Today, ENG testing is commonplace in audiology offices and is considered an integral part of the scope of practice.

A further example of expanding roles is in the area of auditory electrophysiology. Since the late 1970s, audiologists have used what are termed electrophysiologic procedures to estimate hearing ability in infants and other patients who could not cooperate with behavioral testing strategies. The main electrophysiologic procedure is termed the **auditory brainstem response**, or ABR. This technique measures electrical activity of the brain in response to sound and provides an objective assessment of hearing ability. Audiologists have embraced this technology as an excellent means of helping them to assess hearing ability. But the ABR is useful for something else as well. It provides an exquisite means for evaluating the functional integrity of the neural elements of the **VIIIth cranial nerve** and the auditory brainstem. Thus, it is a technique that is very useful to the medical professions that diagnose and treat brain disease, such as **neurology**, **neurosurgery**, and **otolaryngology**. Although imaging and **radiographic techniques** have supplanted the ABR in diagnosis, the use of ABR as a screening tool for neurologic diagnostic purposes remains in widespread use.

Cerumen is earwax, the waxy secretion in the external ear canal. When it accumulates, it can become impacted and block the external ear canal.

An **ear impression** is a cast made of the ear and ear canal for creating a customized earplug or hearing aid.

Otoscopic pertains to an otoscope. An **otoscope** is an instrument used to visually examine the ear canal and eardrum.

Electronystagmography measures eye movements to assess vestibular (balance) function.

An **auditory brainstem response** is an electrophysiologic response to sound, consisting of five to seven identifiable peaks that represent neural function of auditory pathways.

The **VIIIth cranial nerve** refers to the auditory and vestibular nerves.

Neurology is the medical specialty that deals with the nervous system.

Neurosurgery is the medical specialty that deals with operating on disorders of the nervous system.

Otolaryngology is the medical specialty that deals with the ear, nose, and throat.

Techniques used to view the structures of the body through X-rays are called **radiographic techniques**.

Multisensory modality means incorporating the auditory, visual, and tactile senses.

Another direction that audiologists have taken is in the area of **multisensory modality** monitoring in the operating room. This practice was an extension of the use of ABR for assisting in the diagnosis of neurologic impairment. Because the ABR is useful for evaluating function of the VIIIth cranial nerve and the auditory brainstem, surgeons found that, if they monitored function of the VIIIth nerve and other nerves during surgery for removal of a tumor on that nerve, they could often preserve the nerve's function. Because audiologists know how to use the equipment and because of their technical expertise, often they are asked to participate in the surgical monitoring of patients undergoing tumor removal.

What, then, is the scope of practice of audiology? Audiologists are uniquely qualified to evaluate hearing and hearing impairment and to ameliorate communication disorders that result from that impairment. To do this, audiologists may be involved in:

- hearing loss prevention programs,
- **newborn hearing screening**,
- ear canal inspection and cleaning,
- pediatric and adult assessment of hearing,
- determination of hearing impairment, disability, or handicap,
- fitting of hearing aids,
- audiologic rehabilitation, and
- educational programming.

Screening the hearing of an infant during the first 4 weeks of life is called **newborn hearing screening**.

In addition, some audiologists engage in other activities, including evaluation and rehabilitation of vestibular disorders and operating room monitoring of multisensory evoked potentials.

WHERE DO AUDIOLOGISTS PRACTICE?

Audiologists practice their profession in a number of different settings. The largest growth area over the past two decades has been in the area of private practice and other non-residential health-care facilities. Because audiology is primarily a health-care profession, most audiologists practice in health-care settings. An estimate of the distribution of settings is shown in Figure 1-1.

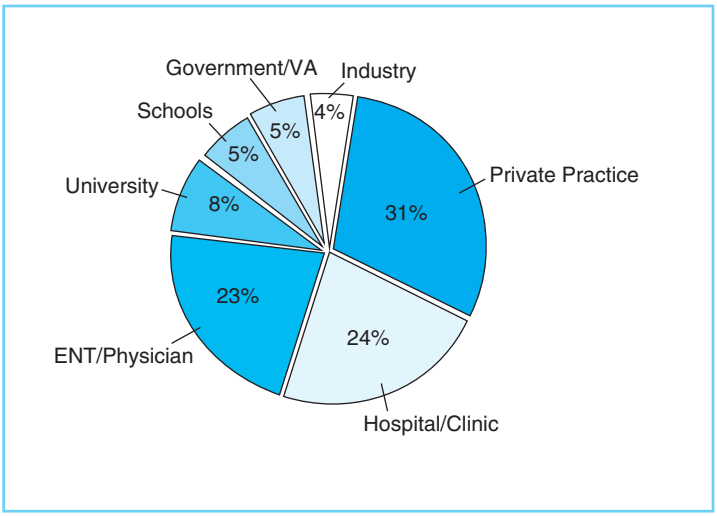


FIGURE 1-1 The distribution of primary settings in which audiologists practice. (Data source: American Academy of Audiology, 2005.)

Over half of all audiologists work in some type of non-residential health-care facility, such as a private clinic, a community speech and hearing center, or a physician's practice. Over 20% of audiologists work in a clinic or medical center facility, and about 5% of audiologists work in a school setting. The remaining 20% of audiologists work in university settings, government health-care facilities, and industry.

With regard to primary employment function, most audiologists, nearly 80%, are clinical service providers, regardless of employment setting. Nearly 10% are involved primarily in administration, and about 5% are college or university professors. The remaining audiologists serve as researchers, consultants, and in other related capacities. Thus, a typical audiologist would provide clinical services in a private practice, hospital, or other health-care facility.

Private Practice

Nearly 40% of all audiologists have some type of private practice arrangement. Of those, over 60% are in private practice on a full-time basis; the rest have a part-time practice, typically as a supplement to their primary employment.

Private-practice arrangements take on a number of forms. Some audiologists have their own stand-alone offices. The offices are often located in commercial office space that is oriented to outpatient health care. In other instances, the offices are located in retail shopping space to provide convenient access for patients. Some private practices are located adjacent to or within practices of related health-care professionals. For example, some audiologists have practices in conjunction with speech-language pathologists. More often, though, audiologists have practices in conjunction with otolaryngologists. This type of arrangement is of practical value in that some patients who have hearing impairment for which they would visit an audiologist also have ear disease for which they would visit an otolaryngologist, and vice versa. Thus, offices that are in close proximity allow for easy and convenient referrals and continuity of care.

Audiologists in private practices typically provide a wide range of services, from diagnostic audiology to the fitting and dispensing of hearing aids. If there is an emphasis for private practitioners, it is usually on the treatment rather than the diagnostic side, although that may vary depending on the location of the practice. Private practices may serve as the entry point for a patient into the health-care system, or they may serve as consultative services after the patient has entered the system through a primary-care physician or a specialist. Audiologists in private practice, then, work closely with **gerontologists**, **pediatricians**, family-practice physicians, and otolaryngologists to assure good referral relationships and good lines of communication. Audiologists in private practice also provide contract services to hospitals, clinics, school systems, nursing homes, retirement centers, and physicians' offices. Services that are contracted range from specialty testing, such as infant hearing screening in a hospital intensive care nursery, to hearing screening of children in school or preschool settings. Some private practitioners also contract with industry to provide screening and testing of individuals who are exposed to potentially damaging levels of noise.

A **gerontologist** is a physician specializing in the health of the aging.

A **pediatrician** is a physician specializing in the health of children.

The challenges and risks associated with private practice are often high, but so are the rewards. Private practices are small businesses that carry all of the responsibilities and challenges associated with small-business ownership. Sound business practices related

to cash management, personnel management, accounting, marketing, advertising, and so on are all essential to the success of a private practice. Successful private practices are usually more financially rewarding than other types of practices. But if you talk with audiologists in private practice, you will learn that perhaps the greatest rewards are related to being an autonomous practitioner, without the institutional and other constraints related to working for hospitals or physicians' practices.

Also emerging are group practices that represent a different type of private-sector practice. Group practices may be local in nature, made up of a network of independent practitioners, or they may be regional or national, owned by corporations. The former usually exist for providing coverage for third-party contracting and to enhance purchasing power for buying hearing aids. The latter resemble "chains" or "franchises," and are usually focused on hearing aid dispensing. This corporate structure takes advantage of group marketing and purchasing and is a growing influence in the distribution of hearing aids.

Physician's Practices

Many audiologists are employed by physicians, predominantly otolaryngologists, to provide audiologic services. Audiologists working in physicians' offices can be private practitioners, but more often are employees of the corporation. Physicians' offices range in size considerably, and audiology practices can vary from single audiologist arrangements to audiology-clinic arrangements.

Audiologic services provided within a physician's practice are usually strongly oriented to the diagnostic side of the profession. This relates to the nature of medical practices as the entry point for all types of disorders, including both ear disease and communication complaints. In many cases, however, hearing aid services are included as a means of maintaining continuity of care for patients.

Audiologists providing services in physicians' practices are usually compensated on a salaried basis. Some practices also provide incentives based on performance of the overall practice or performance of the audiologic aspects of the practice.

Hospitals and Medical Centers

Approximately one quarter of all audiologists work in a clinic, hospital, or medical center facility. Of those in hospital settings, most (70%) work in general medical hospitals; the remainder work in rehabilitation hospitals or other specialized facilities. Within a hospital or medical center structure, audiology services can stand alone as their own administrative entities or can fall under the auspices of a more general medical department, typically otolaryngology or surgery. Audiologists may be employees of the hospital or, in the case of a medical center, may be faculty members of a medical school department and part of a medical group, participating in a professional practice plan.

Audiologic activities in a hospital facility can be nearly as broad as the field. Because of the nature of the setting, emphasis in most hospitals is on the diagnostic side of the profession. Audiologists evaluate the hearing of patients who have complaints such as hearing impairment, ear disease, ear pain, and dizziness. They also evaluate patients who are undergoing **chemotherapy** that is potentially toxic to the auditory system. Most hospital settings also provide in-depth electroacoustic, electro-physiologic, and behavioral assessment of infants and children. In many hospitals, audiologists are also responsible for carrying out or directing the hearing screening of newborns in **intensive care nurseries** or **regular-care nurseries**.

Chemotherapy refers to treating a disease, such as cancer, with chemicals or drugs.

The hospital unit designed to take care of newborns needing special care is the **intensive care nursery**.

The hospital unit designed to take care of normal newborns is called the **regular-care nursery**.

Audiologists also provide a number of services related to assisting physicians in the diagnosis of ear disease and neurologic disorder. In addition, some audiologists monitor auditory or other sensory function during surgery. An example of this is the electrophysiologic monitoring of auditory nerve and **facial nerve** function during surgical removal of a tumor that impinges on the auditory and **vestibular nerves**.

The **facial nerve** is the VIIth cranial nerve.

The **vestibular nerve** is part of the VIIIth cranial nerve.

Although the major emphasis is diagnostic, many hospital settings provide hearing-device services as well. It is not uncommon for audiologists to dispense hearing aids either through the hospital or through a **for-profit practice** within a hospital setting. Many hospital and medical center facilities serve as the centers for cochlear-implant evaluation, surgery, and device programming.

A **for-profit practice** is a privately owned commercial business.

For patients of all ages, audiologists have the primary role in determining implant candidacy and in programming the implant device as a first step in the rehabilitative process.

Audiologists in these settings are also involved in the development and implementation of outreach programs so that patients who receive diagnostic and hearing aid services can be referred appropriately for any necessary rehabilitative services. Most outreach networks include local educational audiologists, schools for the deaf, vocational rehabilitation counselors, and self-help groups.

Hearing and Speech Clinics

In the 1950s and 1960s, a number of prestigious speech and hearing centers were developed and built that provided a wide range of communication services to their communities. These centers were often associated with universities, and many were partially supported with funding from organizations such as Easter Seals or the United Way. Clinics such as these remain today, and audiologic practices are usually broadly based and include a full range of diagnostic and treatment activities. If there is an emphasis, it is usually on the rehabilitative side. One common strength of such a setting is a commitment to the team approach to evaluation and treatment. This is particularly important for children who have both hearing and speech-language disorders. Approximately 6% of audiologists work in a speech and hearing clinic.

Schools

Over 5% of audiologists work in an educational setting. In most cases, educational audiologists work in public schools at the primary-grade level. Some also work at the preschool level. Responsibilities of the educational audiologist are not unlike those of audiologists in general, except that they are oriented more toward a consultative role in assuring optimal access to education by students with hearing impairment.

Educational audiologists' roles in the schools range from the actual provision to the overall coordination of services. For example, in some settings the educational audiologist may be responsible for diagnostic audiology services, whereas in others the audiologist is

responsible for ensuring that those services are adequately provided through resources within the community.

The role of educational audiologists usually begins with oversight of hearing screening programs, which are commonplace in school settings. The role extends to the provision of diagnostic audiologic services to children who have failed the screening or, on an annual basis, to those who have been identified with hearing impairment. Educational audiologists are also responsible for ensuring that students have proper amplification devices and that those devices are functioning appropriately in the classroom. One major role of an educational audiologist is the education of school personnel about:

- the nature of hearing impairment,
- the effects of hearing impairment on learning,
- the effects of room acoustics on auditory perception,
- the way that amplification devices work, and
- the fundamentals of hearing device troubleshooting.

Audiologists who work in educational settings serve as advocates for students with hearing impairment and are involved in decisions about appropriate classroom placement and the necessity for itinerant assistance.

Universities

Eight percent of audiologists are employed in university settings, either as professors of audiology or clinical educators. Many audiology faculty members have teaching and research as their main responsibilities. Their primary roles are:

- the graduate-level education of audiology students,
- the procurement and maintenance of grant funds,
- the provision of audiologic research, and
- community education and outreach.

Other faculty members have as their primary role the clinical education of students in the university clinical setting. It is usually these individuals who provide students with their first exposure to the clinical activities that constitute their future profession.

Audiologist Profile

Jackson Roush, Ph.D.



Where I Live: Chapel Hill, North Carolina

Where I Work: Division of Speech and Hearing Sciences, University of North Carolina School of Medicine, Chapel Hill, North Carolina. UNC offers graduate degree programs in audiology (Au.D.); speech-language pathology (M.S.); and research in speech and hearing sciences (Ph.D.).

What I Do: As director of the Division of Speech and Hearing Sciences, I have administrative responsibility for the graduate programs in speech-language pathology and audiology. My clinical work is in pediatric audiology at our Center for the Study of Development and Learning, where I serve as a preceptor for our Au.D. students and interact with colleagues from other professional disciplines.

Why Audiology? Audiology provides a satisfying balance of technical and interpersonal activities. Working as an audiologist in an academic setting has afforded me the opportunity to combine my interests in pediatric audiology with research, teaching, and administration. My enthusiasm for the profession continues to grow even after 30 years, as we expand and improve our ability to assess and treat disorders of the auditory system.

Hearing Instrument Manufacturers

Some audiologists work for manufacturers of hearing devices or audiometric equipment. They tend to work in one of two areas: research and development; or professional education and sales. Those who work in research and development are responsible for assisting engineers and designers in the development of products for use in hearing diagnosis or treatment. They bring to the developmental process the expertise in clinical matters that is so critical to the design of instrumentation and hearing devices. Those who work in professional education and sales typically represent a single manufacturer and are responsible for educating clinical audiologists in the types of devices available, new technologies that have been developed, and new devices that have been brought to market.

The role of audiologists in this area has been expanding over the past few decades. Audiologists bring to the design and manufacturing process an understanding of the needs of both clinical audiologists and patients with hearing impairment. This has greatly enhanced the applicability of instruments and devices to the clinical setting. In addition, the complexity and sophistication of hearing instruments have grown dramatically over the years, and the need for professional education has grown accordingly. As a result, manufacturers' representatives provide important continuing education to audiology practitioners.

Industry

Industrial hearing conservation is the area of audiology devoted to protecting the ears from hearing loss due to exposure to noise in the workplace.

Audiologists often play an important role in what is known as **industrial hearing conservation**. Exposure to noise in job settings is pervasive. According to the National Institute for Occupational Safety and Health, as many as 30 million workers in the United States are exposed to hazardous levels of noise. As a result, occupational safety and health standards have been developed to protect workers from noise exposure, and audiologists are often involved in assisting industry in meeting those standards. Audiologists' roles in hearing conservation include:

- assessment of noise exposure,
- provision or supervision of baseline and annual audiometric assessment,
- provision of appropriate follow-up services,
- recommendations about appropriate noise protection devices,
- fitting hearing protection, and
- employee education about noise exposure and hearing loss prevention.

Audiologists also work with industry personnel to devise methods for engineering or administrative controls over noise exposure.

An individual hired on an hourly or contract basis for expertise in a profession is called a **consultant**.

The majority of audiologists who work in industry do so on a **consultative** basis. Some audiologists contract to provide a full range of services to a particular company. Others contract only to provide hearing-test review or follow-up audiologic services. Regardless, hearing conservation is a very important aspect of

comprehensive hearing health care, and audiologists often play a major role in the provision of these services.

RELATION TO OTHER PROFESSIONS

As broadly based health-care professionals diagnosing and treating hearing impairment, audiologists come into contact with many other professionals on a daily basis. Much of their work in assessment involves referrals from and to physicians in various specialties and other health-care professions. Much of the work in treatment involves referrals from and to social services, educational personnel, and other professionals involved in outreach programs. The following is an overview of the professions that are most closely related to audiology.

Otolaryngology

Otolaryngology, or otorhinolaryngology, is the medical specialty devoted to the diagnosis and treatment of diseases of the ear, nose, and throat. The focus of the profession has evolved over the years, and now it is routinely referred to as *otolaryngology—head and neck surgery*, which is a title that accurately reflects the current emphasis of the specialty. Physicians who are otolaryngologists have completed medical school and at least a four- or five-year residency in the specialty. The residency program usually includes a year or two in general surgery, followed by an emphasis on surgery of the head and neck. One subspecialty of otolaryngology is otology.

Otology is the subspecialty devoted to the diagnosis and treatment of ear disease. In contrast, audiology is the profession devoted to the diagnosis and treatment of communication disorders that results from hearing loss. Although the roles are clearly defined, the overlap between the professions in daily practice can be substantial. As a result, the two professions are closely aligned.

The relationship between audiology and otology is perhaps best defined by considering the route that patients might take if they have hearing problems. If a patient has a complaint of hearing impairment, that patient is likely to seek guidance from a general medical practitioner, who is likely to refer the patient to either an audiologist or an **otologist**. If the general practitioner does not

An **otologist** is a physician specializing in the ear.

detect any ear disease, the patient is likely to be referred to the audiologist, who will evaluate the hearing of the patient in an effort to determine the need for treatment. The audiologist's first question is whether or not the hearing loss is of a nature that might be treatable medically. If any suspicion of ear disease is detected, the audiologist will recommend to the general practitioner that the patient receive an otologic consultation to rule out a treatable condition. If the general practitioner detects the presence of ear disease at the initial consult, the patient is likely to be referred first to the otologist, who will diagnose the problem and implement treatment as necessary. As part of the otologic assessment, the otologist may consult the audiologist to determine if the medical condition is resulting in a hearing loss and if that hearing loss is of a medically treatable nature. If ear disease is present, the otologist will treat it with appropriate drugs or surgery. The audiologist may be involved in quantifying hearing ability before and after treatment. If ear disease is not present, the otologist will consult with the audiologist to determine the extent of hearing impairment and the prognosis for successful hearing aid use.

From these examples, it is easy to see how the professions of audiology and otology are closely related. *Many patients with ear disease have hearing impairment*, at least until the ear disease is treated. Thus, otologists will diagnose and treat the ear disease. They will consult with audiologists to evaluate the extent to which that ear disease affects hearing and the extent to which their treatment has eliminated any hearing problem. Conversely, *many patients with hearing impairment have ear disease*. Estimates suggest that as many as 5–10% of individuals with hearing impairment have **treatable medical conditions** of the ear. Thus, the medical profession of otology and the hearing profession of audiology are often called on to evaluate the same patients.

Approximately 5–10% of individuals with hearing impairment have **treatable medical conditions**.

Understanding the unique contributions of the two professions is important in defining territories and roles in the assessment and treatment of patients with hearing impairment. Overlap of roles can occur in some patients with hearing loss complaints. For example, audiologists call on otologists to rule out or treat active ear disease in patients with hearing impairment. Once completed, the audiologists can continue their assessment and treatment of any

residual auditory communication disorder that may be present. Similarly, otologists call on audiologists to provide pre- and post-treatment assessment of hearing sensitivity in patients with ear disease. Thus, the two disciplines work together to help patients who have complaints related to ears or hearing.

Other Medical Specialties

Audiologists also work closely with other medical specialists who treat patients at risk for hearing impairment. These specialties include:

- pediatrics,
- neonatology,
- neurology,
- neurosurgery,
- oncology,
- infectious diseases,
- medical genetics,
- community and family medicine, and
- gerontology.

Many infants in intensive-care nurseries are at risk for significant hearing impairment. As a result, audiologists work closely with **neonatologists** to provide or oversee hearing screening and follow-up hearing assessment of infants who might be at risk. Screening efforts have been extended to regular-care nurseries, and audiologists work closely with all medical personnel who have the nursery as part of their professional territory. As children get older, their pediatricians are among the first professionals consulted by parents if a hearing problem is suspected. As a result, audiologists often have close referral relationships with pediatricians.

A **neonatologist** is a physician specializing in the care of newborns.

Patients with neurologic disorders sometimes have hearing impairment as a result. **Tumors**, **cerebrovascular accidents**, or trauma to the central nervous system can affect the central auditory system in ways that result in hearing and balance problems. Audiologists may be called on by neurologists or neurosurgeons to assist in diagnosis, monitor cranial nerve function during surgery, or manage residual communication disorders.

A **tumor** is an abnormal growth of tissue, which can occur on or around the auditory nerve.

A **cerebrovascular accident** (CVA) is an interruption of the blood supply to the brain resulting in a loss of function, a stroke for example.

An **oncologist** is a physician specializing in the treatment of cancer.

When a substance is poisonous to the ear, it is **ototoxic**.

Audiologists also work closely with **oncologists** and specialists in infectious diseases to monitor hearing and balance functions in patients undergoing certain types of drug therapies. Some chemotherapy drugs and antibiotics are toxic to the auditory system, or **ototoxic**. Ingestion of high doses of these drugs may result in permanent damage to the hearing mechanism. Sometimes this is an inevitable consequence of saving someone's life. Drugs used to treat cancer or serious infections may need to be administered in doses that will harm the hearing mechanism. But in many cases, the dosage can be adjusted to remain effective in its purpose without causing ototoxicity. Patients undergoing such treatment will often be referred to the audiologist for monitoring of hearing function throughout the treatment.

Audiologists also work closely with primary-care physicians and those specializing in aging, the gerontologists. One pervasive consequence of the aging process is a loss in hearing sensitivity. Estimates of prevalence suggest that over 20% of all individuals over the age of 65 years have at least some degree of hearing impairment, and the prevalence increases with increasing age. Primary-care physicians are often the first professionals consulted by patients who have hearing impairment. As a result, audiologists often develop close referral relations with physicians who work with aging individuals.

Speech-Language Pathology

Audiology and speech-language pathology evolved from the discipline of communication disorders and were considered to be one profession in the early years. This evolved from the educational model in which one individual would be responsible for hearing, speech, and language assessment and treatment in school-age children. Some professionals are actually certified and licensed in both audiology and speech-language pathology. Today, although some overlap remains, the two areas have evolved into separate and independent professions. Nevertheless, because of historical ties and because of a common discipline of communication disorders, the two professions remain linked.

The unique role of speech-language pathology is the evaluation and rehabilitation of communication disorders that result from speech

and/or language impairment. **Speech-language pathologists** are responsible for evaluation of disorders in:

- articulation,
- voice and resonance,
- fluency,
- language,
- phonology,
- pragmatics,
- augmentative/alternative communication,
- cognition, and
- swallowing

in patients of all ages. Following assessment, speech-language pathologists design and implement treatment programs for individuals with impairments in any of these various areas.

A **speech-language pathologist** is a professional who diagnoses and treats speech and language disorders.

There are at least three groups of patients with whom audiologists and speech-language pathologists work closely together. First, because good speech and oral-language development requires good hearing, auditory disorders in children often result in speech and/or language developmental delays. Thus, children with hearing impairment are usually referred to speech-language pathologists for speech and language assessment and treatment following hearing aid fitting. Second, some children have auditory perceptual problems as a consequence of impaired central auditory nervous systems. These problems result, most importantly, in difficulty discerning speech in a background of noise. The problem is usually referred to as **auditory processing disorder** (APD). Many children with APD have concomitant receptive language processing problems, learning disabilities, and attention deficits. As a result, adequate diagnosis of APD usually requires a multidisciplinary assessment. Third, many older individuals who have language disorders due to **stroke** or other neurologic insult also have some degree of hearing sensitivity loss or auditory processing problem. The audiologist and speech-language pathologist work together in such instances in an effort to determine the extent to which hearing impairment is impacting on receptive language ability.

A disorder of the central auditory structures, which can result in difficulty understanding speech in the presence of noise, is called an **auditory processing disorder** (APD).

A **stroke** is a cerebrovascular accident that can result in problems with processing language.

With these exceptions, the majority of individuals who have hearing impairment do not have speech and language disorders. Similarly, the majority of individuals who have speech and language disorders do not have hearing impairment. Nevertheless, professionals in both audiology and speech-language pathology understand the interdependence of hearing, speech, and language. Thus, during audiologic evaluations, particularly in children, it is important to include an informal screening of speech and language. During speech-language evaluations, it is important to include a screening of hearing sensitivity.

Nonaudiologist Hearing Aid Dispensers

The **American Speech-Language-Hearing Association (ASHA)** was founded in 1925. The original name of the Association (used from 1927–1929) was the American Academy of Speech Correction. The 25 charter members were primarily university faculty members in Iowa and Wisconsin. The primary professional focus of the Association was on stuttering.

Prior to 1977, it was against the Code of Ethics of the **American Speech-Language-Hearing Association (ASHA)** for audiologists to dispense hearing aids. At the time, hearing aids were dispensed mostly by hearing aid dispensers. Nonaudiologist hearing aid dispensers are individuals who dispense hearing aids as their main focus. Most states have developed licensure regulation of hearing aid dispensers, and requirements vary significantly across states.

In the 1970s, audiologists began assuming a greater role in hearing aid dispensing. By the 1990s, audiologists who were licensed to dispense hearing aids outnumbered hearing aid dispensers in many states. Most individuals wishing to dispense hearing aids as a career now pursue the profession of audiology as the entry point. Nevertheless, there remain many individuals who began dispensing hearing aids before these trends were pervasive.

Although the number of traditional hearing aid dispensers is diminishing in proportion to the number of dispensing audiologists, there is considerable overlap in territory. In many settings, audiologists and hearing aid dispensers work together in an effort to provide comprehensive hearing treatment services.

Other Professionals

Audiologists work with many other professionals to ensure that patients with hearing impairment are well served. For children, audiologists often work with educational diagnosticians, neuropsychologists, and teachers to assure complete assessment for educational placement. Audiologists also refer parents of children with hearing impairment to **geneticists** for counseling regarding

possible familial causes of hearing loss. Family counselors, whether social workers, psychologists, or other professionals, are often called on to assist families of children with hearing impairment. For adults with hearing impairment, referrals are often made to professionals for counseling about vocational or emotional needs related to the hearing loss.

A **geneticist** is a professional specializing in the identification of hereditary diseases.

THE EVOLUTION OF AUDIOLOGY

Audiology has evolved over the last 50 years clinically, academically, and professionally. The professional evolution has changed the practice of audiology from a largely academic discipline, conjoined with speech-language pathology and modeled after teacher training and certification, to an independent health-care profession with doctoral-level education and licensure. The clinical evolution has changed the practice from a rehabilitative emphasis to one of diagnosis and treatment of hearing loss.

The Professional Heritage of Audiology

The profession of audiology has progressed over the last 50 years in several important ways that have both promoted and necessitated dramatic change in academic preparation, governmental and regulatory recognition, and professional responsibility and status. This evolution in the professional makeup of audiology has resulted from at least four important influences:

1. the evolution of audiology from primarily an academic discipline into a health-care profession;
2. the evolution from a communication disorder profession into a hearing profession;
3. the evolution from a teacher-training model of education into a health-care model of education; and
4. the evolution from a certification model to a licensure model of defining the privilege and right to practice.

From Academic Discipline to Health-Care Profession

While the clinical roots of the profession were taking hold in government hospitals as a result of World War II, the academic roots were growing in the discipline of communication sciences. The communications sciences and disorders discipline had evolved away from the field of general communications. Speech-language

pathology was an extension of the scientific interest in the anatomy and physiology of speech and its disorders, and the fledgling neuroscience of language and its development and disorders. Audiology, emerging later, was an extension of general communication, bioacoustics, psychoacoustics, and auditory neurosciences.

Change occurred in audiology throughout the 1980s and 1990s. Emphasis began to shift from the discipline to the profession. Educational models began to emerge that emphasized the training of skillful practitioners. By the early twenty-first century, the profession had begun to converge on the use of a single designator, the **Au.D.**, for those students interested in becoming audiologists.

Au.D. designates the professional doctorate in the field of audiology.

From Communication Disorders to Hearing Profession

The profession of audiology has its roots in the discipline of communication sciences and disorders, and the profession of speech-language pathology. Professionals in the early years were knowledgeable in both speech and hearing and were recognized providers in both areas. The strength of the academic programs lay in the overall discipline, and the distinction of two professions took many years to evolve.

By the 1970s, the bodies of knowledge in both speech and hearing had expanded to an extent that academic specialization began to emerge. On the clinical side, the distinction between professions became clearer. Speech-language pathologists most often practiced their profession in the schools, while audiologists were in hospitals, clinics, and private practices. But even in hospital settings, distinctions emerged. Speech-language pathology programs began to align with other therapies, such as physical therapy and occupational therapy, and were commonly more comfortably associated with rehabilitation medicine or neurology. Audiology emerged as more of a diagnostic profession, most often aligned with otolaryngology.

During the 1980s, the divergence of two distinct clinical professions became apparent. Practitioners were primarily practicing in one profession or another. As the first decade of the twenty-first century drew to a close, audiology and speech-language pathology had clearly become independent professions.

From Teacher-Training Model to Health-Care Model of Education

The evolution of audiology education to the doctoral level is perhaps the most important and far-reaching development in the modern era of the profession. The early model of education for speech-language pathologists and audiologists has its roots in the education of classroom teachers. The model was one of didactic education for content learning, with a student-teaching assignment for developing skills in teaching.

By the late 1980s, the field of audiology began to restructure its academic model by converting it into a first-professional-degree model of doctoral-level professional education. The first-professional-degree designation is one used by the United States Department of Education to define certain entry-level professional degree programs. The profession agreed on a degree designator, the Au.D., and embarked on the process of reengineering its programs to a doctoral level, designed to graduate skilled practitioners in audiology.

The change to doctoral-level professional education had many advantages, foremost among them that the model of education fit the desired outcome. Graduate education is now separated into two tracks: professional studies and research studies. The current Au.D. model falls under the category of professional studies; the Ph.D. under research studies. Professional studies prepare students for careers as competent, licensed practitioners. Research studies culminate in degrees (Ph.D., Sc.D., and Ed.D.) that are awarded for demonstration of independent research. The education system recognizes the research degree as preparing graduates to engage in scientific endeavors; the professional degree as preparing graduates for clinical practice.

From Certification to Licensure Model

The question of what defines someone as an audiologist has changed over the last decade. Under the old educational model, a graduate degree in audiology was not the end of the educational process. Students would graduate with any one of a number of degrees, including M.A., M.S., M.C.D., Ph.D., and Sc.D. Following completion of the degree program, the graduate would engage in 9 months of supervised clinical work, pass the national examination

in audiology (Praxis Examination in Audiology, administered by the Educational Testing Service), and become certified and/or licensed in audiology. The certificate that most audiologists held for many years was ASHA's Certificate of Clinical Competence in Audiology, or the CCC-A. More recently, the American Academy of Audiology began offering another certificate created by the American Board of Audiology (ABA).

Certification is the process by which a nongovernment agency or association grants recognition to an individual who has met certain predetermined qualifications specified by that institution. It is a voluntary credential awarded by professional associations or certification bodies. It is generally not legally mandatory for practice of a profession. Rather, it serves as the self-governing aspect of professional activity. By contrast, licensure is the process by which a government agency grants individuals permission to engage in a specified profession. Licensure provides the legal right to practice in a state; it is mandatory in order to practice legally. By 2006, all states and the District of Columbia had some form of regulation, nearly all requiring an audiology license (48 via licensure; 2 via registration). Nearly 60% of states permit audiologists to dispense hearing aids without additional licensure.

In the modern context of audiology as an autonomous health-care profession, licensure has largely replaced the need for entry-level certification. The academic transition to the Au.D. degree and the proliferation of licensure laws throughout the country helped to transform the profession from certification to licensure. Once students earn an Au.D. and pass the national examination, they are granted the privilege to practice through state licensure.

Many audiologists find additional value in certification for the self-governing of professional activity on a voluntary basis and may hold either or both of the CCC-A and ABA certificates.

The Clinical Heritage of Audiology

The definition of audiology as the health-care profession devoted to hearing has its roots in clinical activities that go back as far as the 1920s and 1930s. The term *audiology* can be traced back to the 1940s when it was used to describe clinical practices related

to serving the hearing care needs of soldiers returning from World War II. Following the war, graduate training programs were developed to teach the academic discipline of audiology. Definitions of audiology during the 1950s and 1960s reflected this academic perspective in which audiology was often defined as the study of hearing and hearing disorders. Tremendous strides were made in the 1970s in the technologies available for evaluating hearing. Similarly, tremendous strides were made in the 1980s and 1990s in hearing-aid amplification technologies. As the decades progressed, the number of practitioners of the profession of audiology grew substantially. Audiology had evolved from an academic discipline to a doctoral-level clinical profession.

Audiology's Beginnings (Before 1950)

Credit for the genesis of audiology should be given to a number of individuals, but a few stand out as true leaders in the early years of the profession. Perhaps the first individual to whom credit should go is **C. C. Bunch**. Bunch, first at the University of Iowa and later at Washington University in St. Louis, used the newly developed Western Electric 1-A audiometer to assess the hearing of patients with otologic problems. He did so in the 1920s and 1930s. Working with an otologist, Dr. L. W. Dean, he showed how the electric audiometer could be used as an enhancement to tuning forks to quantify hearing loss. In doing so, he developed what we now know as the pure-tone audiogram and was the first to describe audiometric patterns of many different types of auditory disorders.

C. C. Bunch developed the pure-tone audiogram.

The profession of audiology can be traced back to the 1940s. Near the end of World War II, the Army established three aural rehabilitation centers to provide medical and rehabilitative services to returning soldiers who had developed hearing impairment during the war. The three centers were the Borden General Hospital in Chickasha, Oklahoma; Hoff General Hospital in Santa Barbara, California; and Deshon General Hospital in Butler, Pennsylvania. The Navy also established a center at the Naval Hospital in Philadelphia. Perhaps the most notable of the centers was Deshon hospital, where a young captain in the Army Medical Corps, Raymond Carhart, developed a protocol for the fitting and evaluation of hearing aids that became a model for clinical practice for many years. Carhart had been a student

of C. C. Bunch at Northwestern University, where Bunch was a visiting professor late in his career.

Following World War II, Carhart returned to Northwestern University, where he developed a graduate training program that was to produce many of the leaders of the audiology profession for the remainder of the century. Other leaders emerged from the aural rehabilitation centers as well. Grant Fairbanks, from the Borden Hospital, went to the University of Illinois and established a model program for the training of hearing scientists. William G. Hardy, from the Naval Hospital, went to Johns Hopkins Medical School and pioneered pediatric hearing testing. Also during the post-war era, three pioneers joined together at the Central Institute for the Deaf in St. Louis. Hallowell Davis, a physiologist from Harvard, S. Richard Silverman, an educator of the deaf, and Ira Hirsh, from the psychology department at Harvard, created a powerful program of basic and applied research that provided the basis for many clinical concepts in use today.

Audiology as an Academic Discipline (1950s and 1960s)

In the early 1950s, fewer than 500 individuals considered themselves audiologists. Most worked in otologists' offices, Veteran's Administration hospitals, universities, and speech and hearing centers. The graduate programs at Northwestern University and then at other midwestern universities dominated the academic scene. In 1958, the first textbook on audiology was written by Hayes Newby of Stanford University. In parallel developments in Washington, D.C., Kenneth O. Johnson, the Executive Secretary of the ASHA, was working to establish the profession of speech and hearing in the political realm. During the 1960s, the quality of academic programs was measured by the number and productivity of Ph.D. students.

Practitioners were beginning to expand services, although hearing aid dispensing was considered to be unethical. In the 1960s, James Jerger, a student of Carhart's at Northwestern, traveled south to Houston, where his clinical efforts ushered in the concept of diagnostic audiology. In those days, radiographic techniques were still relatively crude and not very sensitive to neurologic disorders.

Jerger led the way in showing how behavioral measures of auditory function could be used to assist in the diagnosis of these disorders. His highly innovative work, beginning in the middle 1950s, continued throughout the century. In the 1960s, he ushered in new concepts in **speech audiometry** and other diagnostic techniques. In the 1970s, he brought clinical relevance to **impedance audiometry**. In the 1980s, he started the **American Academy of Audiology.** In the 1990s, he established the first Au.D. program. His tireless work over these years will undoubtedly be remembered for its influence on the clinical practice of audiology.

Speech audiometry pertains to measurement of the hearing of speech signals.

Impedance audiometry is now referred to as **immittance audiometry**.

The **American Academy of Audiology** was established in 1988, as an organization of, by, and for audiologists.

Audiology as a Clinical Profession (1970s and Beyond)

By the 1970s, clinical audiology began to flourish. Major technological advances helped to enhance both diagnostic and treatment efforts. Impedance audiometry, later to become known as **immittance audiometry**, enhanced the testing of middle ear function substantially. Discovery of the auditory brainstem response led to major breakthroughs in diagnostic measures and in pediatric audiology.

Another milestone also occurred in the 1970s. Hearing devices, once relegated to the retail market, were declared to be medical devices by the United States Food and Drug Administration. This had a substantial impact on the nature of devices and delivery systems. In the latter part of the 1970s, ethical restrictions to audiologists dispensing hearing aids fell to the concept of comprehensive patient care, and audiologists began dispensing hearing devices routinely.

If the 1970s was the decade of diagnostic breakthroughs, the 1980s was the decade of treatment breakthroughs. Hearing-device amplification improved dramatically. In-the-ear devices that were both reliable and of good sound quality were introduced early in the decade and were embraced by hearing aid users. Computer-based hearing devices that permitted programmability of features were introduced later in the decade and began to set new standards for amplification. By the end of the decade, cochlear implants were becoming routine care for adults with profound hearing loss and were beginning to be used successfully by young children.

Otoacoustic emissions (OAEs) are measurable sounds emitted by the normal cochlea, which are related to the function of the outer hair cells.

The 1990s brought other successes. The introduction of clinically feasible measures of **otoacoustic emissions** led to the notion of hearing screening of all infants born in the United States. By the mid-1990s, efforts to achieve this goal were well under way. Also on the evaluative side, a great deal more attention was being focused on disorders of auditory processing abilities. As diagnostic strategies were enhanced, the practicality of measuring these abilities became apparent.

On the treatment side, the 1990s brought renewed enthusiasm for hearing device dispensing as user satisfaction grew dramatically with enhancements in sound processing technology. The 1990s also brought a healthy emphasis on consumerism, which led to renewed calls by the Food and Drug Administration and the Federal Trade Commission for enhanced delivery systems to consumers and a crackdown on misleading advertising by some manufacturers. Programmable and digital hearing devices began to impact the market in a significant way. Cochlear implants became increasingly common in young children.

The early years of the twenty-first century turned the diagnostic challenge from pediatric audiology to infant audiology. Newborn hearing screening became commonplace across the United States, and the age of hearing loss identification began to drop accordingly. Electrophysiologic prediction of hearing sensitivity gained renewed importance and was buoyed by the clinical introduction and acceptance of auditory steady-state response techniques. Also on the diagnostic front, the differentiation of primary effects of nervous system lesions on auditory nerve function from secondary effects of such lesions on cochlear function made for a fascinating reevaluation and invigoration of the usefulness of functional measures as a supplement to structural imaging of the nervous system.

Technology continued to progress on the treatment side as well. Hearing aids were now exclusively digital in their signal processing, and the distinction between analog and digital became insignificant. Directionality in hearing aid microphones improved to a point of relevancy and became commonplace. Cochlear implant candidacy expanded to increasingly less hearing loss, and distinctions began to blur between candidacy for powerful hearing aids

versus implants. Meanwhile, cochlear implants were being used in the pediatric population at ever-younger ages, with speech, language, and reading outcomes continuing to show proof that the earlier was the intervention, the better the final result.

As the new century progresses, the profession of audiology can look forward with great expectations. The identification of hearing loss in ever-younger babies is leading to significant changes in early childhood education. Growth in the aging population is occurring at a time when hearing aid technological advances promise to extend acceptable hearing for many years. Audiology has progressed to a doctoral-level profession and advanced significantly in its recognition as an autonomous and important provider of health care.

PROFESSIONAL REQUIREMENTS

A typical new audiology graduate in the 2000s:

- holds a bachelor's degree in communication disorders or another health- or science-related area,
- has earned an Au.D. degree,
- has passed a national examination in audiology, and
- has a state license to practice audiology, which includes the dispensing of hearing aids.

Becoming an Audiologist

To become an audiologist, an individual must be granted a doctoral degree (Au.D.) from an academic institution that meets accreditation requirements set forth by an accrediting agency recognized by the U.S. Department of Education. The agency responsible for accrediting audiology and speech-language pathology programs is the Council on Academic Accreditation (CAA) in Audiology and Speech-Language Pathology. During the course of the Au.D. program, and in addition to routine clinical rotations, the candidate must complete an externship, which is typically a fourth-year full-time clinical experience under the guidance and direction of a preceptor. The candidate must also pass the national examination in audiology. On completion of the Au.D. and after passing the national examination, the candidate

becomes eligible for state licensure. The candidate will also be eligible for certification by the ASHA or ABA as desired. Licensure is usually renewed on an annual basis and typically requires evidence of active involvement in continuing education. Some audiologists are exempt from state licensure because of the nature of their employment setting. As a general rule, audiologists who work in public school settings or who work for government agencies are exempt from state licensure, although most seek licensure regardless of their exemption status.

Requirements necessary to dispense hearing aids vary across states. In most states, licensure in audiology also automatically grants licensure to dispense hearing aids. Although there is a growing trend for this type of arrangement, many states still require a separate license to dispense hearing aids. Most dispensing-licensure requirements are less stringent than requirements to practice audiology. Thus, most individuals who meet requirements for audiology licensure have the necessary requirements for a dispensing license. Nonetheless, a separate examination, usually written and practical, may be required by state dispensing boards.

Academic and Clinical Requirements

Academic and clinical requirements for audiology are determined by individual academic institutions, based on guidelines offered by an accreditation agency, the CAA. In order for students to be considered for licensure, they must graduate from an institution that is accredited by the agency. These requirements are intended to ensure educational quality and provide uniformity across programs.

Academic requirements include minimum number of classroom hours of exposure to different aspects of audiology and related bodies of knowledge. In general, audiology students are required or encouraged to take classes in general science areas such as acoustics, anatomy and physiology, electronics, and computer technology. Classes are required in normal processes of hearing, speech, and language development as well as in pathologies of the auditory system. Audiologic diagnosis is usually covered in a number of classes,

including those on basic testing, electroacoustic and electrophysiologic measurement, and pediatric assessment. Audiologic treatment is usually covered in classes on audiologic rehabilitation, amplification, pediatric intervention, and counseling.

Clinical requirements include a minimum number of hours of hands-on diagnosis and treatment in a variety of settings. Some minimum requirements of speech and language evaluation and remediation serve as a precursor to the audiologic experience. In audiology, clinical hours are necessary in basic and advanced assessment of children and adults and in hearing aid assessment and fitting.

Following classroom education and clinical rotations, the aspiring audiologist usually embarks on an externship year as a part of the academic program. This is a focused clinical rotation during which the Au.D. candidate serves in a clinical capacity under the direction of a licensed audiologist serving as a preceptor. The goal of the externship is to enhance and polish the clinical abilities of the audiology candidate.

Summary

- Audiology is the health-care profession devoted to hearing. It is a clinical profession that has as its unique mission the diagnosis of hearing loss and the treatment of impairment that results from hearing disorders.
- An audiologist is a professional who, by virtue of academic and clinical training, and appropriate credentialing, is uniquely qualified to provide a comprehensive array of professional services related to the prevention, diagnosis, and treatment of hearing impairment and its associated communication disorder.
- The audiologist assesses hearing, evaluates and fits hearing aids, and assists in the implementation of treatment.
- The audiologist may also engage in the evaluation of dizziness and balance disorders and the monitoring of multisensory evoked potentials.

- Audiology is an autonomous profession. A patient with a hearing loss can choose to enter the health-care door through the audiologist, without referral from a physician or other health-care provider. Audiologists are practitioners qualified to assess hearing and provide hearing treatment services and are afforded the autonomy to do so.
- Audiologists are employed in a number of different settings, including private practices, physicians' practices, hospitals and medical centers, hearing and speech clinics, schools, universities, hearing instrument manufacturers, and industry.
- As broadly based health-care professionals diagnosing and treating hearing impairment, audiologists come into contact with many other professionals on a daily basis, including otolaryngologists, other physicians, speech-language pathologists, non-audiologist hearing aid dispensers, and other health-care and education professionals.
- Audiology has evolved over the past 50 years clinically, academically, and professionally. The professional evolution has changed the practice of audiology from a largely academic discipline to an independent health-care profession with doctoral-level education and licensure. The clinical evolution has changed the practice from a rehabilitation emphasis to one of diagnosis and treatment of hearing loss.
- In the grand scheme of things, audiology is a relatively young profession. The term audiology can be traced back to the 1940s when it was used to describe clinical practices related to serving hearing care needs of soldiers returning from World War II. Tremendous strides were made in the 1970s in the technologies available for evaluating hearing and in the 1980s in hearing aid amplification technologies. As the decades progressed, the number of practitioners of the profession of audiology grew substantially, and audiology evolved from an academic discipline to a clinical profession.
- A typical new audiology graduate in the first decade of the twenty-first century holds a bachelor's degree in communication disorders or another health- or science-related area, has earned an Au.D. degree, has passed a national examination in audiology, and has a state license to practice audiology, which includes the dispensing of hearing aids.

Short Answer Questions

1. Audiology is a hearing health-care profession with a mission of _____ of hearing ability and amelioration of _____ resulting from hearing disorders.
2. Audiologists are concerned with the prevention, _____, and treatment of _____ disorders resulting from hearing loss.
3. Qualifications for audiologists include an academic degree, _____ education, and appropriate _____ or other credential.
4. Diagnosis of hearing loss involves determining the _____ and _____ of hearing impairment.
5. Activities such as determination of candidacy for hearing instrumentation, programming of hearing devices, auditory training, and education are examples of _____.
6. Participation by an audiologist as an expert witness is known as _____ audiology.
7. Audiologists are involved in the design, implementation, and coordination of occupational and military hearing _____ programs, which are aimed at the identification and amelioration of hazardous noise exposure.
8. Monitoring using _____ sensory evoked potentials to assess sensory and motor neural function during surgical procedures is often performed by audiologists.
9. An _____ profession is one that is independent from the oversight of other professions.
10. Some audiologists are employed by physicians who specialize in _____ (disorder of the ear, nose, and throat), or its subspecialty that focuses only on disorders of the ear, _____. These fields are closely aligned because many individuals with ear disease also have _____ _____ and vice versa.
11. Audiologists frequently work closely with _____-_____ _____, professionals who provide evaluation and rehabilitation for communication disorders results from speech and/or language impairment.
12. The _____ is the degree designator for audiologists.

13. The process by which a nongovernment agency or association grants recognition to an individual meeting specified qualifications is known as _____.
14. The process known as _____, wherein a government agency grants permission to engage in a specified profession, provides the legal right for a professional to practice.
15. The _____ and the pure-tone _____ were developed in the 1920s and 1930s by C. C. Bunch.

Discussion Questions

1. What does it mean to be an autonomous profession? Why is a thorough understanding of the scope of practice and code of ethics necessary in an autonomous profession?
2. Who defines the scope of practice for a profession? Who defines the scope of practice for the profession of audiology?
3. How do certification and licensure relate to one another?
4. How have technological advancements contributed to the expansion of the scope of audiology practice?
5. Why is it important to understand the historical roots of a profession such as audiology? How is audiology, as it is presently practiced, influenced by its historical beginnings?

Resources

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Organizations

American Academy of Audiology (AAA)
Phone: (800) 222-2336
Web site: www.audiology.org

Academy of Doctors of Audiology (ADA)
Phone: (800) 445-8629
Web site: www.audiologist.org

Academy of Rehabilitative Audiology (ARA)
Phone: (612) 920-0484
Web site: www.audrehab.org

American Academy of Otolaryngology—Head and Neck Surgery (AAO-HNS)
Phone: (703) 836-4444
Web site: www.entnet.org

American Auditory Society (AAS)
Phone: (435) 574-0062
Web site: www.amauditorysoc.org

American Speech-Language-Hearing Association (ASHA)
Phone: (301) 897-5700
Web site: www.asha.org

Canadian Academy of Audiology (CAA)
Phone: (416) 494-6672
Web site: www.canadianaudiology.ca

Educational Audiology Association (EAE)
Phone: (800) 460-7322
Web site: www.edaud.org

Hearing Industries Association (HIA)
Phone: (703) 684-6048
Web site: www.hearing.org



2

THE NATURE OF HEARING

Learning Objectives

The Nature of Sound
- What Is Sound?
- Properties of Sound

The Auditory System
- Outer Ear
- Middle Ear
- Inner Ear
- Auditory Nervous System

The Vestibular System
- Anatomy
- Physiology

How We Hear
- Absolute Sensitivity of Hearing
- Differential Sensitivity
- Properties of Pitch and Loudness
- Measurement of Sound

Summary

Short Answer Questions

Discussion Questions

Resources

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- Describe physical properties of matter and the role they play in the generation of sound.
- Identify the properties of sound and their psychological equivalents.
- Define the quantities of the physical properties of sound and explain how they are used to describe hearing loss.
- Identify the three major components of the ear and their specific anatomical structures.
- Explain the roles of the anatomical structures of the ear in perceiving sound.
- Identify the nuclei of the central auditory system.
- Explain the function of the vestibular system and identify its anatomical components.

THE hearing mechanism is an amazingly intricate system. Sound is generated by a source that sends out air pressure waves. These pressure waves reach the eardrum, or tympanic membrane, which vibrates at a rate and magnitude proportional to the nature of the waves. The tympanic membrane transforms this vibration into mechanical energy in the middle ear, which in turn converts it to **hydraulic energy** in the fluid of the inner ear. The hydraulic energy stimulates the **sensory cells** of the inner ear, which send electrical impulses to the auditory nerve, brainstem, and **cortex**. But the passive reception of auditory information is only the beginning. The listener brings to bear upon these acoustic waves attention to the sound, differentiation of the sound from background noise, and experience with similar sounds. The listener then puts all of these aspects of audition into the context of the moment to identify the nature of a sound.

Hydraulic energy is related to the movement and force of liquid.

Sensory cells are hair cells in the cochlea.

The term **cortex** is commonly used to describe the cerebral cortex or outer layer of the brain.

That simple sounds can be identified is testimony to the exquisite sensitivity of the auditory system. Now imagine the intricacy of identifying numerous sounds that have been molded together to create speech. These sounds of speech are made up of pressure waves that by themselves carry no meaning. When they are put together in a certain order and processed by a normally functioning auditory system, they take on the characteristics of speech, which is then processed further to reveal the meaning of what has been said.

When you think about the auditory system, it is easy to become amazed that it serves both as an obligatory sense that cannot be

turned off and as a very specialized means of communication. That is, the auditory system simultaneously monitors the environment for events that might alert the listener to danger, opportunity, or change, while focusing on the processing of acoustic events as complicated as speech. The importance of continual environmental monitoring, the intricacy of turning pressure waves into meaningful constructs, and the complexity of doing all of this at once speaks to the extraordinary capability of the auditory system.

This chapter provides an overview of the nature of sound and its characteristics, the structure and function of the auditory and vestibular systems, and the way in which sound is processed by the auditory system to allow us to hear.

THE NATURE OF SOUND

You have undoubtedly heard the question about whether or not a tree that falls in a forest makes a sound if no one is around to hear it. The question is of interest because it serves to illustrate the difference between the physical properties that we know as **sound** and the psychological properties that we know as **hearing**.

Sound is vibratory energy transmitted by pressure waves in the air or other media.

Hearing is the perception of sound.

What Is Sound?

Sound is a common type of energy that occurs as a result of *pressure waves* that emanate from some force being applied to a sound source. For example, a hammer being applied to a nail results in vibrations that propagate through the air, the hammer, the nail, and the wood. Sound results from the compression of molecules in the medium through which it is traveling. In this example, the sound that emanates through the air results from a disturbance of air molecules. Groups of molecules are compressed, which, in turn, compress adjacent groups of molecules. This results in waves of pressure that emanate from the source.

There are several requirements for sound to exist. Initially there must be a source of vibratory energy. This energy must then be delivered to and cause a disturbance in a medium. Any medium will do, actually, as long as it has mass and is compressible, or

elastic, which most are. The disturbance is then propagated in the medium in the form of sound waves that carry energy away from the source. These waves occur from a *compression* of the medium, or **condensation**, followed by an *expansion* of the medium, or **rarefaction**. This compression and expansion of particles results in pressure changes propagated through the medium. The waves are considered longitudinal in that the motion of the medium's particles is in the same direction as the disturbance.

During **condensation**, the density of air molecules is increased, causing increased pressure.

During **rarefaction**, the density of air molecules is decreased, causing decreased pressure.

Thus, sound results from a force acting on an elastic mass that is then propagated through a medium in the form of longitudinal condensation and rarefaction waves that create pressure changes and create sound. Perhaps an example will clarify.

Suppose for a moment that you are an air molecule. You are surrounded on all sides by other air molecules. Your position in space is fixed (the analogy is not perfect, but bear with me). You are free to move in any direction, but because of your elasticity, you always move back to your original position after you have been displaced. That is, your movement will always be opposed by a restoring force that will bring you back to where you were. This movement of yours is illustrated in Figure 2-1.

Okay, now an earphone diaphragm moves outward from behind you. You and your neighbors to your left and right get pushed from behind by those neighbors behind you. This causes you to bump into your neighbors in front of you, who in turn push those in front of them. Your elasticity keeps you from moving too far, and so basically, you get squished or compressed in the crowd. You haven't really moved much, but the energy from the loudspeaker has been passed by the action of you bumping into those in front of you, who bump into those in front of them, and so on. Thus the pressure caused by the loudspeaker movement is passed on in a wave of compression. But wait, now the diaphragm moves back and you are pulled backwards by a low pressure area, resulting in an expansion (rarefaction) of space between you and the neighbors behind and in front of you. Then, just as the elbow room is feeling good, the diaphragm moves back the other way and squishes you back together, and so on. This series of compression and expansion waves is depicted in Figure 2-2.

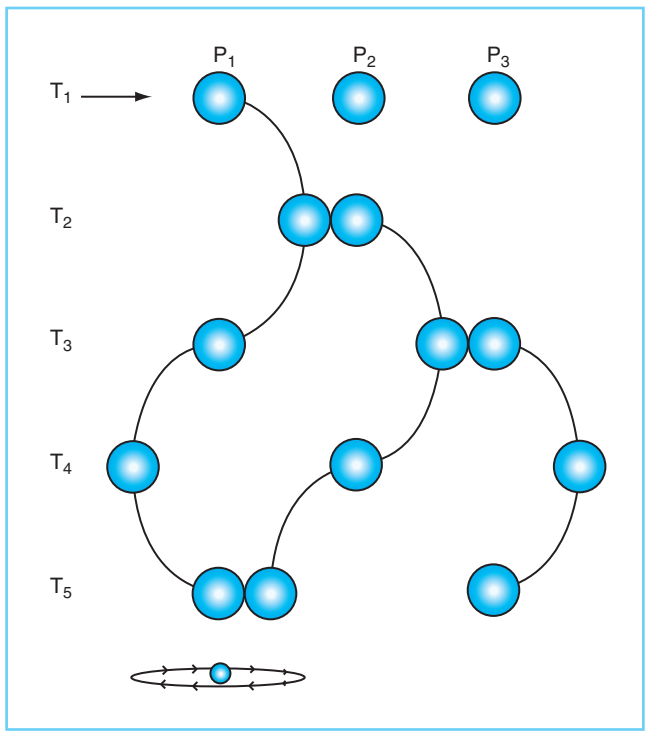


FIGURE 2-1 Schematic representation of the motion of particles in a medium over time (T). Here, a sound wave, designated by an arrow, moves particle PI into its neighbor, P2. Due to elasticity, PI moves back to its original position after displacement, and P2 continues the energy transfer by moving into P3. The small inset shows the displacement of a single particle. The lines connecting particles trace the movement over time.

As mentioned, the analogy is not perfect. Air molecules are constantly moving in a random manner. You do not move along because your net displacement, or movement from your original place, is zero (i.e., you are going nowhere) due to the elasticity restoring your original position; rather the energy in the wave of disturbance gets passed along as a chain reaction. That is, it is your motion that is passed on to your neighboring molecule rather than you being displaced. You pass on the wave of disturbance rather than move with it.

Mass is the quantity of matter in a body.

The restoring force of a material that causes it to return to its original shape after displacement is called **elasticity**.

Energy is the ability to do work.

You have **mass**, you are **elastic**, and you pass **energy** along in the form of pressure waves.

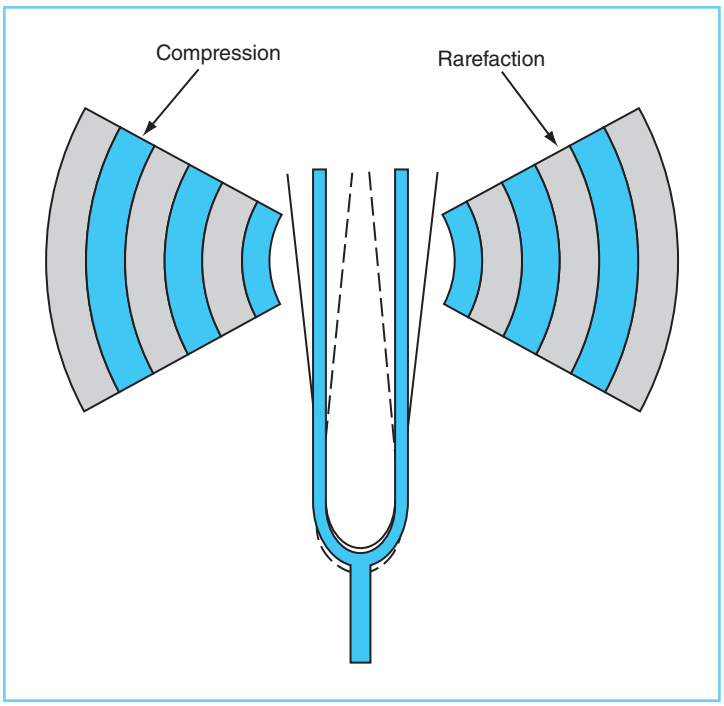


FIGURE 2-2 Alternate regions of *compression* (darker shading) and *rarefaction* (lighter shading) move outward through an air mass because of the vibratory motion of a tuning fork.

Properties of Sound

The back and forth movement is referred to as **simple harmonic motion**, or **sinusoidal motion**. Now suppose that we were to graph the movement. We give you a pencil and ask you to hold it as we plot your movement over time. The result is shown in Figure 2-3. This graphic representation is called a sinusoid, and the simple harmonic motion produces a sinusoidal **waveform**, or sine wave. Because the displacement as an air molecule is propagated, or passed on, through the pressure wave, the simple harmonic motion also describes the pressure changes of the sound wave over time. Thus, a sine wave is a graphic way of representing the pressure waves of sound. This is illustrated in Figure 2-4.

The continuous, periodic back and forth movement of an object is called **simple harmonic motion**.

Sinusoidal motion is harmonic motion plotted as a function of time.

A **waveform** is a form or shape of a wave, represented graphically as magnitude versus time.

This sinusoidal waveform is used as a means of describing the various properties of sound, as shown in Figure 2-5. The magnitude

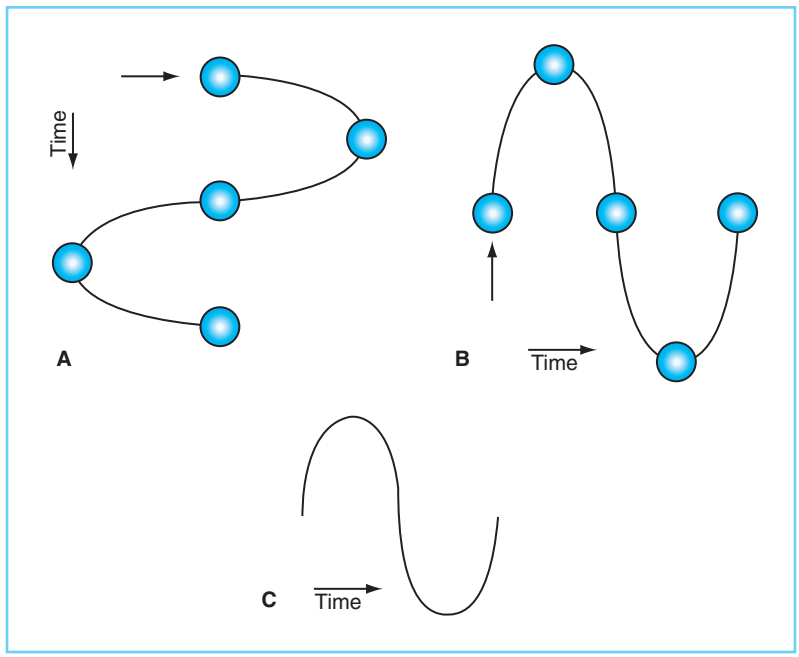


FIGURE 2-3 The back and forth movement of an air molecule over time can be represented as harmonic or sinusoidal motion. In A, the particle is set into motion by sound vibration, and its course is traced over time. The graph is replotted in B to show time along the x-axis. The line in C is a sinusoid that describes the movement.

A **cycle** is one complete period of compression and rarefaction of a sound wave.

A **phase** is any stage of a cycle.

Intensity is the quantity or magnitude of sound.

or amplitude of displacement dictates the intensity of the sound. How often a complete **cycle** of displacement occurs dictates the frequency of a sound. The point along the displacement path describes the **phase** element of a waveform.

Intensity

The magnitude of a sound is described as its **intensity**. Intensity is related to the perception of loudness. As described above, an air molecule that is displaced will be moved a certain distance, return past its original location to an equal displacement in the opposite direction, and then return to its original location. The total displacement can be thought of as one cycle in the movement of the molecule. The magnitude of the cycle, or the distance that the molecule moves, is called its intensity. The higher the force or

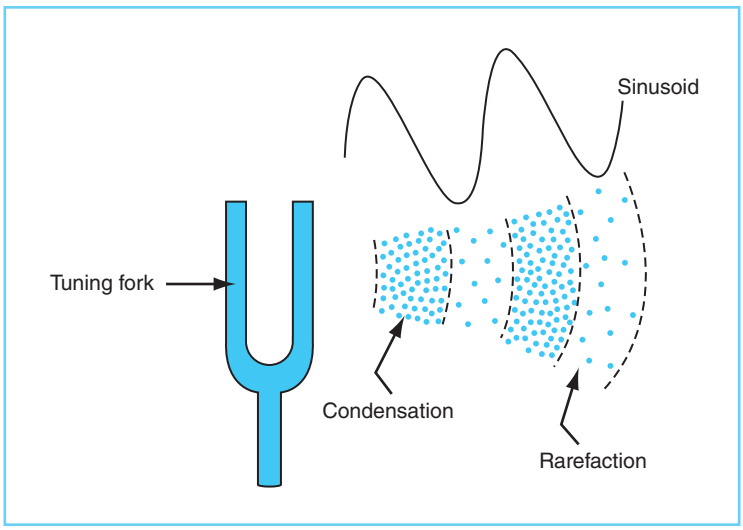


FIGURE 2-4 The relation between condensation and rarefaction waves and the sinusoidal function.

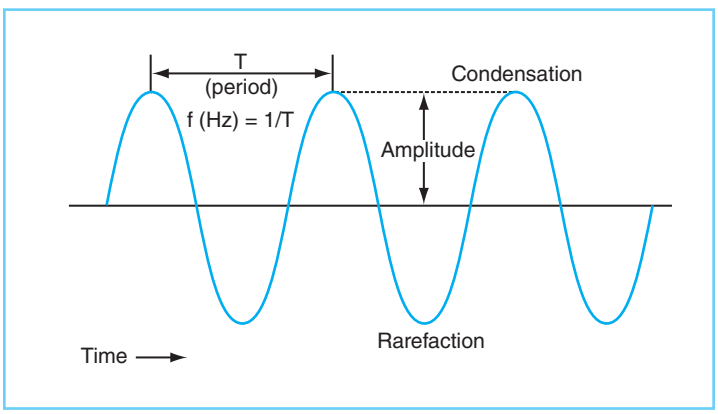


FIGURE 2-5 A sinusoidal waveform, describing the various properties of sound, including amplitude and frequency (f).

magnitude of the compression wave, the higher the intensity of the signal. Figure 2-6 illustrates two waveforms that are identical in frequency and phase but vary in amplitude or intensity.

The range of intensity of sound is quite large. For example, the pressure level of a sound that is just barely audible is approximately 20 μPa (or microPascals, a unit of measure of pressure).

The pressure level of a sound that is so intense that it is painful is 200,000,000 μPa. This relationship is shown in Figure 2-7. As a result of this large range, the description of sound pressure

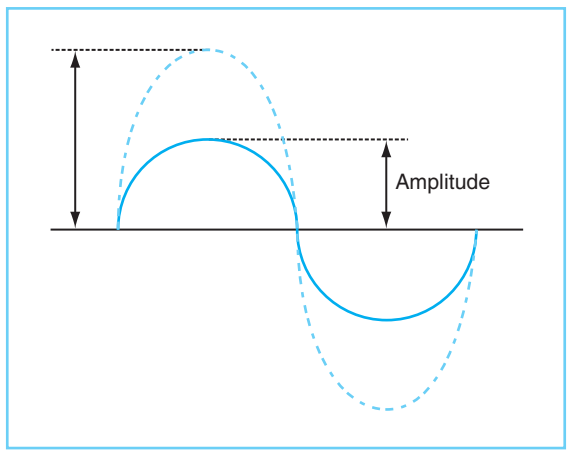


FIGURE 2-6 Two waveforms that are identical in frequency and phase but vary in magnitude.

Ratio	dB SPL	μPa
1:1	0	20
10:1	20	200
100:1	40	2,000
1,000:1	60	20,000
10,000:1	80	200,000
100,000:1	100	2,000,000
1,000,000:1	120	20,000,000
10,000,000:1	140	200,000,000
100,000,000:1		
1,000,000,000:1		
10,000,000,000:1		
100,000,000,000:1		
1,000,000,000,000:1		
10,000,000,000,000:1		
100,000,000,000,000:1		

FIGURE 2-7 The relationship of the ratio of sound magnitude to the range of sound intensity expressed in sound pressure level. Sound ranges from barely audible at 20 μPa to painful at 200,000,000 μPa.

level in absolute units is intractable. Instead, intensity has come to be described in units called **decibels** (dB).

A **decibel** (dB) is one tenth of a Bel.

The decibel was derived to describe the magnitude of sound in the early days of telephone. The convention described intensity as the **logarithm** of the ratio of a measured power to a reference power. Power was used rather than pressure because of the nature of measuring the output of telephone lines. But the concept held, and the unit of measure used was referred to as a **Bel**, named after **Alexander Graham Bell**. By using logarithms, the large intensity range was made to vary between 1 and 14 Bels. This proved to be too small a resolution, and the notion of a decibel was created so that 1 Bel would equal 10 decibels, 2 Bels would equal 20 decibels, and so on.

The exponent expressing the power to which a fixed number, the base, must be raised to produce a given number is the **logarithm**.

A **Bel** is a unit of sound intensity relative to a reference intensity.

Alexander Graham Bell, who invented the telephone, also championed aural education of the deaf. The A.G. Bell museum is located in Baddeck, Nova Scotia.

Today, we most often express intensity in decibels (dB) **sound pressure level**, or dB SPL. Here's how we got there. First, intensity level (IL), or the magnitude of sound expressed as power, is described by the following formula:

$$\text{dB IL} = 10 \log (\text{power/reference power})$$

Sound pressure level (SPL) = magnitude of sound energy relative to a reference pressure .0002 dyne/cm^2 or 20 μPa.

But we don't want to measure power, we want to measure sound pressure. Well, it turns out that power is proportional to pressure squared, so the formula that applies is:

$$\text{dB SPL} = 10 \log (\text{pressure/reference pressure})^2$$

Of course, the log of something squared is 2, so we can restate the formula as:

$$\text{dB SPL} = 2 \times 10 \log (\text{pressure/reference pressure})$$

And, of course, we all know that 2×10 equals 20, so the decibel formula that we use to describe intensity in sound pressure level is, finally:

$$\text{dB SPL} = 20 \log (\text{pressure/reference pressure})$$

where pressure is the measured pressure and reference pressure is a chosen standard against which to compare the measured pressure.

TABLE 2-1 Various units of measure for pressure

dB SPL	dynes/cm^2 (microbar)	Nt/m^2 (Pa)	μNt/m^2 (μPa)
0	0.0002	0.00002	20
20	0.002	0.0002	200
40	0.02	0.002	2,000
60	0.2	0.02	20,000
80	2.0	0.2	200,000
100	20.0	2.0	2,000,000

This reference pressure is expressed in various units of measure as described in Table 2-1.

This is probably not as difficult as it seems. There are at least two important points to remember that should make this easier and more useful to comprehend.

Important Point #1. The logarithm idea is a way of reducing the range of pressure levels to a tractable one. By using this approach, pressures that vary from 1:1 to a hundred-million: 1 can be expressed as varying from 0 to 140 dB.

Important Point #2. Decibels are expressed as a ratio of a measured pressure to a reference pressure. This means that *0 dB does not mean no sound*. It simply means that the measured pressure is equal to the reference pressure, as follows:

$$\text{dB SPL} = 20 \log (20\ \mu\text{Pa}/20\ \mu\text{Pa})$$
$$\text{dB SPL} = 20 \log (1)$$
$$\text{dB SPL} = 20 \times 0$$
$$\text{dB SPL} = 0$$

So, if the measured pressure is 20 μPa, and 20 μPa is the standard reference pressure, then 20/20 equals 1, and we all remember that the log of 1 is 0 and that 20 times 0 equals 0. Therefore, as

you can see, 0 dB SPL does not mean no sound. It also means that having a sound with an intensity of −10 dB is possible.

As you will learn later in this section when we get to the **audiogram**, we are not content to stop with SPL as a way of expressing decibels. In fact, one of the most common referents for decibels in audiometry is known as **hearing level (HL)**, which represents decibels according to *average normal hearing*. Thus, 0 dB HL would refer to the intensity of a signal that could just barely be heard by the human ear. Human hearing ranges from the threshold of audibility, around 0 dB HL, to the threshold of pain, around 140 dB HL. Normal conversational speech occurs at around 40 to 50 dB HL, and the point of discomfort is approximately 90 dB HL.

An **audiogram** is a graph of thresholds of hearing sensitivity as a function of frequency.

Hearing level (HL) refers to the dB level of a sound referenced to audiometric zero.

Frequency

The second major way that sound is characterized is by its frequency. **Frequency** is the speed of vibration and is related to the perception of **pitch**. Recall that, as an air molecule, you were pushed in one direction, pulled in the other, and then returned to your original position. This constitutes one cycle of displacement. Frequency is the speed with which you moved. One way to describe this speed is by the time elapsed for one complete cycle to occur. This is called the **period**. Another way is by the number of cycles that a molecule moves in a specified period of time, which can be calculated as 1/period. Figure 2-8 illustrates three waveforms that are identical in amplitude and phase but vary in frequency.

Frequency is the number of cycles occurring in 1 second, expressed in Hertz (Hz).

Pitch is the perception of frequency.

The length of time for a sine wave to complete one cycle is called the **period**.

Frequency is usually expressed in cycles-per-second or **Hertz** (Hz). Human hearing in young adults ranges from 20 Hz to 20,000 Hz. Middle C on the piano has a frequency of 250 Hz. For audiometric purposes, frequency is not expressed in a linear form (i.e., with equal intervals), rather it is partitioned into **octave** intervals. An octave is simply twice the frequency of a given frequency. For audiometry, convention sets the lowest frequency at 125 Hz. Octave intervals then are 250, 500, 1000, 2000, 4000, and 8000 Hz.

Hertz (Hz) is unit of measure of frequency, named after physicist Heinrich Hertz.

The frequency interval between one tone and a tone of twice the frequency is called an **octave**.

Phase

Phase is the location at any point in time in the displacement of an air molecule during simple harmonic motion. Phase is expressed in degrees of a circle, as shown in Figure 2-9. That back and forth

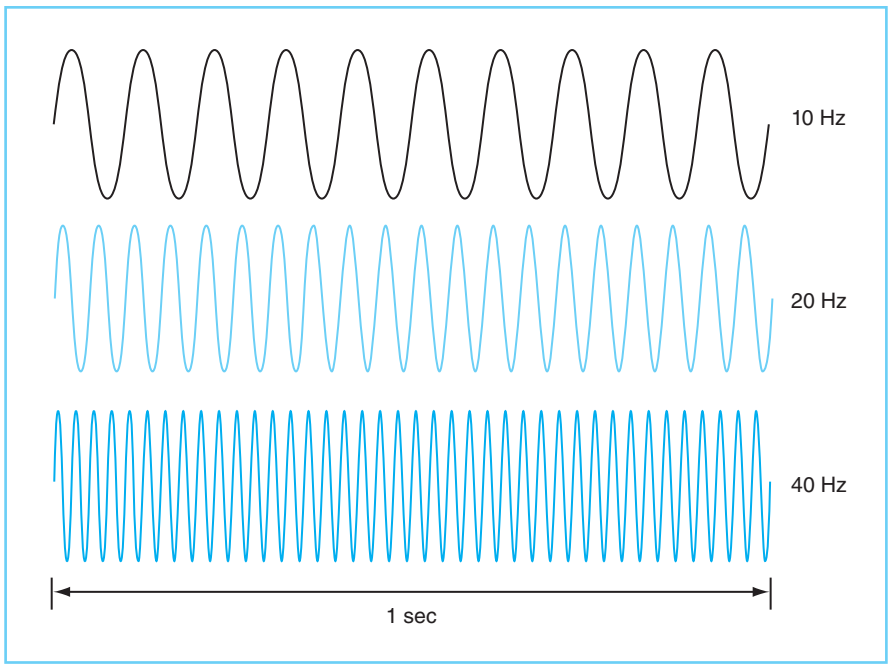


FIGURE 2-8 | Three waveforms that are identical in amplitude and phase but vary in frequency.

vibratory motion can be equated to circular motion may not be altogether intuitive. Figure 2-10 shows what would happen to an air molecule if it were being moved by the motion of a wheel. As the wheel approached 90°, it would be maximally displaced away from the vibrating source; as the wheel approached 270°, it would be maximally displaced toward the vibrating source, and so on.

One important aspect of phase is in its description of the starting point of a waveform. Figure 2-11 illustrates two waveforms that are identical in amplitude and frequency but vary in starting phase.

Spectrum

A **pure tone** is a sound wave having only one frequency of vibration.

Thus far, sound has been described in it simplest form, that of a sinusoid or **pure tone** of one frequency. Simplifying to this level is helpful in describing the basic aspects of sound. Although pure tones are not commonly found in nature, they are used extensively in audiometry as a method of assessing hearing sensitivity.

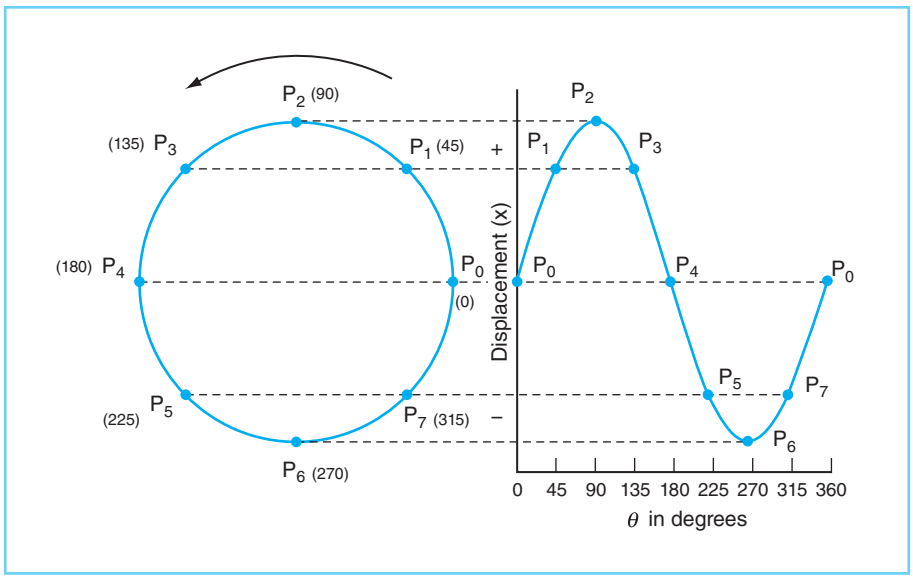


FIGURE 2-9 Schematic representation of a turning wheel undergoing simple harmonic motion. Points on the wheel are projected on a sinusoidal function, showing the magnitude of displacement corresponding to the angle of rotation and expressed in degrees of a circle.

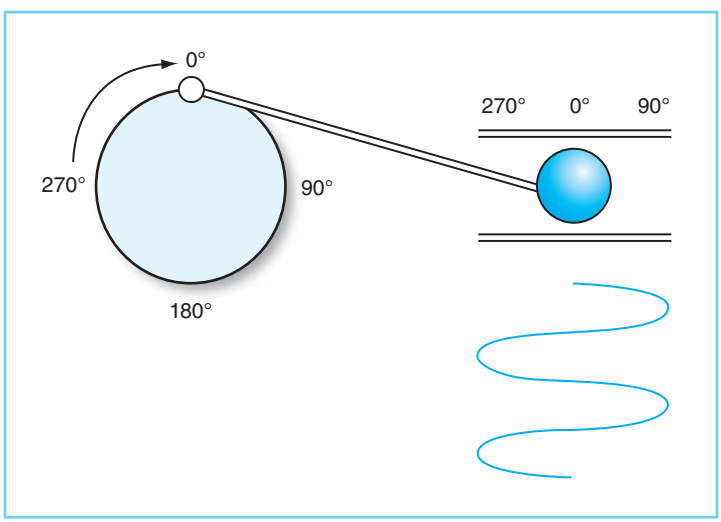


FIGURE 2-10 Schematic of the relationship between circular motion and the back and forth movement of an air molecule. Movement of the molecule results in sinusoidal motion.

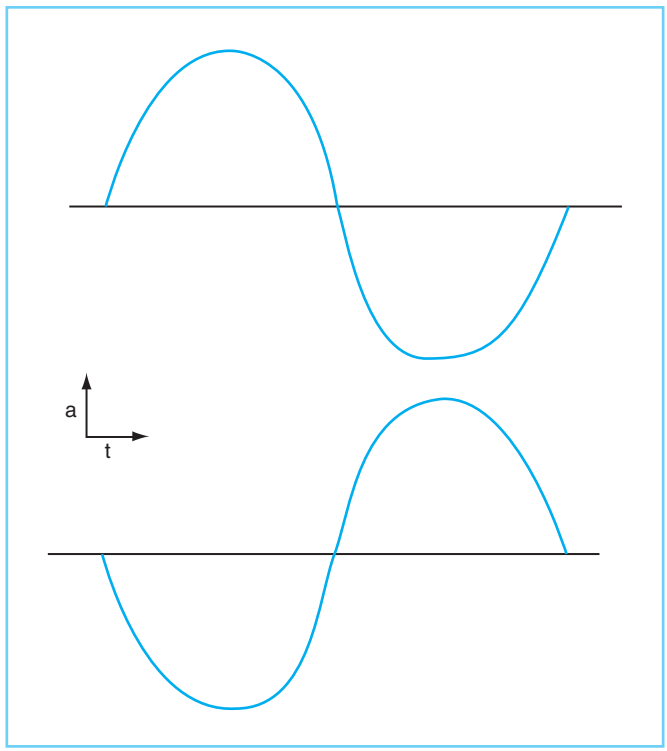


FIGURE 2-11 | Two waveforms that are identical in amplitude (a) and frequency but vary in starting phase.

A sinusoid is a *periodic* wave in that it repeats itself at regular intervals over time.

Waves that are not sinusoidal are considered *complex*, as they are composed of more than one sinusoid that differ in amplitude, frequency, and/or phase. Complex waves can be periodic, in which some component repeats at regular intervals, or they can be *aperiodic*, in which the components occur randomly.

The distribution of the magnitude of frequencies in a sound is called the **spectrum.**

Sounds in nature are usually complex, and they are rarely sufficiently described on the basis of the intensity of a single frequency. For these more complex sounds, the interaction of intensity and frequency is referred to as the sound's **spectrum**. The spectral content of a complex sound can be expressed as the intensity of the various frequencies that are represented at a given moment in time. An example is shown in Figure 2-12.

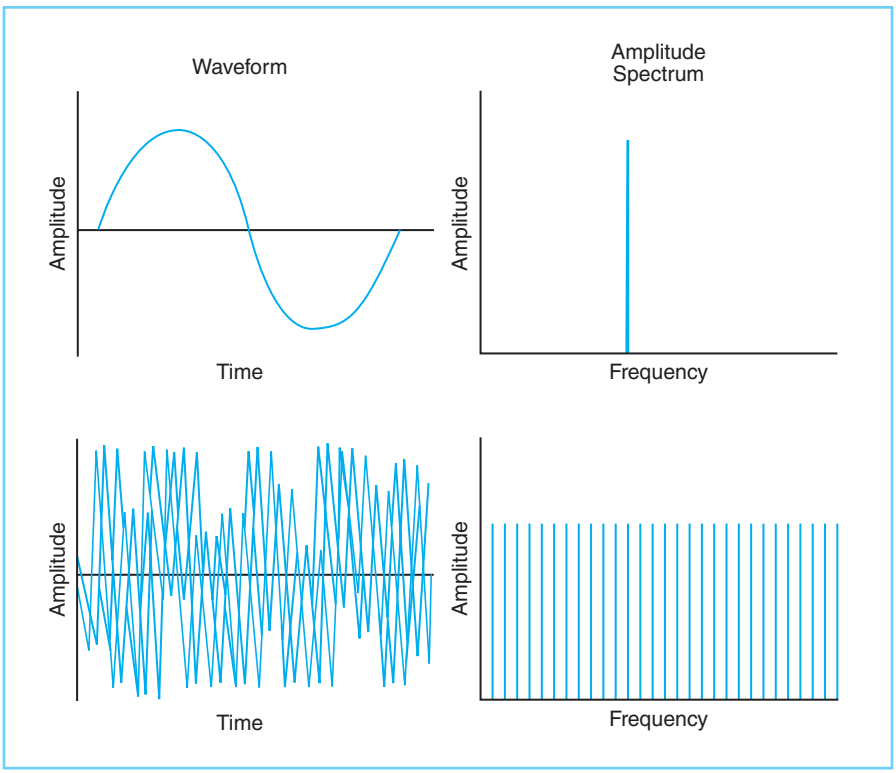


FIGURE 2-12 The spectral content of a single-frequency tone *(top)* and of a complex sound *(bottom)* are expressed as amplitude spectra, or amplitude of the individual frequency components.

THE AUDITORY SYSTEM

Hearing is an obligatory function; it cannot be turned off. Hearing is also a distance sense that functions mostly to monitor the external environment. In most animals, hearing serves a protective function, locating potential predators and other danger. It also serves a communication function, with varying levels of sophistication.

The auditory system is an amazingly intricate system, which has high sensitivity, sharp frequency tuning, and wide dynamic range. It is sensitive enough to perceive **acoustic** signals with pressure wave amplitudes of minuscule magnitudes. It is very finely tuned to an extent that it is capable of resolving, or distinguishing, frequencies with remarkable acuity. Finally, it is able to process acoustic signals varying in magnitude, or intensity range, in astonishing proportion.

Acoustic pertains to sound.

The physical processing of acoustic information occurs in three groups of structures, commonly known as the outer, middle, and inner ears. Neural processing begins in the inner ear and continues, via the VIIIth cranial nerve, to the central auditory nervous system. Psychological processing begins primarily in the brainstem and pons and continues to the auditory cortex and beyond. A useful diagrammatic representation of the auditory system is shown in Figure 2-13.

Outer Ear

The **outer ear** includes the auricle, external auditory meatus, and lateral surface of the tympanic membrane.

The external cartilaginous portion of the ear is called the **auricle**.

Pinna = auricle

The **helix** is the prominent ridge of the auricle.

The **outer ear** serves to collect and resonate sound, assist in sound localization, and function as a protective mechanism for the middle ear. The outer ear has three main components: the auricle, the ear canal or meatus, and the outer layer of the eardrum or tympanic membrane.

The **auricle** is the visible portion of the ear, consisting of skin-covered cartilage. It is also known as the **pinna** and is shown in the drawing of the anatomy of the ear in Figure 2-14. The upper rim of the ear is often referred to as the **helix** and the lower

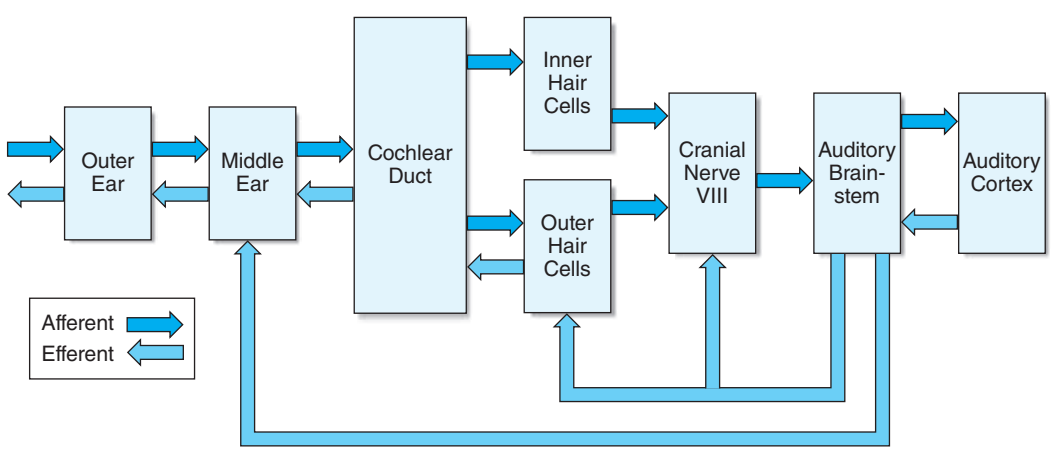


FIGURE 2-13 Schematic representation of structures and function of the auditory system, showing both afferent and efferent pathways. (Adapted from "Cochlear Neurobiology: Revolutionary Developments," by P. Dallos, 1988, *ASHA, 30*, p. 55.)

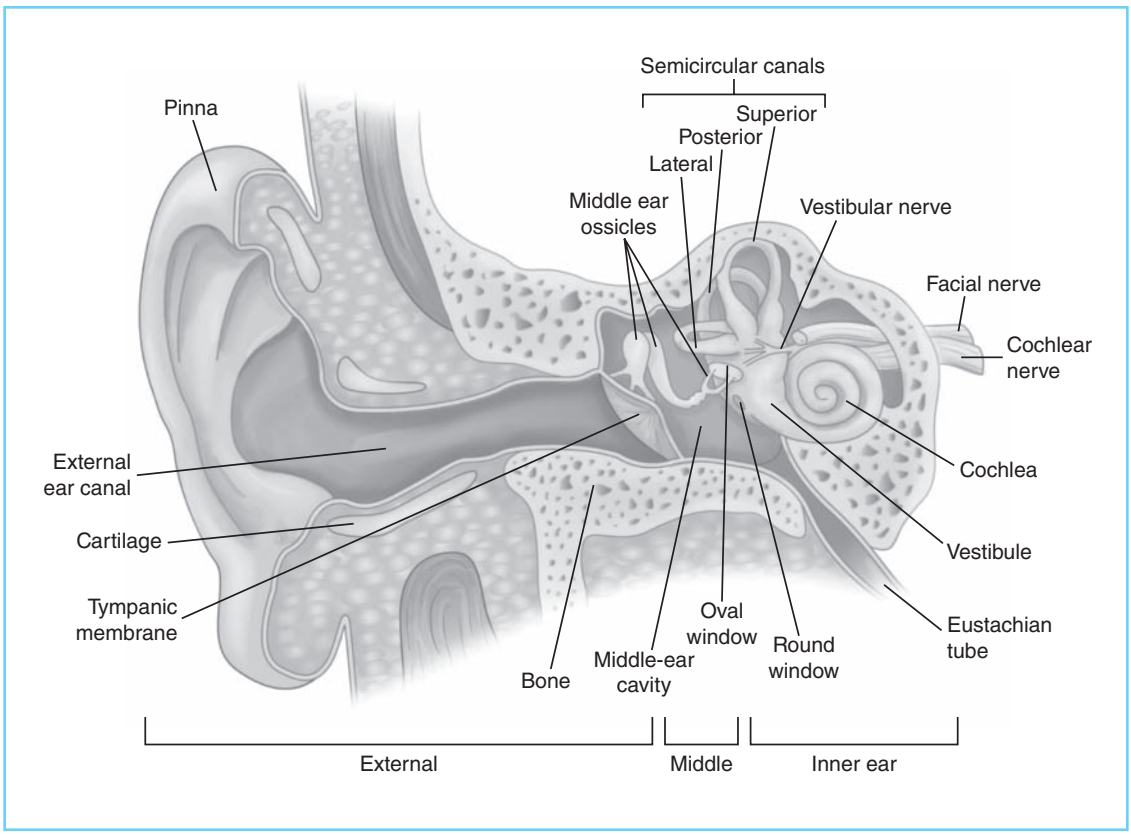


FIGURE 2-14 | Anatomy of the ear.

flabby portion as the **lobule**. The bowl at the entrance to the external auditory meatus is known as the **concha**.

The lobule is another term for earlobe.

The concha is the bowl of the auricle.

The auricles serve mainly to collect sound waves and funnel them to the external auditory canal. In humans, the auricles serve a more minor role in sound collection than in other animals. The auricles are important for sound localization in the vertical plane (ability to locate sound above and below) and for protection of the ear canal. The auricles also serve as **resonators**, enhancing sounds around 4500 Hz.

A system that is set into vibration by another vibration is called a **resonator**. The action of this additional vibration is to enhance the sound energy at the vibratory frequency.

The external auditory meatus is a narrow channel leading from an opening in the side of the head that measures 23–29 mm in length. The outer two thirds of the canal is composed of

skin-covered cartilage. The inner one third is skin-covered bone. The canal is elliptical in shape and takes a downward bend as it approaches the tympanic membrane. The skin in the cartilaginous portion of the canal contains glands that secrete earwax or cerumen.

The external auditory meatus directs sound to the eardrum or tympanic membrane. It serves as a resonator, enhancing sounds around 2700 Hz. It also serves to protect the tympanic membrane by its narrow opening. Cerumen in the canal also serves to protect the ear from intrusion by foreign objects, creatures, and so on.

Tympanic membrane = eardrum

The superior, smaller, compliant portion of the tympanic membrane is called the **pars flaccida**.

The larger and stiffer portion of the tympanic membrane is called the **pars tensa**.

The **tympanic membrane** lies at the end of the external auditory canal. It is a membrane made of several layers of skin embedded into the bony portion of the canal. The membrane is fairly taut, much like the head of a drum. Its shape is concave, curving slightly inward.

A schematic of the tympanic membrane is shown in Figure 2-15. There are two main sections of the tympanic membrane, the **pars flaccida** and the **pars tensa**. The pars flaccida is the smaller and

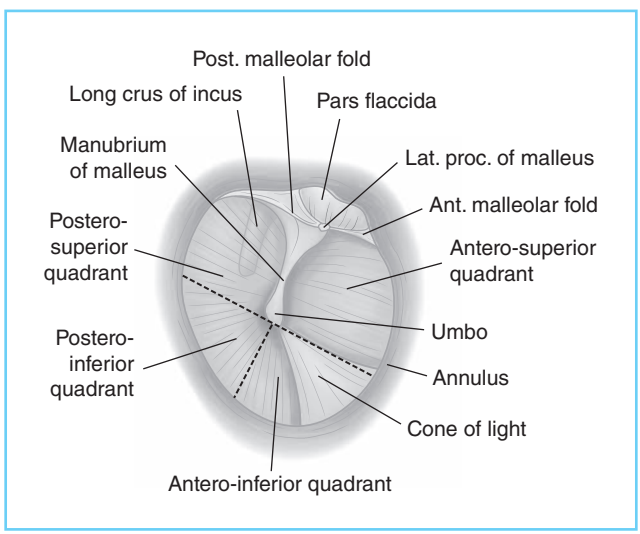


FIGURE 2-15 | Schematic of the tympanic membrane.

more compliant section of the drum, located superiorly and containing two layers of tissue. The pars tensa is the larger portion located inferiorly. It contains four membranous layers and is stiffer than the pars flaccida.

The tympanic membrane is set into motion by acoustic pressure waves striking its surface. The membrane vibrates with a magnitude proportional to the intensity of the sound wave at a speed proportional to its frequency.

Middle Ear

The *middle ear* is an air-filled space located within the temporal bone of the skull. It contains the **ossicular chain**, which consists of three contiguous bones suspended in space, linking the tympanic membrane to the oval window of the cochlea. The middle-ear structures function as an impedance matching device, providing a bridge between the airborne pressure waves striking the tympanic membrane and the fluid-borne traveling waves of the cochlea.

You may have learned the bones in the **ossicular chain** as the hammer, anvil, and stirrup.

Anatomy

The middle ear begins most laterally as the inner layers of the tympanic membrane. Beyond the tympanic membrane lies the middle-ear cavity. A schematic representation of the middle-ear cavity and its contents can be seen in Figure 2-14. The cavity is air-filled. Air in the cavity is kept at atmospheric pressure via the **Eustachian tube**, which leads from the cavity to the back of the throat. If air pressure changes suddenly, such as it does when ascending or descending in an airplane, the cavity will have relatively more or less pressure than in the ear canal, and a feeling of fullness will result. Swallowing often opens the Eustachian tube, allowing the pressure to equalize.

The **Eustachian tube** is the passageway from the nasopharynx to the anterior wall of the middle ear.

Attached to the tympanic membrane is the ossicular chain (Figure 2-16). The ossicular chain is a series of three small bones or ossicles. The **ossicles**, called the malleus, incus, and stapes, transfer the vibration of the tympanic membrane to the inner ear or cochlea. The **malleus** consists of a long process called the **manubrium** that is attached to the tympanic membrane and a head that is attached to the body of the *incus*. A short process or **crus** (leg) of the incus is fitted into a recess in the wall of the

The **ossicles** are the malleus, incus, and stapes.

The handle portion of the **malleus** is called the **manubrium**.

Crus = leg

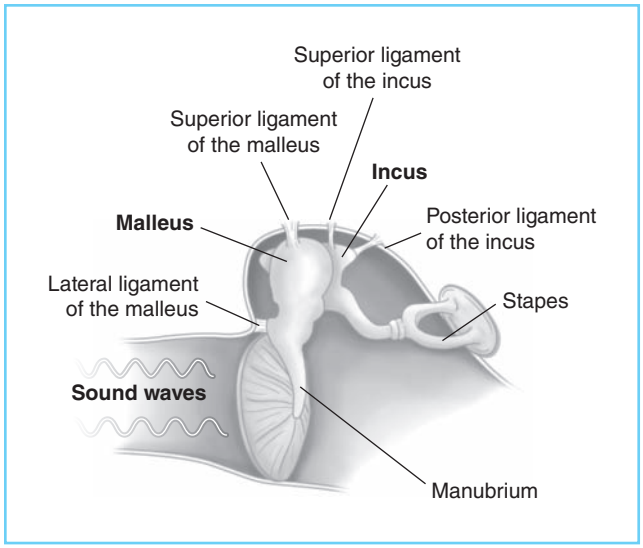


FIGURE 2-16 | The ossicular chain.

Crura = legs

The **oval window** leads into the scala vestibuli of the cochlea.

The **annular ligament** holds the footplate of the stapes in the oval window.

The two muscles of the middle ear are the **tensor tympani** muscle and the **stapedius** muscle.

tympanic cavity. The long crus of the incus attaches to the head of the stapes. The *stapes* consists of a head and two **crura** that attach to a footplate. The *footplate* is fitted into the **oval window** of the cochlear wall, held in place by the **annular ligament**. The ossicular chain is suspended in the middle-ear cavity by a number of ligaments, allowing it freedom to move in a predetermined manner. Two muscles also influence the ossicular chain, the **tensor tympani** muscle, which attaches to the malleus, and the **stapedius** muscle, which attaches to the stapes. Thus, when the tympanic membrane vibrates, the malleus moves with it, which vibrates the incus and, in turn, the stapes. The stapes footplate is loosely attached to the bony wall of the fluid-filled cochlea and transmits the vibration to the fluid.

Physiology

Although it is by no means the entire story, the function of the middle ear can probably best be thought of as a means of matching the energy transfer from air to fluid. That is, the middle ear acts as an *impedance matching transformer*. Briefly, the ease (or difficulty) of energy flow is different through air than it is through fluid. Pressure waves propagating through air are substantively reflected by

a fluid-filled space because of the difference in which energy flows through the two media. The different impedances of these two media need somehow to be matched or the functional gap between them bridged. The ossicular chain serves this purpose.

Air pressure waves vibrate the tympanic membrane, which vibrates the ossicles and sets the fluid of the cochlea into motion. If the middle ear did not exist, the air pressure waves would have to set the fluid of the cochlea into motion directly, and a substantial amount of energy would be lost in the process. Perhaps the best way to understand this is to understand that fish do not need a middle ear. Because the sounds that fish hear are propagated through water, the energy waves travel as fluid motion and set the inner-ear fluids into motion directly. Very little loss of energy results. But in humans, the energy waves are airborne and need to be transformed into mechanical energy before being converted to hydraulic energy. The mechanical energy of the middle ear serves as an efficient energy converter from air to fluid.

The middle ear is designed to accomplish this in several ways. First, there is a substantial area difference between the tympanic membrane and the oval window. This area difference serves much the same purpose as the head of a nail. Pressure applied on the large end results in substantially greater pressure at the narrow end. The ossicles also act as a lever, pivoting around the **incudomalleolar joint**, which contributes to an increase in vibrational amplitude at the stapes.

The juncture of the incus and the malleus is called the **incudomalleolar joint**.

Inner Ear

The inner ear consists of the auditory and vestibular labyrinths. The term *labyrinth* is used to denote the intricate maze of connecting pathways in the **petrous** portion of each temporal bone. The *osseous labyrinth* is the channel in the bone; the *membranous labyrinth* is composed of soft-tissue fluid-filled channels within the osseous labyrinth that contain the end-organ structures of the hearing and vestibular systems. The auditory labyrinth is called the cochlea and is the sensory **end-organ** of hearing. It consists of fluid-filled membranous channels within a spiral canal that encircles a bony central core. Here the sound waves, transformed into mechanical energy by the middle ear, set the fluid of the cochlea into motion in

Petrous means resembling stone.

End-organ is the terminal structure of a nerve fiber.

a manner consistent with their intensity and frequency. Waves of fluid motion impinge on the membranous labyrinth and set off a chain of events that results in neural impulses being generated at the VIIIth cranial nerve.

Anatomy

The *cochlea* is a fluid-filled space within the temporal bone, which resembles the shape of a snail shell with 2.5 turns. An illustration of the bony labyrinth is shown in Figure 2-17. Suspended

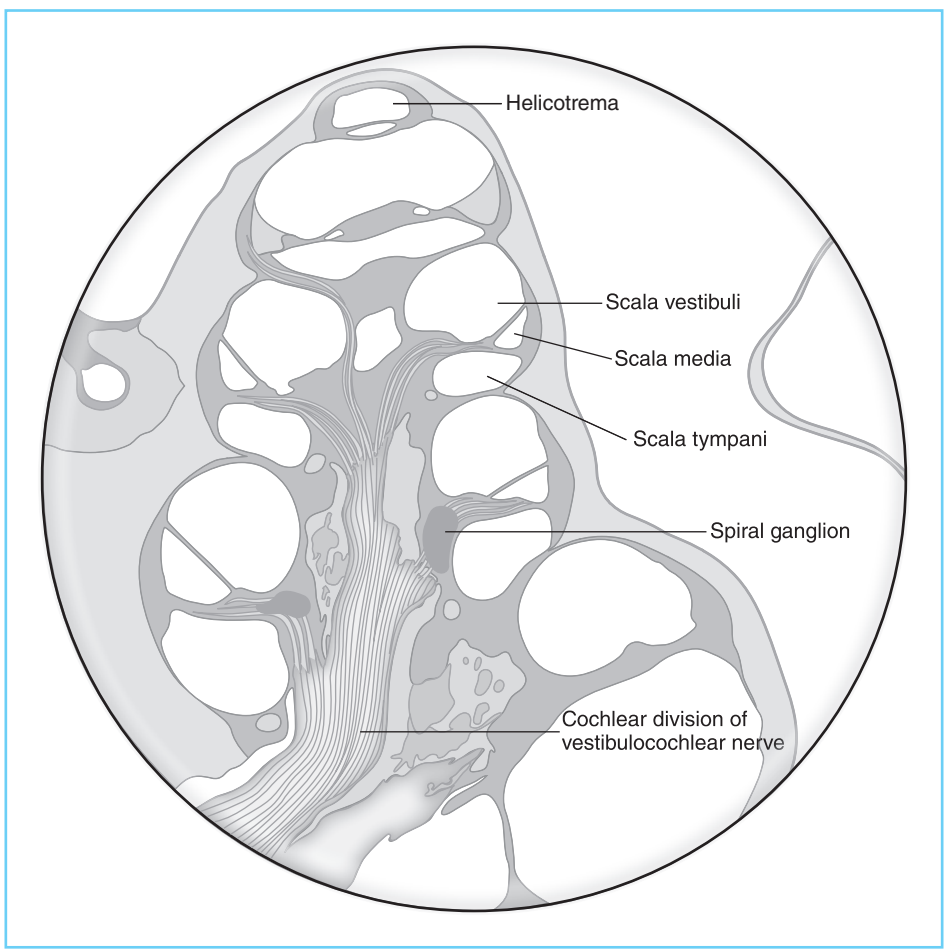


FIGURE 2-17 A section through the center of the cochlea, illustrating the bony labyrinth.

within this fluid-filled space, or *cochlear duct*, is the membranous labyrinth, which is another fluid-filled space often referred to as the *cochlear partition* or **scala media**. An illustration of the membranous labyrinth is shown in Figure 2-18.

The cochlear partition separates the **scala vestibuli** from the **scala tympani**, as shown in Figure 2-19. The scala vestibuli is the uppermost of two **perilymph**-filled channels of the cochlear duct and terminates basally at the *oval window*. The scala tympani is the lowermost channel and terminates basally at the *round window*. Both of these channels terminate at the apical end of the cochlea at the **helicotrema**.

The cochlear partition or scala media is an **endolymph**-filled channel that lies between the scala vestibuli and scala tympani. It is cordoned off by two membranes. *Reissner's membrane* serves as the cover of the partition, separating it from the scala vestibuli. The *basilar membrane* serves as the base of the partition,

The middle channel of the cochlear duct is called the **scala media** and is filled with endolymph.

The uppermost channel of the cochlear duct is called the **scala vestibuli** and is filled with perilymph.

The lowermost channel of the cochlear duct is called the **scala tympani** and is filled with perilymph.

Perilymph is cochlear fluid that is high in sodium and calcium.

The passage connecting the scala tympani and the scala vestibuli is called the **helicotrema**.

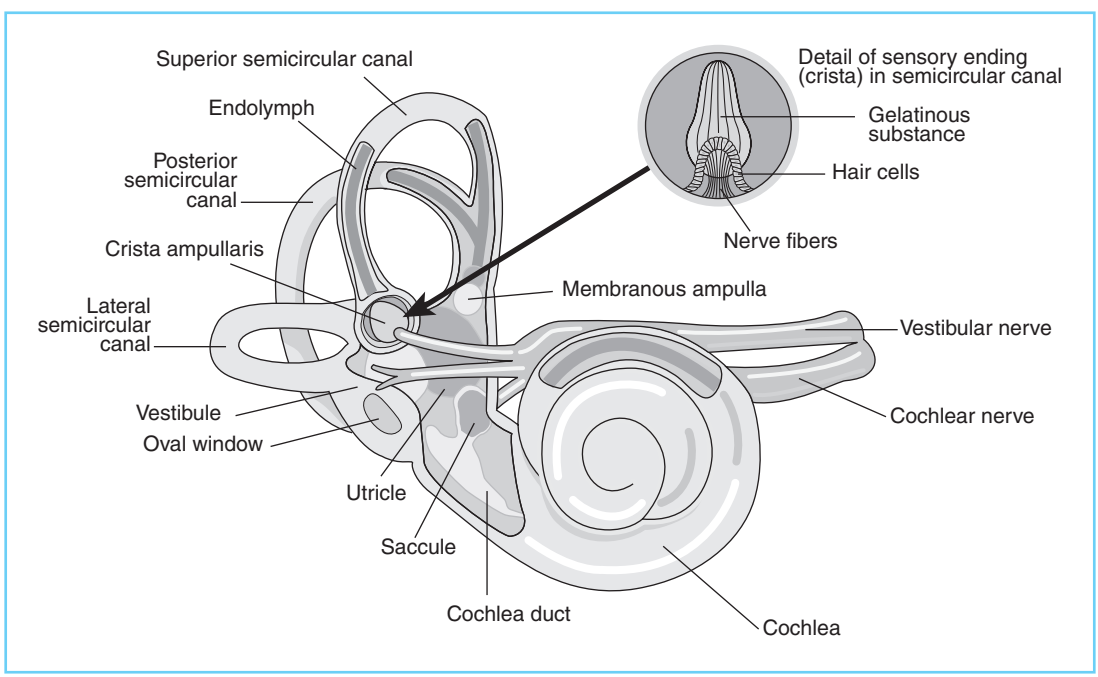


FIGURE 2-18 The membranous labyrinth.

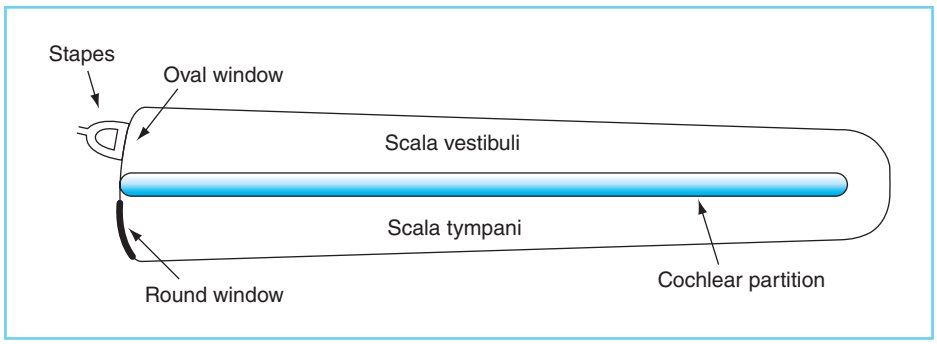


FIGURE 2-19 Schematic of an uncoiled cochlea, showing that the cochlear partition separates the scala vestibuli from the scala tympani.

Endolymph is cochlear fluid that is high in potassium and low in sodium.

separating it from the scala tympani. Riding on the basilar membrane is the *organ of Corti*, which contains the sensory cells of hearing. Illustrations of the cochlear duct and organ of Corti are shown in Figures 2-20 and 2-21. It is obvious from the latter illustration that the microstructure of the organ of Corti is complex, containing numerous nutrient, supporting, and sensory cells.

There are two types of sensory cells, both of which are unique and very important to the function of hearing. These are termed the outer hair cells and inner hair cells. Outer hair cells are elongated in shape and have small hairs, or cilia, attached to their top. These cilia are embedded into the *tectorial membrane*, which covers the organ of Corti. There are three rows of outer hair cells throughout most of the length of the cochlea. The outer hair cells are innervated mostly by efferent, or motor, fibers of the nervous system. There are about 13,000 outer hair cells in the cochlea. Outer hair cells and their innervation are shown in Figure 2-22.

Inner hair cells are also elongated and have an array of cilia on top. Inner hair cells stand in a single row, and their cilia are in proximity to, but not in direct contact with, the tectorial membrane. The inner hair cells are innervated mostly by afferent, or sensory, fibers of the nervous system. There are about 3,500 inner hair cells in the cochlea. An illustration of inner hair cells is shown in Figure 2-23.

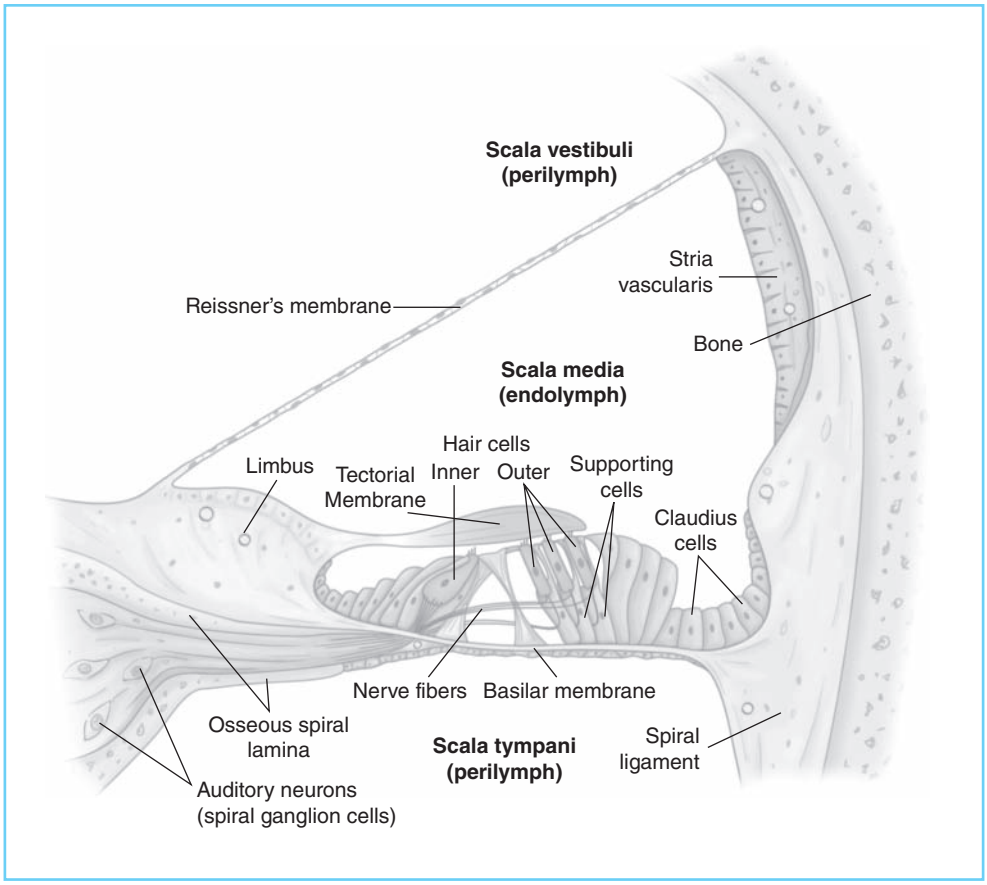


FIGURE 2-20 **The cochlear duct.** (Adapted by B.A. Bohne, 2004 from Davis, H., et. al. (1953). Acoustic trauma in the guinea pig. *Journal of the Acoustical Society of America, 25,* 1180-1189.)

The blood supply to the inner ear structures is from arteries that branch from the vertebral arteries. The vertebral arteries course up both sides of the vertebral column, enter the skull, and merge to form the basilar artery. One branch of the basilar artery is the internal auditory artery, also known as the labyrinthine artery. The internal auditory artery courses up through the internal auditory meatus, supplying blood to the auditory and vestibular portions of the VIIIth cranial nerve and the facial (VIIth cranial) nerve. The artery then branches again into cochlear and vestibular arteries. The cochlear artery branches further to provide independent blood supply to the basal and apical turns of the cochlea.

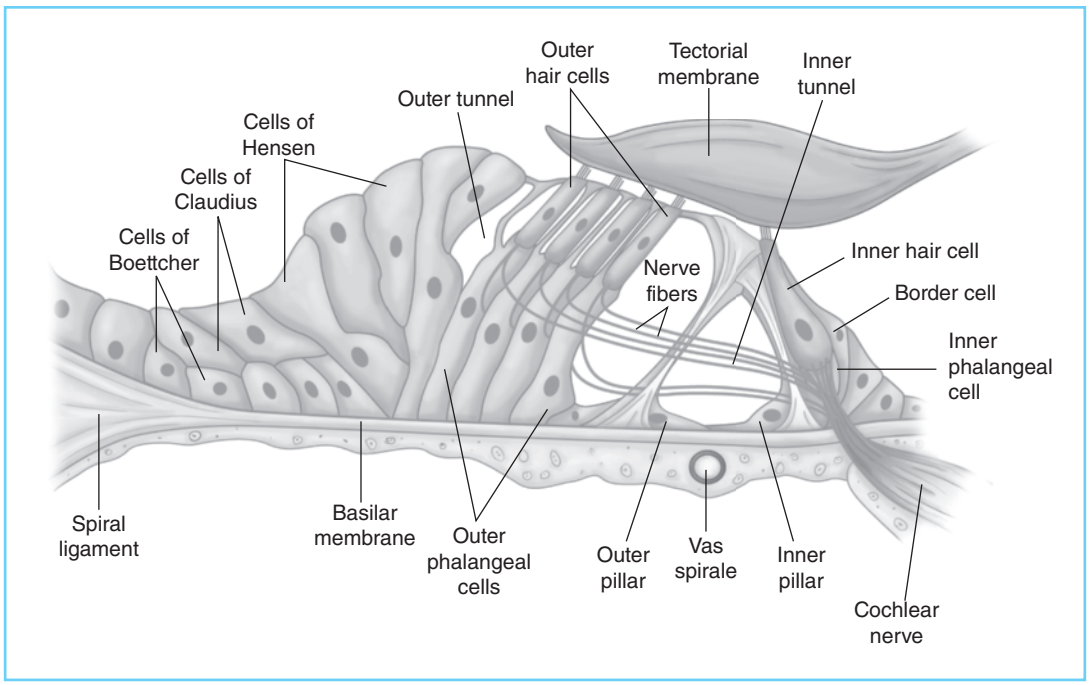


FIGURE 2-21 The organ of Corti.

Physiology

Vibration of the stapes in and out of the oval window creates fluid motion in the cochlea, causing the structures of the membranous labyrinth to move, resulting in stimulation of the sensory cells and generation of neural impulses.

As the stapes moves in and out of the oval window vibrating the fluid, the basilar membrane is set into a wavelike motion. This motion is referred to as the *traveling wave* and is depicted in Figure 2-24. This so-called traveling wave proceeds down the course of the basilar membrane, growing in magnitude, until it reaches a certain point of maximum displacement. For higher frequencies, this occurs closer to the oval window, nearer the basal end of the cochlea. For lower frequencies, it occurs farther from the oval window, at the apical end of the cochlea. Thus, the basilar membrane is arranged tonotopically in that each frequency stimulates a different place along its course.

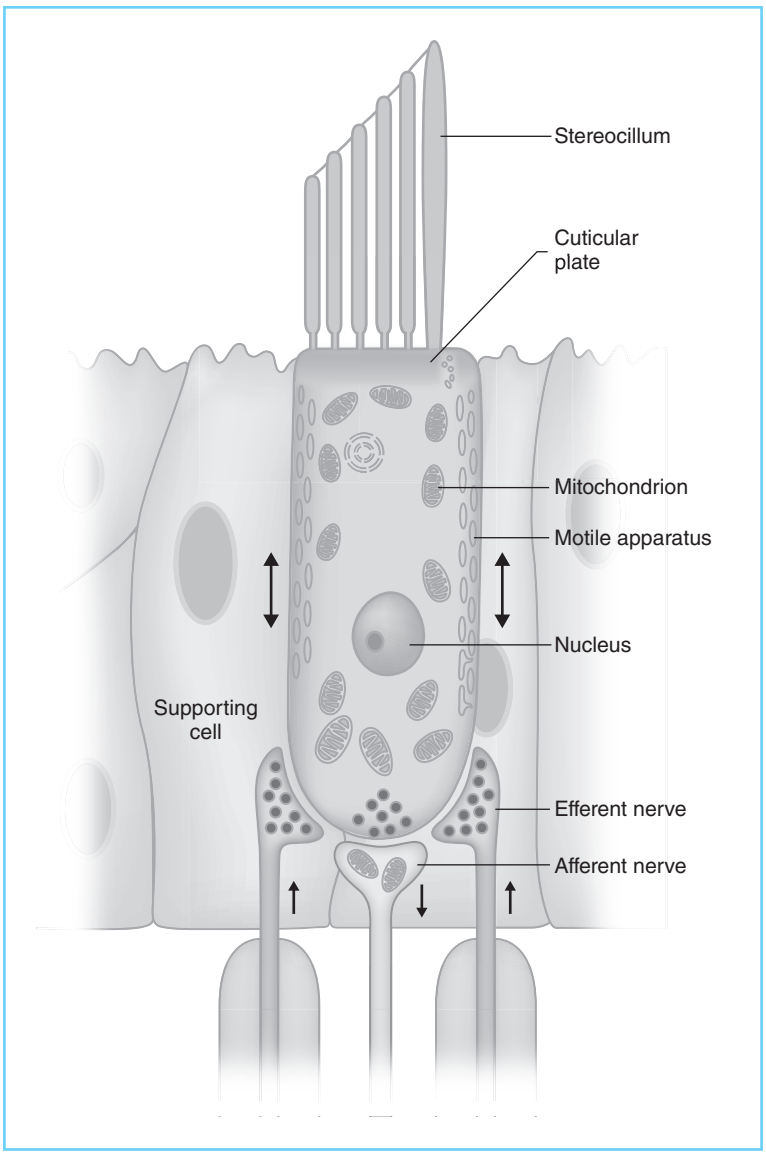


FIGURE 2-22 | Diagram of a single outer hair cell.

When the traveling wave reaches its point of maximum displacement, the inner hair cells are stimulated, sending neural impulses to the auditory nerve.

The traveling wave by itself does not explain the extraordinary sensitivity and frequency selectivity of the cochlea. This concept

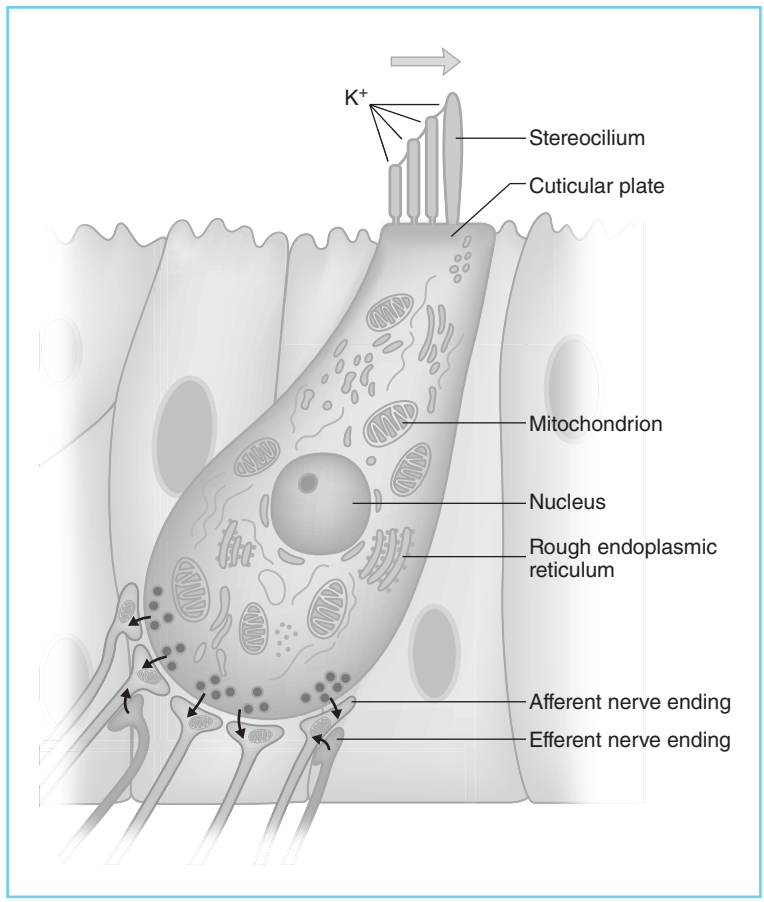


FIGURE 2-23 | Diagram of a single inner hair cell.

is illustrated in Figure 2-25. This figure shows the "tuning" of an inner hair cell versus the tuning that can be explained by the traveling wave. Clearly some process must be intervening to turn the basilar membrane displacement by the traveling wave into a sensitive, sharply tuned response at the inner hair cell.

The mechanism for this active process is beginning to be well understood. In brief, the sensitivity of the inner hair cells is controlled to some extent by the outer hair cells. Recall that the outer hair cells are embedded in the tectorial membrane and that they receive most of their innervation from efferent fibers of the brain. It appears that low-intensity sounds trigger the

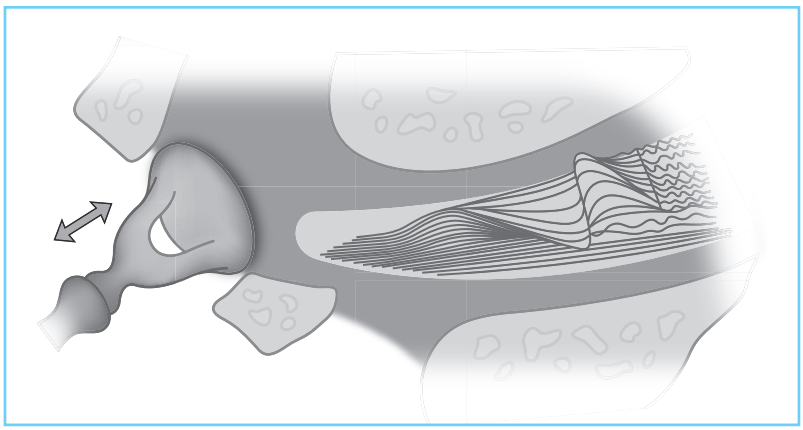


FIGURE 2-24 Schematic drawing of the traveling wave along the cochlear partition.

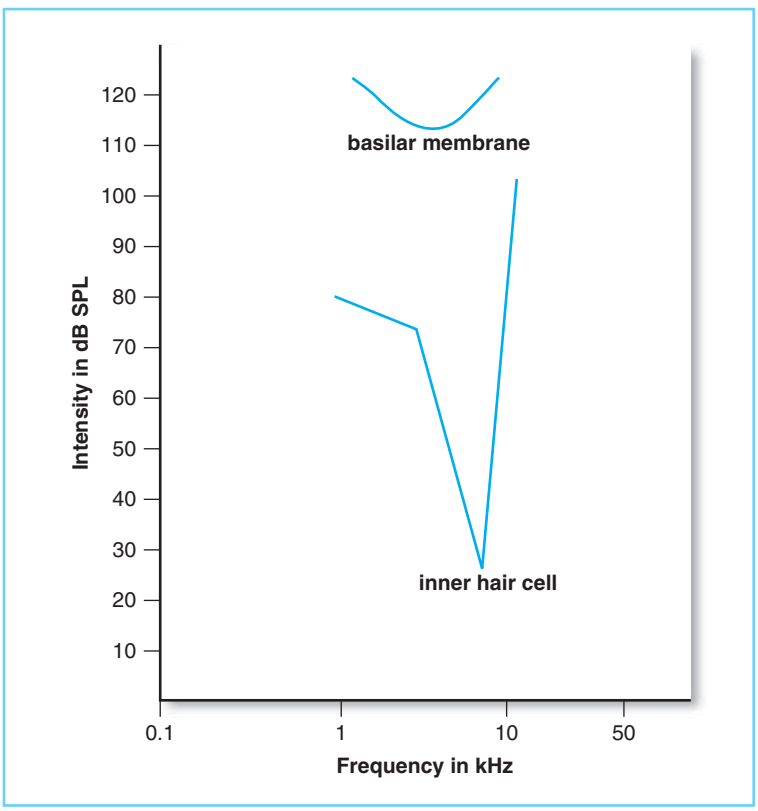


FIGURE 2-25 Generalized drawing of the "tuning" of an inner hair cell versus the tuning that can be explained by the traveling wave along the basilar membrane.

Audiologist Profile

KELLY TREMBLAY, M.S., PH.D., CCC-A



Where I Live: Seattle, Washington

Where I Work: University of Washington. The University of Washington has a long history of training audiologists and hearing scientists and is consistently ranked as one of the top five graduate programs in the nation when it comes to graduate training programs in speech and hearing. With a population of almost 45,000 students, the University of Washington is a large public education facility that is nestled between the Cascade Mountain Range and the Puget Sound.

What I Do: I am an associate professor who spends much of her time in the classroom, in the research laboratory, and writing/speaking for the many hearing-related professional organizations. I try to advance the field of audiology by asking clinically related research questions that pertain to rehabilitating people with hearing loss. Although my approach to these research questions involves physiological methods, and most people think of me as a hearing scientist, I enjoy spending time in the classroom, conveying information about the many ways we can improve the quality of life for people with hearing loss. I am very grateful for the years I spent as a practicing clinician, and my current interactions with clinicians and patients, because they provide the foundation for the work I am doing today.

Why Audiology? Audiology is a career that I accidentally stumbled upon when deciding between medicine and teaching. Just as I suspected, it turned out to be the perfect blend of patient care and science. Because the nature of hearing loss impacts communication, the ability to improve people's quality of life and teach people how to advocate for themselves is truly a gift that comes with the job.

excitation or inhibition of outer hair cells, causing them to produce a force that influences the position of the tectorial membrane in a manner that affects the inner hair cells, enhancing their sensitivity.

Regardless, when the traveling wave reaches its maximum displacement, the inner hair cells are stimulated, resulting in the secretion of neurotransmitters that stimulate the nerve endings of the cochlear branch of the VIIIth nerve.

Auditory Nervous System

The auditory nervous system is a primarily afferent system that transmits neural signals from the cochlea to the auditory cortex. Like other nervous system activity, the auditory mechanism is functionally crossed, so that information from the right ear is transmitted primarily to the left cortex and information from the left ear primarily to the right cortex.

The auditory system also has an efferent component, which has multiple functions, including regulation of the outer hair cells and general inhibitory action throughout the central auditory nervous system.

Neurons leave the cochlea in a rather orderly manner, as shown in Figure 2-26, and **synapse** in the lower brainstem. From that point on, the system becomes richly complex, with multiple crossing pathways and substantial efferent and intersensory interaction.

Neurons are the basic unit of the nervous system containing axons, cell bodies, and dendrites.

A **synapse** is the point of communication between neurons.

The VIIIth Cranial Nerve

Nerve fibers from the inner hair cells exit the organ of Corti through the **osseous spiral lamina** beyond which their cell bodies cluster to form the **spiral ganglion** in the **modiolus**. The nerve fibers exit the modiolus in an orderly manner, so that the frequency arrangement of the cochlea is preserved anatomically. This so-called **tonotopic** arrangement is preserved throughout the primary auditory pathways all the way to the cortex.

The bony shelf in the cochlea onto which the inner margin of the membranous labyrinth attaches and through which the nerve fibers of the hair cells course is called the **osseous spiral lamina**.

The **spiral ganglion** is a collection of cell bodies of the auditory nerve fibers, clustered in the modiolus.

The **modiolus** is the central bony pillar of the cochlea through which the blood vessels and nerve fibers of the labyrinth course.

The cochlear branch of the VIIIth cranial nerve exits the modiolus, joins the vestibular branch, and leaves the cochlea through the *internal auditory canal* of the temporal bone. The cochlear branch of the nerve consists of some 30,000 nerve fibers, which carry information to the brainstem.

The VIIIth nerve codes auditory information in several ways. In general, intensity is coded as the rate of neural discharge. Frequency is coded as the place of neural discharge by fibers that are arranged tonotopically. Frequency may be additionally coded by temporal aspects of the discharge patterns of neuronal firing.

Tonotopic means arranged according to frequency.

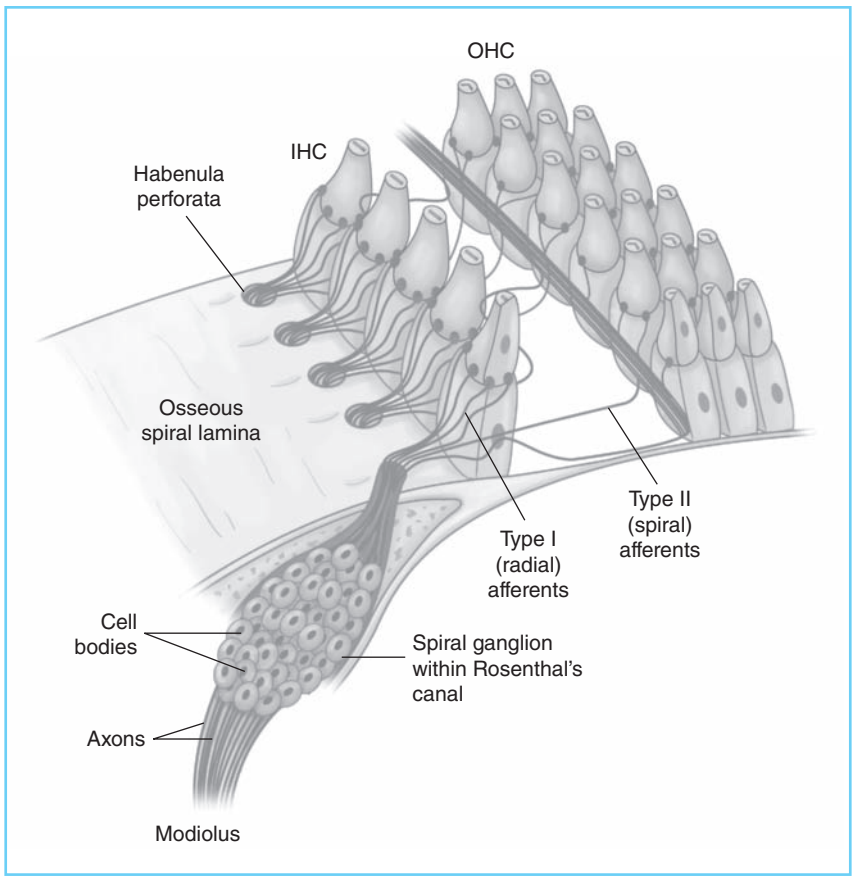


FIGURE 2-26 The departure of afferent neurons from the inner and outer hair cells (IHC and OHC).

The Central Auditory Nervous System

The central auditory nervous system is best described by its various nuclei. Nuclei are bundles of cell bodies where nerve fibers synapse. Each nucleus serves as a relay station for neural information from the cochlea and VIIIth nerve to other nuclei in the auditory nervous system and to nuclei of other sensory and motor systems. The nuclei involved in the primary auditory pathway of the central auditory nervous system are:

- cochlear nucleus,
- superior olivary complex,
- lateral lemniscus,

- inferior colliculus, and
- medial geniculate.

A schematic representation of these various way stations in the brain is shown in Figure 2-27.

All VIIIth-nerve fibers have an obligatory synapse at the *cochlear nucleus* on the same, or **ipsilateral**, side of the brain. Fibers entering the cochlear nucleus **bifurcate**, with one fiber synapsing in the primary auditory portion of the nucleus and the other synapsing in portions of the nucleus that spawn secondary or parallel pathways.

Ipsilateral pertains to the same side.

Bifurcate means to divide into two branches.

From the cochlear nucleus, approximately 75% of the nerve fibers cross over to the **contralateral** side of the brain. Some fibers terminate on the *media nucleus of the trapezoid body* and some on the *medial superior olive*. Others proceed to nuclei beyond the superior olivary complex. Of the 25% that travel on the ipsilateral side of the brain, some terminate at the media superior olive, some at the *lateral superior olive*, and others at higher level nuclei.

Contralateral pertains to the opposite side.

From the superior olivary complex, neurons proceed to the *lateral lemniscus*, the *inferior colliculus*, and the *medial geniculate*. Nerve fibers may synapse on any of these nuclei or proceed beyond. Also, at each of these nuclei, some fibers cross over from the contralateral side of the brain. From the medial geniculate, nerve fibers proceed in a tract called the *auditory radiations* to the *auditory cortex* in the temporal lobe.

The blood supply to the auditory nervous system is primarily from two sources: one that supplies the brainstem structures and the other the cortical structures. The auditory brainstem receives its primary blood supply from the basilar artery. Different branches of the basilar artery supply the various auditory nuclei:

- anterior inferior cerbral artery – cochlear nucleus
- pontine arteries – superior olivary complex
- superior cerebellar artery – inferior colliculus and lateral lemniscus

The auditory subcortex and cortex receive blood supply from a branch of the carotid artery known as the middle cerebral artery.

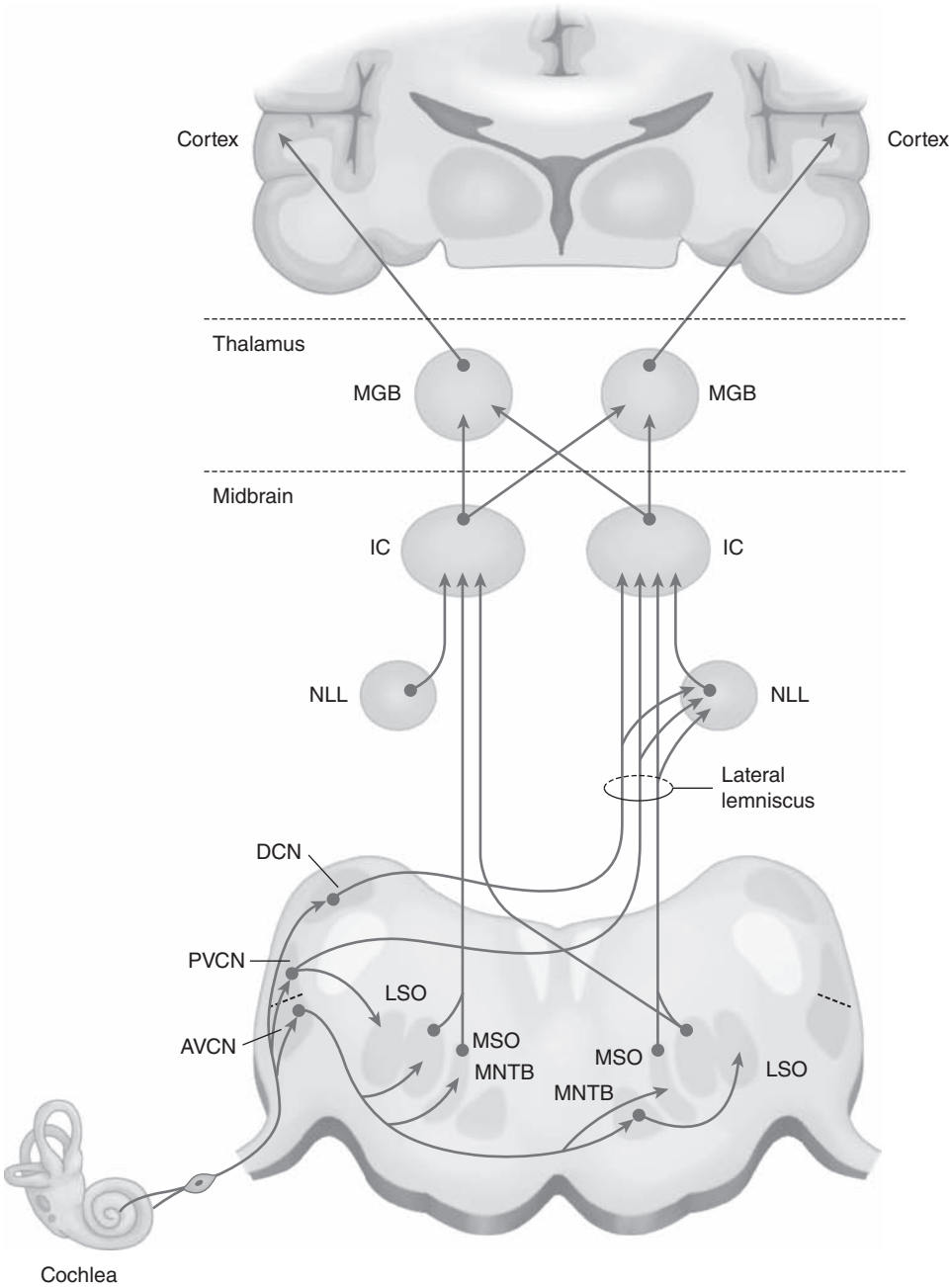


FIGURE 2-27 **The central auditory nervous system.** (Adapted from Pickles, J.O. (1982). *Introduction to the physiology of hearing.* New York: Academic Press.)

This simplified explanation of the central auditory nervous system belies its rich complexity. For example, sound that is processed through the right cochlea has multiple, redundant pathways to both the right and left cortices. What begins as a pressure wave striking the tympanic membrane sets into motion a complex series of neural responses spread throughout the auditory system.

Much of the rudimentary processing of sound begins in the lower brainstem. For example, initial processing for sound localization occurs at the superior olive complex where small differences between sound reaching the two ears are detected. As another example, a simple reflex arc that triggers a contraction of the *stapedius muscle* occurs at the level of the cochlear nucleus. This *acoustic reflex* occurs when sound reaches a certain loudness and causes the stapedius muscle to contract, resulting in a stiffening of the ossicular chain.

Processing of speech information occurs throughout the central auditory system. Its primary location for processing, however, occurs in the **left temporal lobe** of most humans. Speech that is detected by the right ear proceeds through the dominant contralateral auditory channels to the left temporal lobe. Speech that is detected by the left ear proceeds through the dominant contralateral channel to the right cortex and then, via the **corpus callosum** to the left auditory cortex. Thus, in most humans, the right ear is dominant for the processing of speech information.

Processing of speech information occurs in the **left temporal lobe** in most people.

The **corpus callosum** is the white matter that connects the left and right hemispheres of the brain.

Our ability to hear relies on this very sophisticated series of structures that process sound. The pressure waves of sound are collected by the pinna and funneled to the tympanic membrane by the external auditory canal. The tympanic membrane vibrates in response to the sound, which sets the ossicular chain into motion. The mechanical movement of the ossicular chain then sets the fluids of the cochlea in motion, causing the hair cells on the basilar membrane to be stimulated. These hair cells send neural impulses through the VIIIth cranial nerve to the auditory brainstem. From the brainstem, networks of neurons act on the neural stimulation, sending signals to the auditory cortex.

Although the complexity of these structures is remarkable, so too is the complexity of their function. All of this processing is

The range between the threshold of sensitivity and the threshold of discomfort is called the **dynamic range**.

obligatory and occurs constantly. The system is very sensitive in its ability to detect soft sounds, is very sensitive in its ability to detect small changes in sound characteristics, and has a very large **dynamic range**. And when we call on our auditory system to do the complicated tasks of listening to speech, it does so even under extremely adverse acoustic conditions.

THE VESTIBULAR SYSTEM

The way we maintain our balance and equilibrium is through complex interaction of the visual, somatosensory/proprioceptive, and vestibular systems of the body. Although a complete treatment of balance function is beyond the scope of this introductory textbook, it is important for the student of audiology to understand the function of the vestibular system and its relation to the auditory mechanism. One important reason is that the auditory and vestibular systems share the inner ear bony labyrinth, and the vestibular and auditory nerves join to form the VIIIth cranial nerve. As a result of this proximity, disorders often affect both systems, and knowledge of their interaction is often helpful in the evaluative process. In addition, some audiologists are routinely involved in the assessment of patients with balance disorders and evaluate vestibular function as part of that assessment.

The role of the balance systems is to provide accurate information about our position in space and about the direction and speed of our movement. It also serves to prevent falling by rapidly correcting for any changes that might occur in body position with respect to gravity. Finally, the system functions to control eye movement to maintain accurate vision during movement. Our ability to maintain balance is primarily the result of three systems of the body that work together. The contributions of the systems vary as a function of what we are doing at the moment. For example, if we are standing still, proprioception plays an important role, with vision helping out. The vestibular system rests relatively quietly. When we are in motion, however, the vestibular system contributes substantially to our stability, with vision and proprioception playing a smaller role.

Anatomy

The vestibular portion of the inner ear also consists of a membranous labyrinth within the fluid-filled bony labyrinth of the temporal bone. The membranous labyrinth consists of five groups of sensory receptors: two otoliths and three semicircular canals. The two otoliths are known as the **saccule** and **utricle**. The three semicircular canals are known as the **superior**, **lateral**, and **posterior semicircular canals**. At the entrance to each of these canals is an enlarged portion of the tube called an ampulla. The vestibular labyrinth is shown in Figure 2-28.

The **saccule** and **utricle** are responsive to linear acceleration.

The **superior**, **lateral**, and **posterior semicircular canals** are three canals in the osseous labyrinth of the vestibular (balance) apparatus containing sensory epithelia that respond to angular motion.

Like the auditory system, the sensory cells of the vestibular system are known as hair cells. Each hair cell has a fiber bundle protruding from the top known as stereocilia. Unlike the auditory system, these stereocilia are bound together by a taller fiber known as a kinocilium, as shown in Figure 2-29. The arrangements of **sensory epithelia** that provide input to the vestibular nerve are

Sensory epithelia are groups of sensory and supporting cells.

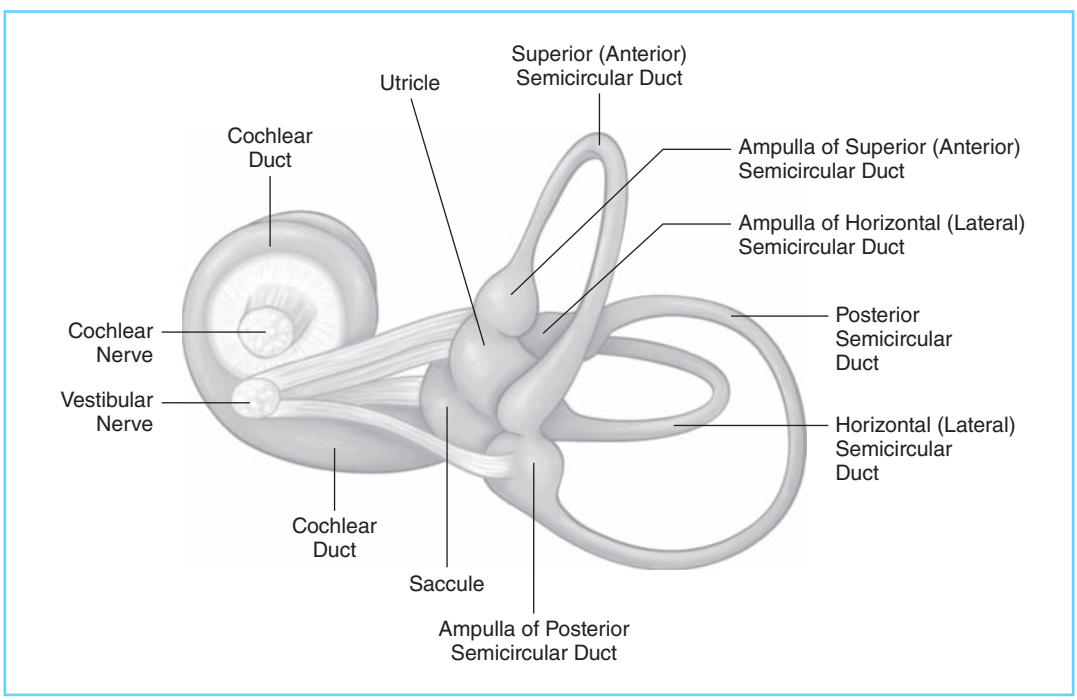


FIGURE 2-28 The vestibular labyrinth.

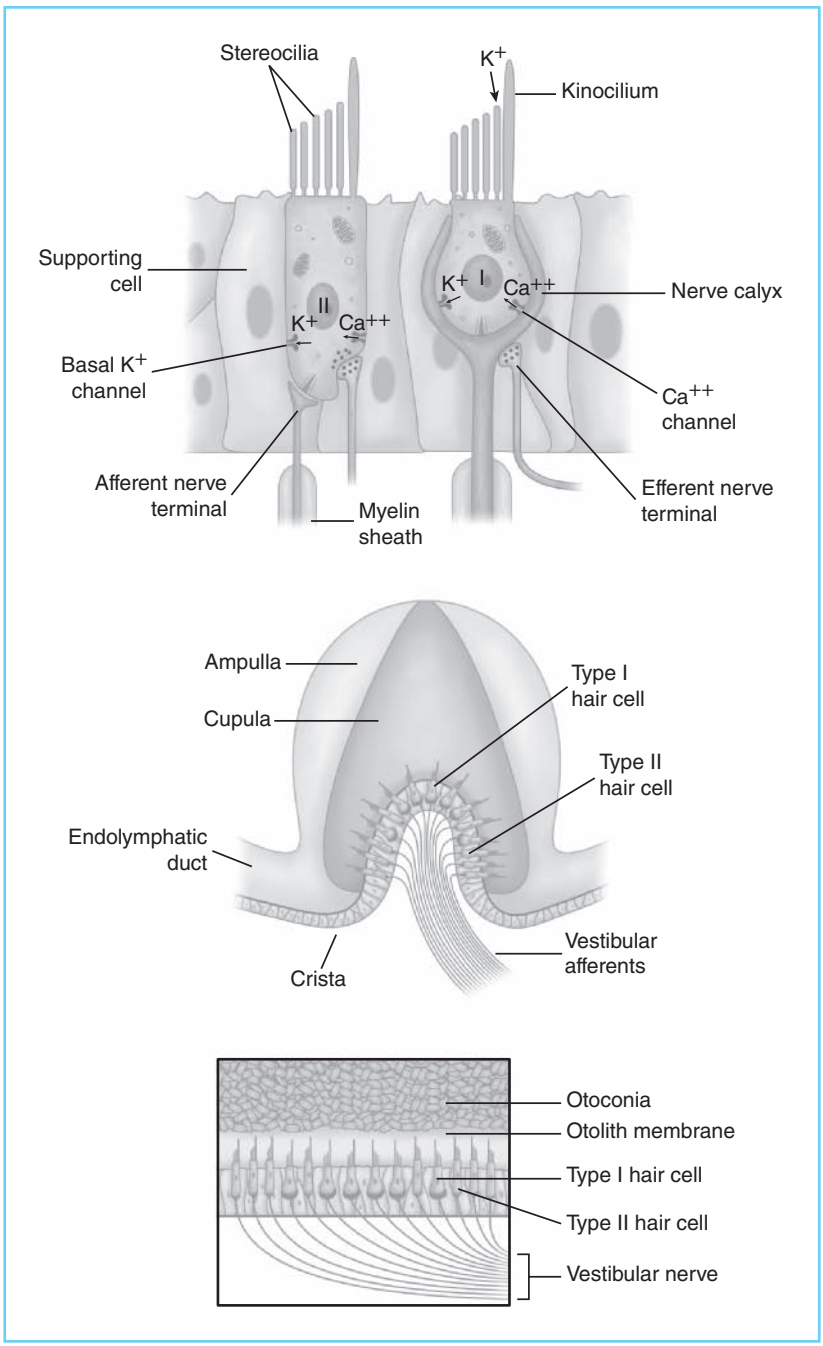


FIGURE 2-29 Vestibular hair cells, the crista of a semicircular canal, and the macula of an otolith.

known as the crista of the ampulla of each semicircular canal and the macula of each otolith. The arrangement of the sensory receptors is slightly different in the cristae and maculae.

The utricle is a membranous tube that plays a role in orientation to gravity and in horizontal movement. The saccule is an ovoid structure that is oriented in the vertical plane. The hair cells of the utricular macula and saccular macula are similar in organizational structure. Both are covered with a gelatinous membrane, the otolithic membrane, that contains calcium carbonate crystals called otoconia. The otoconia give the otolithic membrane a density that is greater than the surrounding endolymph, making the hair cells sensitive to gravity.

The semicircular canals are arranged at right angles to each other and are responsible for detecting head movement. The **ampullae** are enlarged portions of the membranous tubes located at the entrance to each canal. Within each ampulla, the hair cells are arranged on the crista. The hair cells project into a gelatinous membrane called the cupula. Unlike the otolithic membrane, the cupula has a density that is the same as the surrounding endolymph, and the hair cells of the ampulae are not responsive to gravitational influences.

The bulbous portion at the end of each of the three semicircular canals is called the **ampulla**.

Nerve fibers leave the maculae and the cristae through two branches of the vestibular nerve, the superior and inferior vestibular nerves. The superior vestibular nerve carries fibers from the cristae of the superior and lateral semicircular canals and from the macula of the utricle. The inferior vestibular nerve carries fibers from the crista of the posterior canal and the macula of the saccule. The nerve fibers meet at the lateral end of the internal auditory canal, with the cell bodies of the nerve clustering to form Scarpa's ganglion. From there the nerve fibers join the auditory branch of the VIIIth cranial nerve and course through the internal auditory canal. Upon entering the brainstem, the nerve divides into ascending and descending branches. Fibers eventually synapse at various vestibular nuclei and the cerebellum.

Physiology

The vestibular system acts as a motion detector. The utricle and saccule are responsive to linear acceleration in the horizontal and vertical planes, respectively. The ampullae of the semicircular canals are responsive to angular acceleration. As the head turns or body

moves, the fluid in these structures flows in a direction opposite to the movement, resulting in stimulation of the sensory epithelium and increased neural activity of the vestibular branch of the VIIIth nerve.

The vestibular hair cells are responsive to both movement and to the influences of gravity. The stereocilia of the hair cells are bundled with a kinocilium that is moved one way or the other by the relative motion of the otolithic membrane or the cupula. Any motion that causes the stereocilia to move toward the kinocilium results in an increase in electrical activity and has an excitatory influence on nerve function. Any motion that causes the stereocilia to move away from the kinocilium results in a reduction in electrical activity and has an inhibitory influence on nerve function. This relationship is depicted in Figure 2-30.

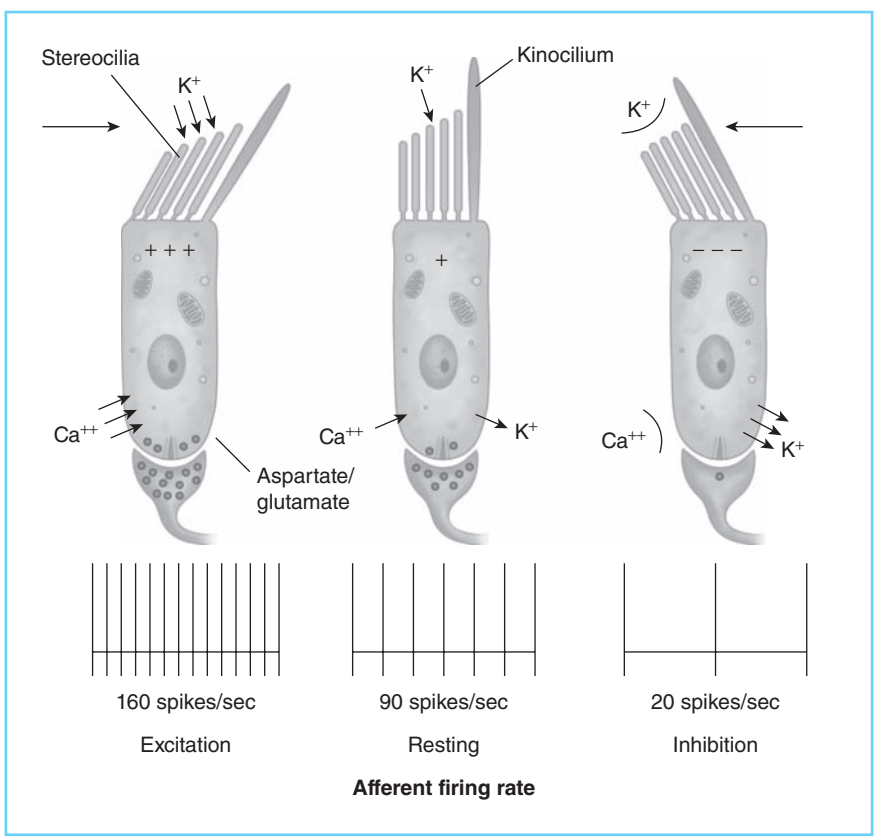


FIGURE 2-30 The excitation and inhibition of vestibular hair cells.

The structures of the vestibular system essentially work in pairs to provide information about gravity and movement. When the head is turned, fluid in the structures on one side move in opposite direction to fluid on the other side. This results in corresponding excitatory and inhibitory signals presented to the vestibular nuclei for comparison.

HOW WE HEAR

As mentioned previously, the auditory system is an obligatory one. We simply cannot turn it off. In simpler life forms, the main function of the auditory system is protection. Because it is obligatory, it serves to constantly assess the surroundings for danger, as prey, and opportunity, as predator. In more evolved life forms, it takes on an increasingly important communication function, whether that be for mating calls or for talking on the telephone.

As you have seen, the auditory system is highly complex. It is a sensitive system that can detect the smallest of pressure waves. It also is a precise system that can effectively discriminate very small changes in the nature of sound, with a large dynamic range. Remember that the difference in the magnitude of sound that can just barely be detected and the magnitude of sound that causes pain is on the order of 100 million to one.

Describing the function of such a rich, complex system is an academic discipline in and of itself, called **psychoacoustics**. Psychoacoustics is a branch of psychophysics concerned with the quantification of auditory sensation and the measurement of the psychological correlates of the physical characteristics of sound. The knowledge base of this field is broad and well beyond the scope of this text. However, there are some fundamentals that are necessary for you to understand as you pursue the study of clinical audiology. Much in the way of quantification of disordered systems stems from our knowledge of the response of normal systems and the techniques designed to measure those responses.

Psychoacoustics is the branch of psychophysics concerned with the quantification of auditory sensations and the measurement of the psychological correlates of the physical characteristics of sound.

Absolute Sensitivity of Hearing

As you will learn later in this textbook, one of the hallmarks of audiology is the assessment of hearing sensitivity. Sensitivity is defined as the capacity of a sense organ to detect a stimulus.

Absolute sensitivity is the ability to detect faint sound.

Differential sensitivity is the ability to detect differences or changes in intensity, frequency, or other dimensions of sound.

It is quantified by the determination of threshold of audibility or threshold of detection of change. There are at least two kinds of sensitivity, absolute and differential. **Absolute sensitivity** pertains to the capacity of the auditory system to detect faint sound. **Differential sensitivity** pertains to the capacity of the auditory system to detect differences or changes in intensity, frequency, or some other dimension of a sound.

Hearing sensitivity most commonly refers to absolute sensitivity to faint sound. In contrast, *hearing acuity* most accurately refers to the differential sensitivity, usually to the ability to detect differences in signals that differ in the frequency domain.

Threshold is the level at which a stimulus is just sufficient to produce a sensation.

Absolute threshold is the lowest level at which a sound can be detected.

Differential threshold is the smallest difference that can be detected between two signals.

Inherent in the description of hearing sensitivity is the notion of **threshold**. A threshold is the level at which a stimulus or change in stimulus is just sufficient to produce a sensation or an effect. Here again, it is useful to differentiate between absolute and differential threshold. In hearing, **absolute threshold** is the threshold of audibility, or the lowest intensity level at which an acoustic signal can be detected. It is usually defined as the level at which a sound can be heard 50% of the times that it is presented. **Differential threshold**, or *difference limen*, is the smallest difference that can be detected between two signals that vary in some physical dimension.

The Nature of Hearing Sensitivity

Absolute sensitivity of hearing for humans varies as a function of numerous factors, including psychophysical technique, whether ears are tested separately or together, whether testing is done under earphones or in a sound field, the type of earphone that is used, the type of cushion on that earphone, and so on. Once these variables are defined and controlled, a consistent picture of hearing sensitivity emerges.

Figure 2-31 shows a graph of hearing sensitivity, defined as the threshold of audibility of pure-tone signals, graphed in sound pressure level (SPL) across a frequency range that encompasses most of human hearing. This curve representing hearing sensitivity is often referred to as the *minimum audibility curve*. The minimum audibility curve is clearly not a straight line, indicating that

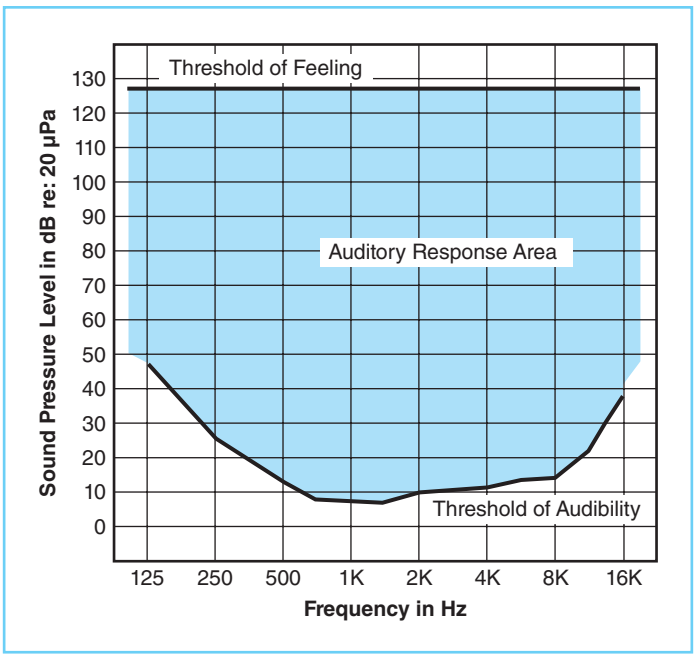


FIGURE 2-31 Auditory response area from the threshold of audibility to the threshold of feeling across the frequency range that encompasses most of human hearing.

hearing sensitivity varies as a function of signal frequency. That is, it takes more sound pressure at some frequencies to reach threshold than at others. You can see that hearing in the low-frequency and high-frequency ranges is not as sensitive as it is in the mid-frequency range. It should probably be no surprise that human audibility thresholds are best at frequencies corresponding to the most important components of speech.

The minimum audibility curve will vary as a function of measurement parameters. If it is determined by delivering signals to one ear via an earphone, it is referred to as the *minimum auditory pressure* response. If it is determined by delivering signals to both ears via loudspeaker, it is called the *minimum audible field* response.

Also shown on Figure 2-31 is the threshold of feeling, at which a tactile response will occur if the subject can tolerate sounds of this magnitude. This is the upper limit of hearing and has a clearly flatter profile across the frequency range. The area between the

threshold of audibility and the threshold of feeling is known as the *auditory response area* and represents the range of human hearing. You will notice that the range varies as a function of frequency, so that the number of decibels of difference between audibility and feeling is substantially less at the low frequencies than at the high frequencies.

The minimum audible pressure curve serves as the basis for pure-tone audiometry, in which a patient's threshold of audibility is measured and compared to this normal curve. For clinical purposes, this curve is converted into a graph known as the audiogram.

The Audiogram

The audiogram is a graphic representation of the threshold of audibility across the audiometric frequency range. It is a plot of absolute threshold, designated in dB *hearing level* (HL), at octave or mid-octave intervals from 125 to 8000 Hz.

The designation of intensity in dB HL is an important one to understand. Recall from the minimum audibility curve that hearing sensitivity varies as a function of frequency. For clinical purposes, this curve is simply converted into a straight line and called **audiometric zero**. Audiometric zero is the sound pressure level at which the threshold of audibility occurs in average normal listeners. We know from the minimum audibility curve that the SPL required to reach threshold will vary as a function of frequency. If a standard SPL level is applied at each frequency, and threshold for the average normal listener is designated as 0 dB HL for each frequency, then we have effectively flattened out the curve and represented average normal hearing sensitivity as a flat line of 0 dB.

Audiometric zero is the sound pressure level at which the threshold of audibility occurs for normal listeners.

The concept of designating audiometric zero as different sound pressure levels across the frequency range is shown in Figure 2-32. Here you see the average normal threshold values, or audiometric zero plotted in SPL. When this curve is flattened by designating each of these levels as 0 dB HL and then the entire graph is flipped over, an audiogram results. The conversion is shown in Figure 2-33.

Figure 2-34 is an audiogram. The **abscissa** on the graph is frequency in Hz. It is divided into octave intervals, ranging from

Abscissa indicates the horizontal or X axis on a graph.

250 Hz to 8000 Hz. The **ordinate** on the graph is signal intensity in dB HL. It is divided into 10 dB segments, usually ranging from −10 dB to 120 dB HL. Typically on an audiogram, the HL will be further referenced to a standard, such as ANSI 2004. This standard, from the **American National Standards Institute (ANSI)**, relates to the SPL assigned to 0 dB HL, depending on the type of earphone and cushion used.

Ordinate indicates the vertical or Y axis on a graph.

The **American National Standards Institute (ANSI)** is an association of specialists, manufacturers, and consumers that determines standards for measuring instruments, including audiometers.

An audiogram will usually also have a shaded area, designating the range of normal hearing. You will learn in the next section

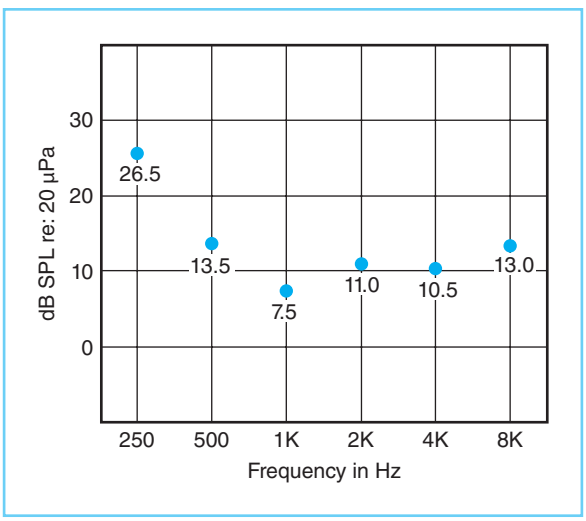


FIGURE 2-32 The designation of audiometric zero as different sound pressure levels across the frequency range.

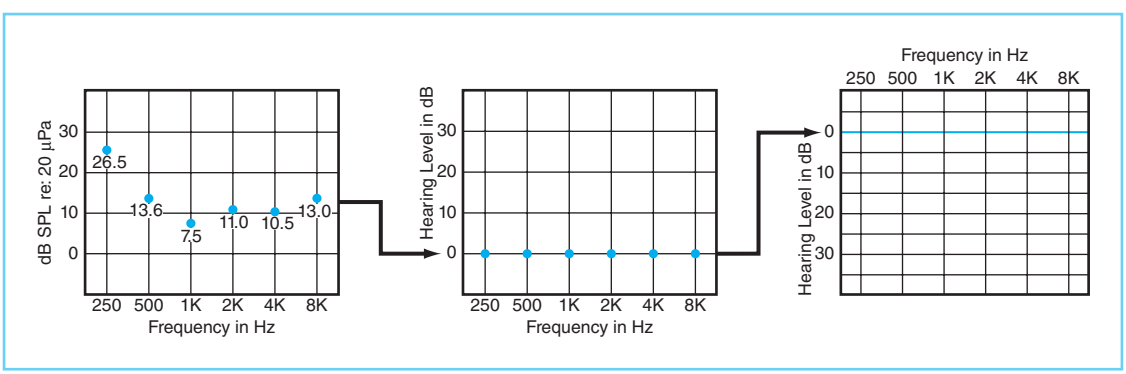


FIGURE 2-33 The conversion from sound pressure level to hearing level to an audiogram.

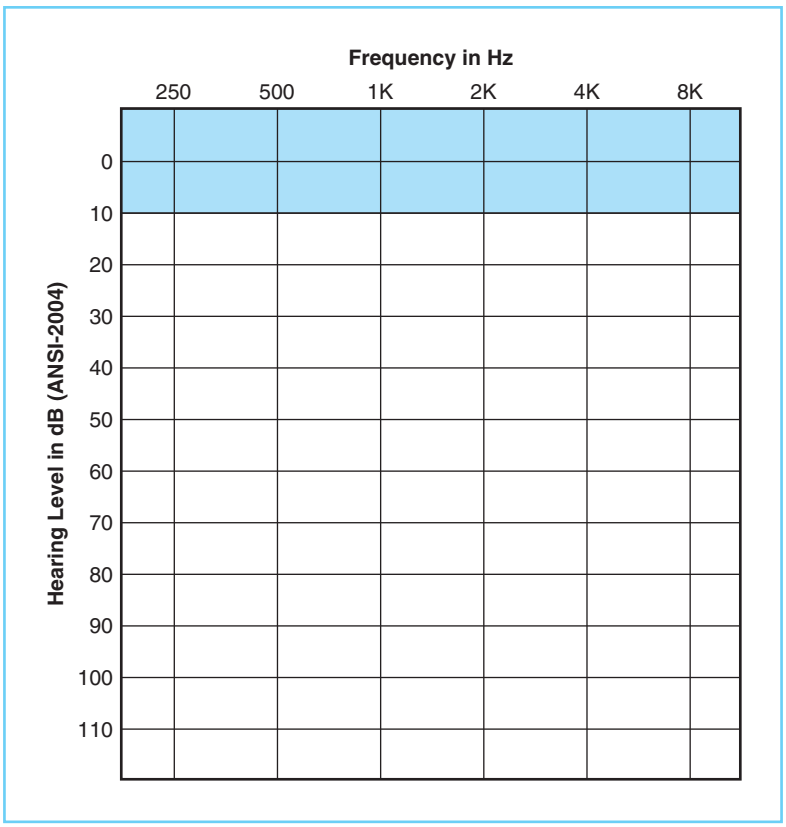


FIGURE 2-34 An audiogram with intensity, expressed in hearing level, plotted as a function of frequency, expressed in Hertz.

that there is some variability in determining hearing threshold and that normal responses can vary by as many as 10 decibels around audiometric zero. It is not uncommon then to have a shaded range from −10 to +10 dB to designate the normal range of hearing. On some audiograms, that range will be extended to 25 dB or so. This idea defines the normal range not in statistical terms, but in some notion of functional terms. The assumption here would be that, for example, 20 dB is not enough of a hearing loss to be considered meaningful, therefore it should be classified as normal. As you will learn in subsequent chapters, impairment cannot be defined by the audiogram alone, and increasingly the shaded range is either being defined by a statistical approach or being eliminated.

An audiogram is obtained by carrying out pure-tone audiometry to determine threshold of audibility. The techniques used to

do this are described in detail in Chapter 6. Basically, signals are presented, and the patient responds to those that are audible. The level at which the patient can just barely detect the presence of a pure-tone signal 50% of the time is determined. That level is then marked on the audiogram. Figure 2-35 shows the audiogram of someone with normal hearing. Note that all of the symbols fall within the normal range. Figure 2-36 shows the audiogram of someone with a hearing loss. Note that, at each frequency, the intensity of the signal had to be increased significantly before it became audible. This represents a hearing sensitivity loss as a function of the normal, audiometric zero range.

There are two main ways to deliver signals to the ear, and they are plotted separately on the audiogram. One way is by the use of earphones. Here signals are presented through the air to the

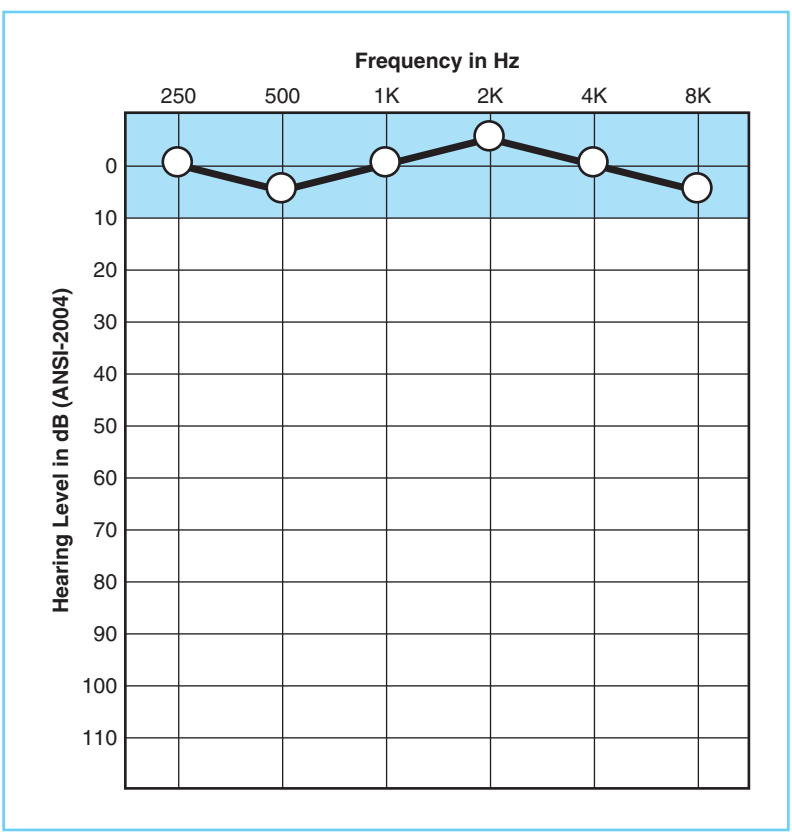


FIGURE 2-35 | An audiogram depicting normal hearing.

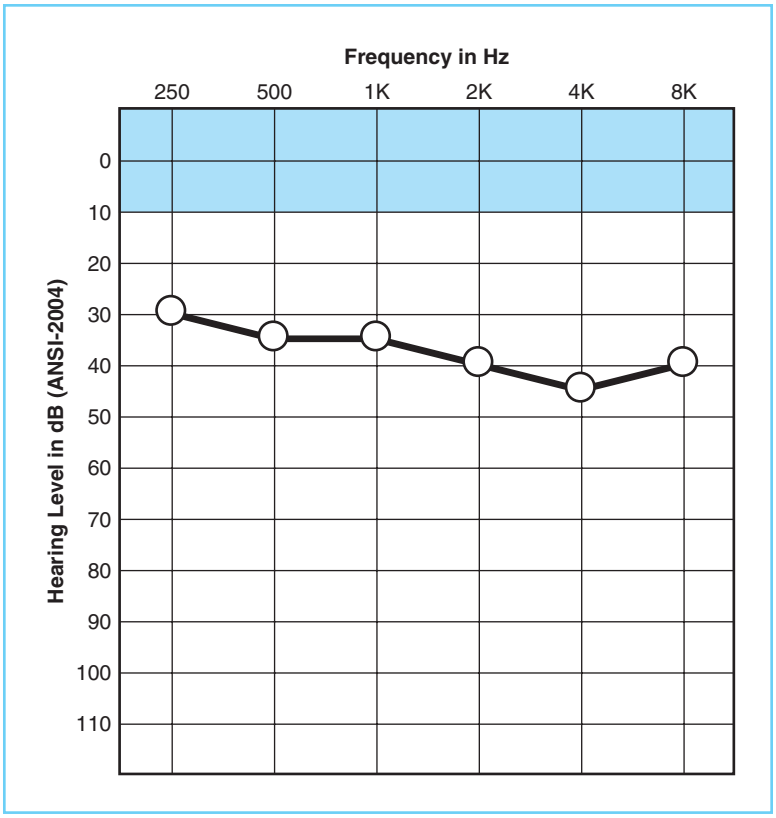


FIGURE 2-36 An audiogram depicting a hearing loss.

tympanic membrane and middle ear to the cochlea. Signals presented in this manner are considered air-conducted, and thresholds are called *air-conduction* thresholds. The other way is by use of a bone vibrator. Signals are delivered via a vibrator, usually placed on the forehead or on the **mastoid process** behind the ear, through the bones of the skull directly to the cochlea. Signals presented in this manner are considered bone-conducted, and thresholds are called *bone-conduction* thresholds. Because bone-conducted signals bypass the outer and middle ear, thresholds determined by bone conduction represent sensitivity of the cochlea. When the outer and middle ears are functioning normally, air-conduction and bone-conduction thresholds are the same, as shown in Figure 2-37. If there is a hearing loss of cochlear origin, a so-called **sensorineural hearing loss**, then both air and bone conduction thresholds will be

The part of the temporal bone that creates a protuberance behind and below the auricle is called the **mastoid process**.

Sensorineural hearing loss is of cochlear origin.

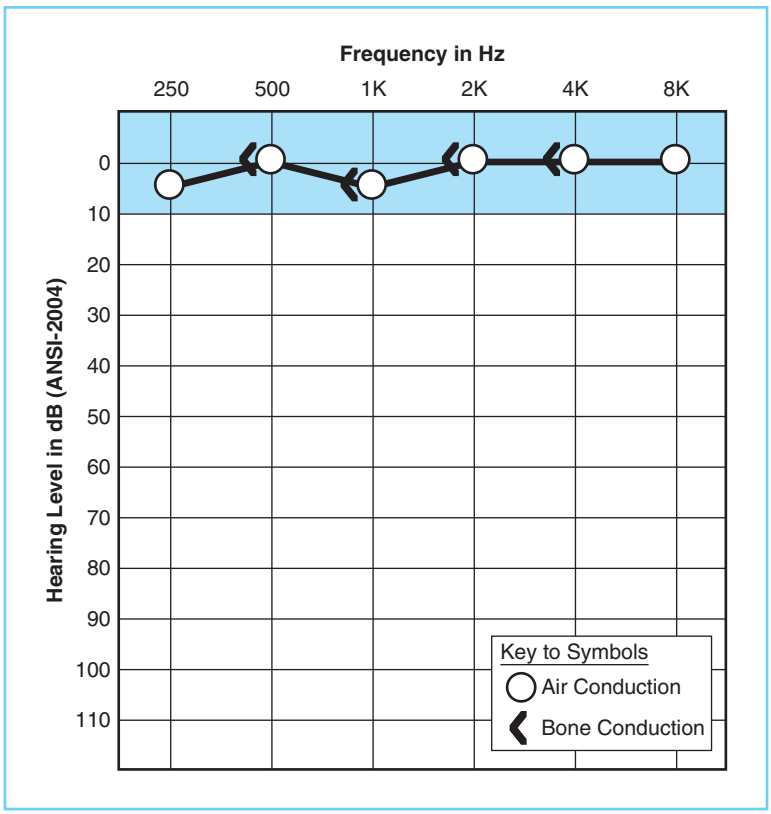


FIGURE 2-37 An audiogram showing that when the outer and middle ears are functioning normally, air-conduction and bone-conduction thresholds are the same.

affected similarly, as shown in Figure 2-38. When the outer or middle ears are not functioning normally, the intensity of the air-conducted signals must be raised before threshold is reached, although the bone-conduction thresholds will remain normal, as shown in Figure 2-39. You will learn more about this type of **conductive hearing loss** in the next chapter.

Conductive hearing loss is of outer- or middle-ear origin.

Differential Sensitivity

Differential sensitivity is the capacity of the auditory system to detect change in intensity, frequency, or some other dimension of sound. It is usually measured as the differential threshold or difference limen (DL), defined as the smallest change in a stimulus that is detectable. When we measure absolute threshold, we are trying to determine the presence or absence of a stimulus.

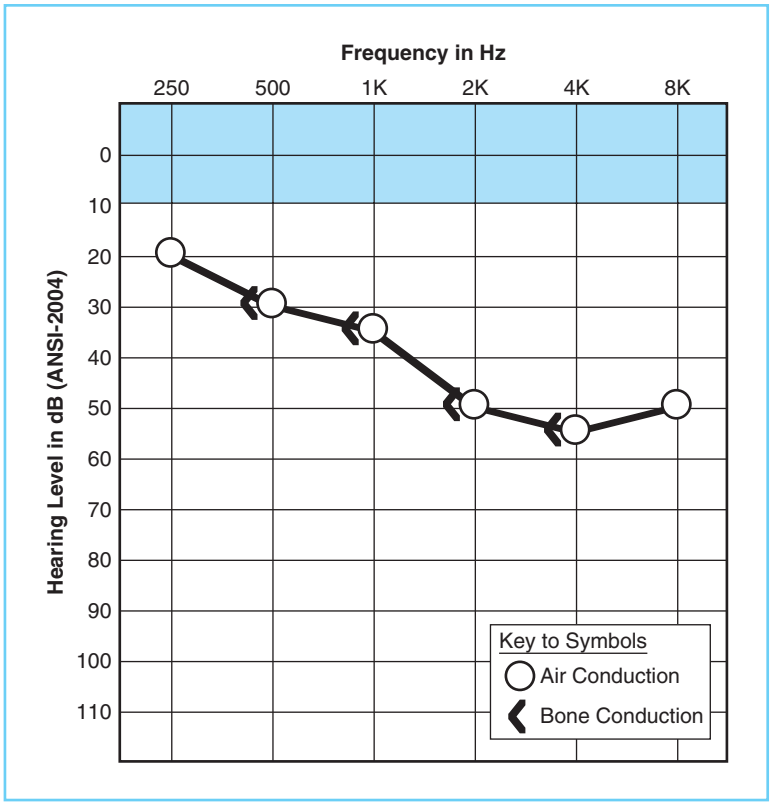


FIGURE 2-38 An audiogram demonstrating that when a hearing loss is of cochlear origin, resulting in a sensorineural hearing loss, both air- and bone-conduction thresholds are affected similarly.

When we measure differential threshold, we are trying to determine how small a change in some parameter of the signal can be detected. Another term that is often used to describe differential threshold is *just noticeable difference*, a term that accurately describes the perception that is being measured.

A **paradigm** is an example or model.

The difference limens for intensity and frequency have been studied extensively. A typical **paradigm** for determining difference limen would be to present a standard stimulus of a given intensity, followed by a variable stimulus of a slightly different intensity. The intensity of the variable stimulus would be manipulated over a series of trials until a determination was made of the intensity

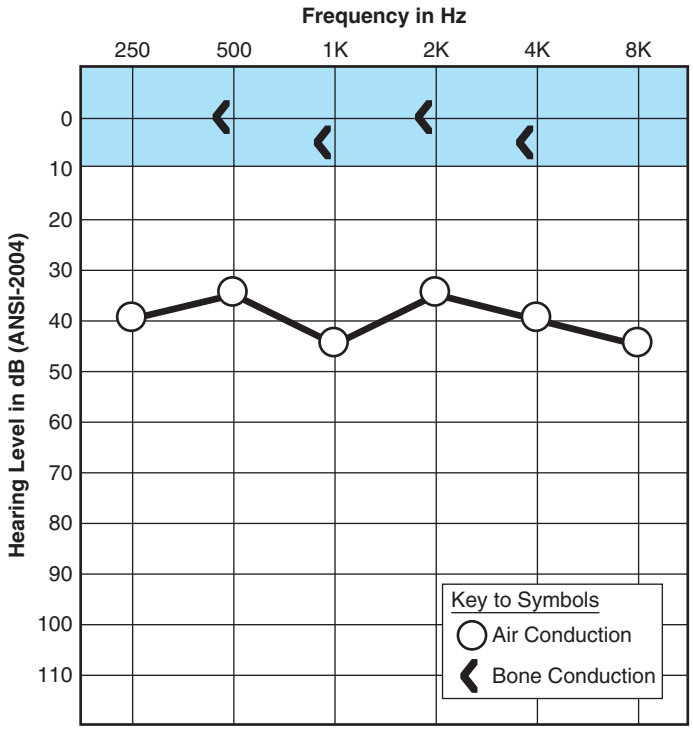


FIGURE 2-39 An audiogram demonstrating that when the outer or middle ears are not functioning normally, resulting in a conductive hearing loss, the intensity of the air-conducted signals must be raised before threshold is reached, while the bone-conduction thresholds remain normal.

level at which a difference could be detected. An example of the difference limen for intensity is shown in Figure 2-40. The difference limen for intensity varies little across frequency. However, it is significantly poorer at levels near absolute threshold than at higher intensity levels.

An example of the difference limen for frequency is shown in Figure 2-41. In general, the difference limen for frequency increases with increasing frequency, so that a larger change is required at higher frequencies than at lower frequencies. As with intensity, the ability to detect changes becomes significantly poorer at intensity levels near absolute threshold.

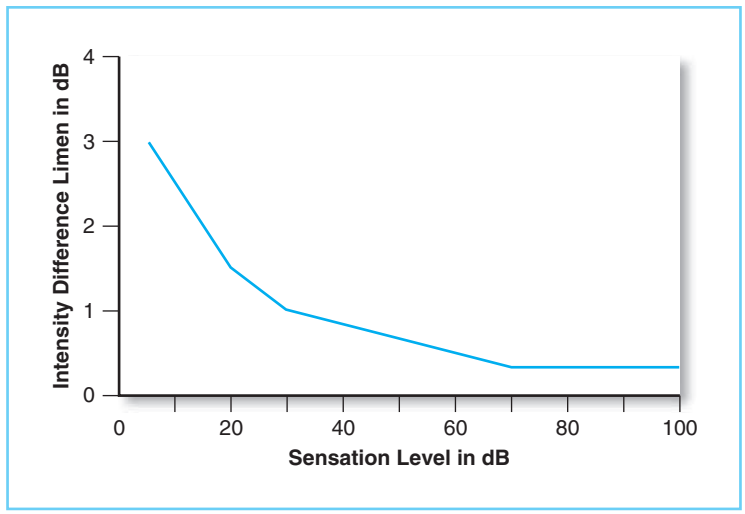


FIGURE 2-40 Generalized drawing of the relationship between intensity of a signal and difference limen for intensity.

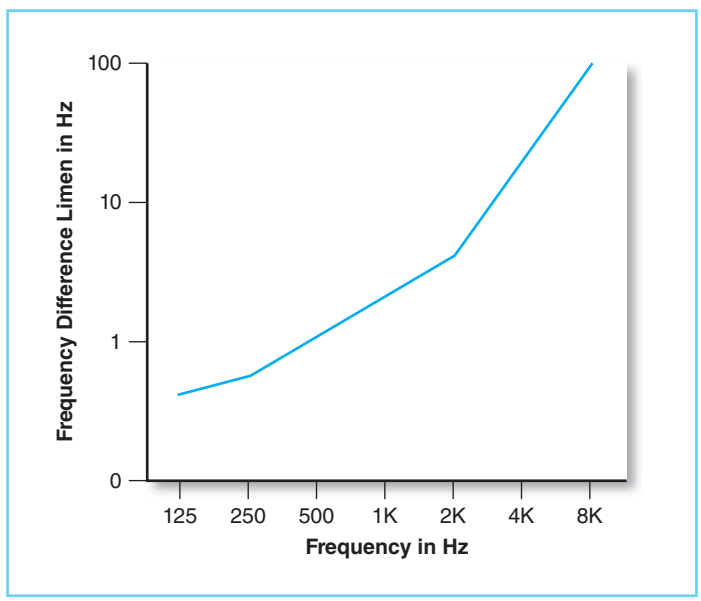


FIGURE 2-41 Generalized drawing of the relationship between frequency of a signal and the difference limen for frequency.

Properties of Pitch and Loudness

An intensity level that is above threshold is considered **suprathreshold**.

The threshold of hearing sensitivity is just one way to describe hearing ability. It can also be described in terms of **suprathreshold** hearing perception.

Earlier you learned about the physical properties of intensity and frequency of an acoustic signal. The psychological correlates of these physical measures of sound are loudness and pitch, respectively.

Loudness refers to the perception that occurs at different sound intensities. Low intensity sounds are perceived as soft sounds, while high intensity sounds are perceived as loud sounds. As intensity increases, so too does the perception of loudness.

Intensity translates to the perception of **loudness**.

Pitch refers to the perception that occurs at different sound frequencies. Low-frequency sounds are perceived as low in pitch, and high-frequency sounds as high in pitch. As frequency increases, so does the perception of pitch.

Understanding of these basic aspects of hearing, absolute threshold, differential threshold, and perception of pitch and loudness, is, of course, only the beginning of understanding the full nature of how we hear. Once sound is audible, the auditory mechanism is capable of processing complex speech signals, often in the presence of similar, yet competing, background noise. The auditory system's ability to process changes in intensity and frequency in rapid sequence to perceive speech is truly a remarkable processing accomplishment.

Measurement of Sound

The accurate measurement of sound is an important component of hearing assessment. The standard audiogram is a plot of frequency versus intensity. The intensity level is referenced to a standard sound pressure level. Specifications for this sound pressure level are based on internationally accepted standards. To meet those standards, the instrumentation that produces the signals, the **audiometer**, must do so in an accurate and consistent manner.

An **audiometer** is an electronic instrument used to measure hearing sensitivity.

The output of any audiometer is periodically checked to ensure that it meets *calibration* standards. An audiometer is considered to be calibrated if the pure tones and other signals emanating from the earphones are equal to the standard levels set by the American National Standards Institute or the International Organization for

Standardization (ISO). To ensure calibration, the output must be measured. The instrument used to measure the output is called a *sound level meter.*

A sound level meter is an electronic instrument designed specifically for the measurement of acoustic signals. For audiometric purposes, the components of a sound level meter include:

- a standard coupler to which an earphone can be attached,
- a sensitive microphone to convert sound from acoustical to electrical energy,
- an amplifier to boost the low-level signal from the microphone,
- adjustable attenuators to focus in on the intensity range of the signal,
- filtering networks to focus in on the frequency range of the signal, and
- a meter to display the measured sound pressure level.

As you might expect, all of these components must meet certain specifications as well to ensure that the sound level meter maintains its accuracy. Sound level meters are used for purposes other than audiometric calibration. Importantly, sound level meters are used to measure noise in the environment and are an important component of industrial noise measurement and control.

For audiometric calibration purposes, the sound level meter is used to measure the accuracy of the output of the audiometer through its transducers, either earphones or a bone-conduction vibrator. The process is one of placing the earphone or vibrator onto the standard coupler and turning on the pure tone or other signal at a specified level. The sound level meter is set to an intensity and frequency range, and the output level of the earphone is read from the meter. The output is expressed in dB SPL. Standard output levels for audiometric zero have been established for the earphones that are commonly used in audiometric testing. If the output measured by the sound level meter is equal to the standard output, then the audiometer is in calibration. If it is not in calibration, the output of the audiometer

must be adjusted. The following measurements are typically made during a calibration assessment:

- output in dB SPL to be compared to a standard for audiometric zero for a given transducer,
- attenuator linearity to ensure that a change of 5 or 10 dB on the audiometer's attenuator dial is indeed that much change in intensity of the output,
- frequency in Hz to ensure that it is accurate to within standardized tolerances,
- **distortion** of the output to make sure that a pure tone is relatively pure or undistorted, and
- rise-fall time to ensure that the onset and offset of a tone are sufficiently slow to avoid **transient distortion** of a pure-tone signal.

Distortion is the inexact reproduction of sound.

Transient distortion occurs when the electrical signal applied to the earphone is changed too abruptly, resulting in a *transient*, or click, response of the earphone.

The standard output levels for audiometric zero, known as *reference equivalent threshold sound pressure levels* (RETSPL), are shown in Table 2-2 for two common types of earphones, supra-aural and insert earphones. You will learn more about the audiometer and earphones in Chapter 6.

TABLE 2-2 Reference equivalent threshold sound pressure levels (re: 20 μPa) for supra-aural earphones on the NBS 9-A coupler and insert earphones on a HA-1 acoustic coupler

Frequency (Hz)	Supra-aural (TDH-49, TDH-50)	Insert (ER-3A)
125	47.5	26.0
250	26.5	14.0
500	13.5	5.5
1000	7.5	0.0
2000	11.0	3.0
3000	9.5	3.5
4000	10.5	5.5
6000	13.5	2.0
8000	13.0	0.0

Note: Based on American National Standards Institute 53.6-2004 standards.

Summary

- Sound is a common type of energy that occurs as a result of pressure waves that emanate from some force being applied to a sound source. A sine wave is a graphic way of representing the pressure waves of sound.
- The magnitude of a sound is described as its intensity. Intensity is related to the perception of loudness. Intensity is expressed in decibels sound pressure level, or dB SPL. One of the most common referents for decibels in audiometry is known as hearing level (HL), which represents decibels according to average normal hearing.
- Frequency is the speed of vibration and is related to the perception of pitch. Frequency is usually expressed in cycles-per-second or Hertz (Hz).
- The physical processing of acoustic information occurs in three groups of structures, commonly known as the outer, middle, and inner ears.
- The outer ear has three main components: the auricle, the ear canal or meatus, and the outer layer of the eardrum or tympanic membrane. The outer ear serves to collect and resonate sound, assist in sound localization, and function as a protective mechanism for the middle ear.
- The middle ear is an air-filled space located within the temporal bone of the skull. It contains the ossicular chain, which consists of three contiguous bones suspended in space, linking the tympanic membrane to the oval window of the cochlea. The middle ear structures act as an impedance matching device, providing a bridge between the airborne pressure waves striking the tympanic membrane and the fluid-borne traveling waves of the cochlea.
- The inner ear contains the cochlea, which is the sensory end-organ of hearing. The cochlea consists of fluid-filled membranous channels within a spiral canal that encircles a bony central core. Here the sound waves, transformed into mechanical energy by the middle ear, set the fluid of the cochlea into motion in a manner consistent with their intensity and frequency. Waves of fluid motion impinge on the membranous labyrinth and set off a chain of events that result in neural impulses being generated at the VIIIth cranial nerve.

- The auditory nervous system is primarily an afferent system that transmits neural signals from the cochlea to the auditory cortex. Neurons leave the cochlea via the VIIIth nerve in an orderly manner and synapse in the lower brainstem. From that point on, the system becomes richly complex, with multiple crossing pathways and plenty of opportunity for efferent and intersensory interaction.
- Absolute threshold of hearing is the threshold of audibility, or the lowest intensity level at which an acoustic signal can be detected.
- The standard audiogram is a plot of absolute threshold, designated in dB HL, at octave or mid-octave intervals from 125 to 8000 Hz. The intensity level is referenced to a standard sound pressure level. Specifications for this sound pressure level are based on internationally accepted standards.

Short Answer Questions

1. Sound occurs as a result of _____ _____, which emanate from a force applied to a sound source.
2. Energy is transferred through a medium that has the properties of _____ and _____, and is defined as the ability to do _____.
3. The density of air molecules increases during _____ and decreases during _____.
4. The periodic back and forth motion of molecules, set into motion by sound vibration, is known as _____ _____ _____.
5. The property of _____ describes the magnitude of a sound. Its psychophysical equivalent is _____. On a waveform, it is represented as _____.
6. The property of _____ describes the speed of molecular vibration. Its psychophysical equivalent is _____.
7. The property of _____ describes the location at any point in time of displacement of an air molecule during simple harmonic motion.

8. The ear consists of three major components: the _____ _____, _____ _____, and _____ _____.
9. The _____, _____ _____ _____, and _____ _____ together make up the outer ear.
10. The bones of the middle-ear space are collectively known as the _____. The three bones, called the _____, _____, and _____ are the smallest bones in the body.
11. The _____ is the snail-shaped space in the petrous portion of the temporal bone that consists of 2.5 turns.
12. The three compartments of the cochlea are the _____ _____, and _____.
13. There are two fluids in the cochlea: _____, which exists in the scala vestibule, and scala tympani, and _____, which exists in the scala media.
14. The two types of hair cells in the cochlea are the _____ and _____ hair cells.
15. The audiovestibular nerve is the _____ cranial nerve. It carries sensory information from the cochlea to the auditory brainstem.
16. Organization of nerve fibers according to frequency, known as _____ organization, exists throughout all levels of the auditory system.
17. The _____ of a sound, the level at which a stimulus is just sufficient to produce a sensation, is generally measured as the level at which sound can be heard 50% of the time presented.
18. The graph used to plot audiometric test results is known as the _____. It shows the _____ of hearing sensitivity as a function of _____.
19. A _____ hearing loss is demonstrated when air-conduction and bone-conduction thresholds are affected similarly. A _____ hearing loss is demonstrated when air-conduction thresholds are worse than bone-conduction thresholds.
20. The _____ system is responsible for the maintenance of balance along with the _____ and _____ systems.

21. The sensory organ of the otoliths is the _____, which exists in the _____ and _____.
22. The sensory organ of the semicircular canals is the _____.

Discussion Questions

1. Describe the process by which sound is transferred through air to the eardrum.
2. Describe the function of the Eustachian tube and discuss how failure of the Eustachian tube to function properly may lead to dysfunction of the auditory system.
3. Describe how the intensity of sound pressure waves is related to decibels of hearing loss.
4. Discuss how the outer hair cells work to increase hearing sensitivity.
5. Describe how turning of the head results in the vestibular system response to provide sensory information to the brain about angular acceleration.

Resources

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3

THE NATURE OF HEARING DISORDER

Learning Objectives

Types of Hearing Disorder
- Hearing Sensitivity Loss
- Suprathreshold Hearing Disorder
- Functional Hearing Loss

Impact of Hearing Disorder
- Patient Factors
- Degree and Configuration of Hearing Sensitivity Loss
- Type of Hearing Loss

Summary

Short Answer Questions

Discussion Questions

Resources

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- Describe the differences between hearing sensitivity loss and suprathreshold hearing disorders.
- Explain the breakdown of function in the various types of hearing sensitivity losses (conductive, sensorineural, and mixed).
- Explain the consequences of each type of hearing sensitivity loss.
- Compare and contrast retrocochlear disorders and auditory processing disorders.
- Define functional hearing loss and explain the various motivational factors that may underlie its existence.
- List and describe hearing loss and other factors that play a role in the impact of hearing impairment on communication.

HEARING disorder results from a number of causes and is usually characterized by the type and degree of hearing loss. Type of hearing loss is related to the site of the disorder within the auditory system, and degree of loss is related to the extent that the disorder is infringing on normal function. Defining both the type and degree of hearing loss is a cornerstone of audiology. This chapter covers types of hearing disorder and their functional consequences.

TYPES OF HEARING DISORDER

Hearing disorders are of two major types:

- hearing sensitivity loss, and
- suprathreshold hearing disorders.

Hearing sensitivity loss is the most common form of hearing disorder. It is characterized by a reduction in the sensitivity of the auditory mechanism so that sounds need to be of higher intensity than normal before they are perceived by the listener. *Suprathreshold disorders* are less common, may or may not include hearing sensitivity loss, and often result in reduced ability to perceive speech properly. A third type is known as *functional hearing loss*. Functional hearing loss is the exaggeration or fabrication of a hearing loss.

In addition to type of loss, a hearing disorder can be described in terms of time of onset, time course, and whether one or both ears is involved.

A hearing disorder can be described by the time of onset:

- congenital: present at birth
- acquired: obtained after birth
- adventitious: not congenital; acquired after birth

Hearing disorder can also be described by its time course:

- acute: of sudden onset and short duration
- chronic: of long duration
- sudden: having a rapid onset
- gradual: occurring in small degrees
- temporary: of limited duration
- permanent: irreversible
- progressive: advancing in degree
- fluctuating: aperiodic change in degree

In addition, hearing disorder can be described by the number of ears involved:

- unilateral: pertaining to one ear only
- bilateral: pertaining to both ears

Hearing Sensitivity Loss

The major cause of hearing disorder is a loss of hearing sensitivity. A loss of hearing sensitivity means that the ear is not as sensitive as normal in detecting sound. Stated another way, sounds must be of a higher intensity than normal to be perceived.

A **conductive hearing loss** is a reduction in hearing sensitivity due to a disorder of the outer or middle ear.

Hearing sensitivity loss is caused by an abnormal reduction of sound being delivered to the brain by a disordered ear. This reduction of sound can result from a number of factors that affect the outer, middle, or inner ears. When sound is not *conducted* well through a disordered outer or middle ear, the result is a **conductive hearing loss**. When the *sensory* or *neural* cells or their connections within the cochlea are absent or not functioning,

the result is a **sensorineural hearing loss**. When structures of both the conductive mechanism and the cochlea are disordered, the result is a **mixed hearing loss**.

A sensorineural hearing loss can also be caused by a disorder of the VIIIth nerve or auditory brainstem. That is, a tumor on the VIIIth nerve or a space-occupying **lesion** in the brainstem can result in a loss of hearing sensitivity that will be classified as sensorineural, rather than conductive or mixed. Generally, however, such disorders are treated separately as **retrocochlear** disorders, because their diagnosis, treatment, and impact on hearing ability can differ substantially from a sensorineural hearing loss of cochlear origin.

A **sensorineural hearing loss** is a reduction in hearing sensitivity due to a disorder of the inner ear.

A **mixed hearing loss** is a reduction in hearing sensitivity due to a combination of a disordered outer or middle and inner ear.

A **lesion** is the structural or functional pathologic change in body tissue.

A **retrocochlear** lesion results from damage to the neural structures of the auditory system beyond the cochlea.

Conductive Hearing Loss

A conductive hearing loss is caused by an abnormal reduction or **attenuation** of sound as it travels from the outer ear to the cochlea. You will recall that the outer ear serves to collect, direct, and enhance sound to be delivered to the tympanic membrane. The tympanic membrane and other structures of the middle ear transform acoustic energy into mechanical energy in order to serve as a bridge from the air pressure waves in the ear canal to the motion of fluid in the cochlea. These outer and middle-ear systems can be thought of collectively as a *conductive mechanism*, or one that conducts sound from the atmosphere to the cochlea.

Attenuation means a decrease in magnitude.

If a structure of the conductive mechanism is in some way impaired, its ability to conduct sound is reduced, resulting in less sound being delivered to the cochlea. Thus, the effect of any disorder of the outer or middle ear is to reduce or attenuate the energy that reaches the cochlea. In this way, a soft sound that is perceptible by a normal ear might not be of sufficient magnitude to overcome the conductive deficit and reach the cochlea. Only when the intensity of this sound is increased can it overcome the conductive barrier.

Perhaps the simplest way to think of a conductive hearing loss is by placing earplugs into your ear canals. Sounds that would normally enter the ear canal are attenuated by the earplugs, resulting in reduced hearing sensitivity. The only way to hear the sound normally is to get closer to its source or to raise its volume.

A conductive hearing loss or the *conductive component* of a hearing loss is best measured by comparing air- and bone-conduction thresholds on an audiogram. Air-conduction thresholds represent hearing sensitivity as measured through the outer, middle, and inner ears. Bone-conduction thresholds represent hearing sensitivity as measured primarily through the inner ear. Thus, if air-conduction thresholds are poorer than bone-conduction thresholds, it can be assumed that the attenuation of sound is occurring at the level of the outer or middle ears.

Audiometric zero is the lowest level at which normal hearers can detect a sound.

An example of a conductive hearing loss is shown in Figure 3-1. Note that bone-conduction thresholds are at or near **audiometric zero**, but air-conduction thresholds require higher intensity levels before threshold is reached. The ear is acting as if the sound being

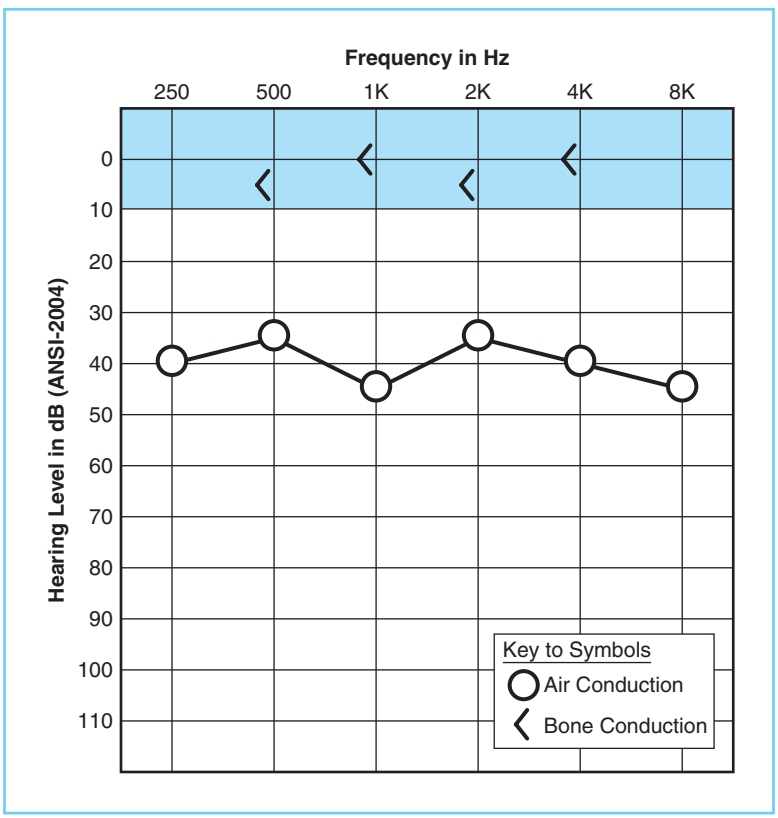


FIGURE 3-1 Audiogram showing a conductive hearing loss.

delivered has been attenuated by, in this case, 30 dB. The size of the conductive component, often referred to as the *air-bone gap*, is described as the difference between the air- and bone-conduction thresholds. In this case, the conductive component to the hearing loss is 30 dB.

A conductive hearing loss is often described by its degree and audiometric configuration. The degree is the size of the conductive component and relates to the extent or severity of the disorder causing the hearing loss. As you will learn in Chapter 4, a number of disorders of the outer and middle ears can cause conductive hearing loss. Whether the disorder causes a conductive hearing loss and the degree of the loss that it causes are based on many factors related to the impact of the disorder on the functioning of the various parts of the conductive mechanism.

Audiometric configuration of a conductive hearing loss varies from low frequency to flat to high frequency depending on the physical obstruction of the structures of the conductive mechanism. In general, any disorder that adds mass to the conductive system will differentially affect the higher audiometric frequencies; any disorder that adds or reduces stiffness to the system will affect the lower audiometric frequencies. Any disorder that changes both mass and stiffness will affect a broad range of audiometric frequencies.

Because a conductive hearing loss acts primarily as an **attenuator** of sound, it has little or no impact on *suprathreshold* hearing. That is, once sound is of a sufficient intensity, the ear acts as it normally would at suprathreshold intensities. Thus, perception of loudness, ability to discriminate loudness and pitch changes, and speech-recognition ability are all normal once the conductive hearing loss is overcome by raising the intensity of the signal.

An **attenuator** is something that reduces or decreases the magnitude.

Sensorineural Hearing Loss

A sensorineural hearing loss is caused by a failure in the cochlear transduction of sound from mechanical energy in the middle ear to neural impulses in the VIIIth nerve. You will recall that the cochlea is a highly specialized sensory receptor organ that converts hydraulic fluid movement, caused by mechanical

energy from stapes movement, into electrical potentials in the nerve endings on the hair cells of the organ of Corti. The intricate sensory system composed of receptor cells that convert this fluid movement into electrical potentials contains both sensory and neural elements.

When a structure of this sensorineural mechanism is in some way damaged, its ability to transduce mechanical energy into electrical energy is reduced. This results in a number of changes in cochlear processing, including:

- a reduction in the sensitivity of the cochlear receptor cells,
- a reduction in the frequency-resolving ability of the cochlea, and
- a reduction in the dynamic range of the hearing mechanism.

A sensorineural hearing loss is most often characterized clinically by its effect on cochlear sensitivity and, thus, the audiogram. If the outer and middle ears are functioning properly, then air-conduction thresholds accurately represent the sensitivity of the cochlea and are equal to bone-conduction thresholds. An example of a sensorineural hearing loss is shown in Figure 3-2. Note that air-conduction thresholds match bone-conduction thresholds, and both require higher intensity levels than normal before threshold is reached.

A sensorineural hearing loss is often described by its degree and audiometric configuration. The degree is based on the range of decibel loss and relates to the extent or severity of the disorder causing the hearing loss. As you will learn in Chapter 4, a number of disorders of the cochlea and peripheral auditory nervous system can cause sensorineural hearing loss. Whether the disorder causes a sensorineural hearing loss, and the degree of the loss that it causes, is based on many factors relating to the impact of the disorder on the functioning of the various components of the sensorineural mechanism.

Audiometric configuration of a sensorineural hearing loss varies from low frequency to flat to high frequency depending on the location along the basilar membrane of hair cell loss or other damage.

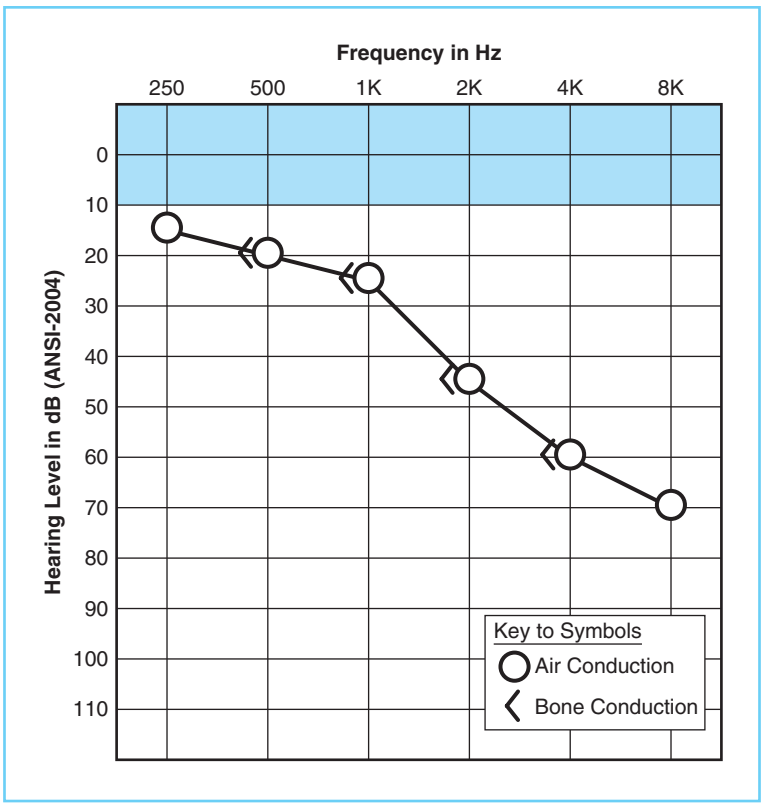


FIGURE 3-2 Audiogram showing a sensorineural hearing loss.

Various causes of sensorineural hearing loss have characteristic configurations, which will be shown later in this section.

The complexity of a sensorineural hearing loss tends to be greater than that of a conductive hearing loss because of its effects on frequency resolution and dynamic range. Recall that one important processing component of cochlear function is to provide fine tuning of the auditory system in the frequency domain. The broadly tuned traveling wave of cochlear fluid is converted into finely tuned neural processing of the VIIIth nerve by the active processes of the outer hair cells of the organ of Corti. One effect of the loss of these hair cells is a reduction in the sensitivity of the system. Another is broadening of the frequency-resolving ability. An example is shown in Figure 3-3.

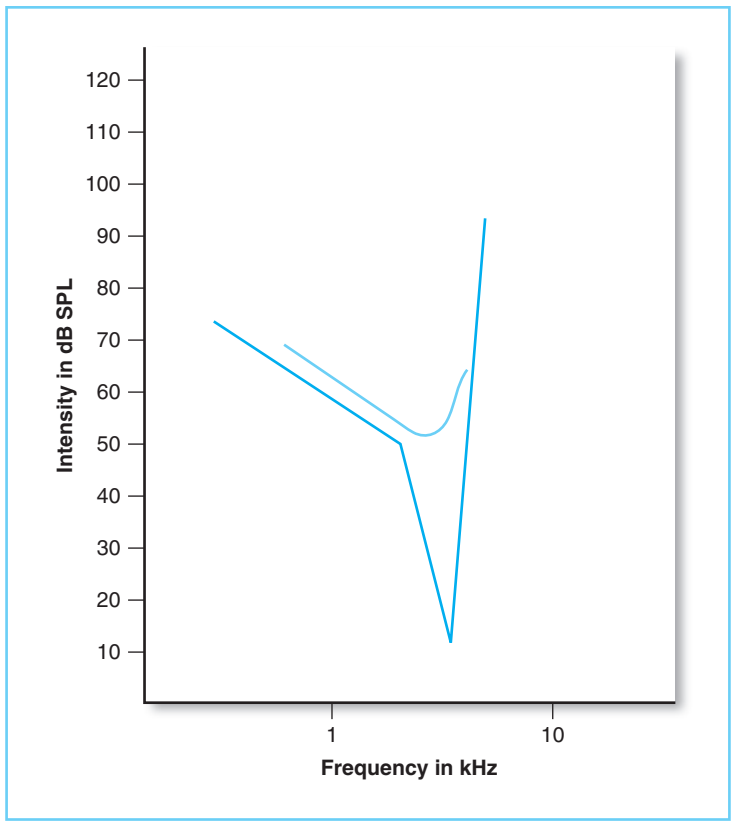


FIGURE 3-3 Generalized drawing of the broadening of the frequency resolving ability of the auditory system following outer hair cell loss. The thick line represents normal tuning; the thin line represents reduced tuning capacity.

Another important effect of cochlear hearing loss is that it reduces the dynamic range of cochlear function. Recall that the auditory system's range of perception from threshold of sensitivity to pain is quite wide. Unlike a conductive hearing loss, a sensorineural hearing loss reduces sensitivity to low intensity sounds but has little effect on perception of high intensity sounds. The relationship is shown in Figure 3-4. A normal dynamic range exceeds 100 dB; the dynamic range of an ear with sensorineural hearing loss can be considerably smaller.

Because of these complex changes in cochlear processing, a sensorineural hearing loss can have a significant impact on

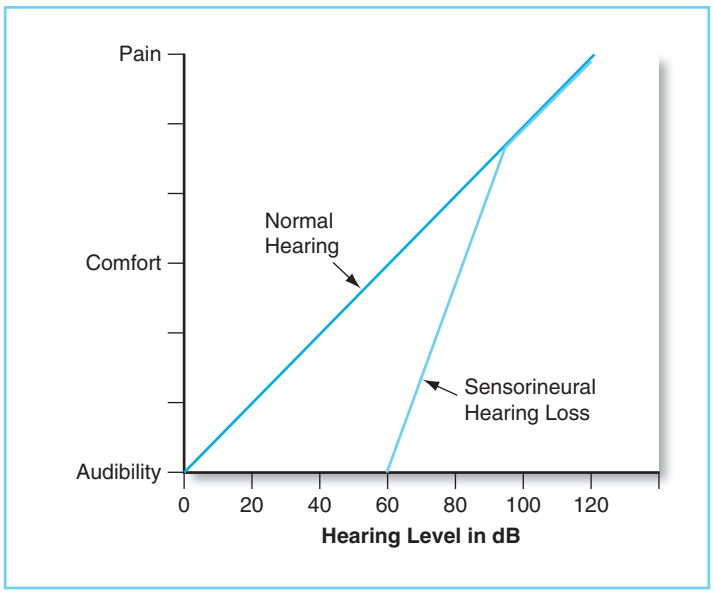


FIGURE 3-4 Generalized drawing of the relationship of loudness and intensity level in normal hearing and in sensorineural hearing loss.

suprathreshold hearing. That is, even when sound is of a sufficient intensity, the ear does not necessarily act as it normally would at suprathreshold intensities. Thus, for example, speech recognition ability does not necessarily return to normal at intensity levels sufficient to overcome the sensitivity loss.

Mixed Hearing Loss

A hearing loss that has both a sensorineural component and a conductive component is considered a mixed hearing loss. A mixed hearing loss results when sound being delivered to an impaired cochlea is attenuated by a disordered outer or middle ear.

Figure 3-5 shows an example of a mixed hearing loss. Bone-conduction thresholds reflect the degree and configuration of the sensorineural component of the hearing loss. Air-conduction thresholds reflect both the sensorineural loss and an additional conductive component.

The causes of mixed hearing loss are numerous and varied. In some cases, a mixed loss is simply the addition of a conductive

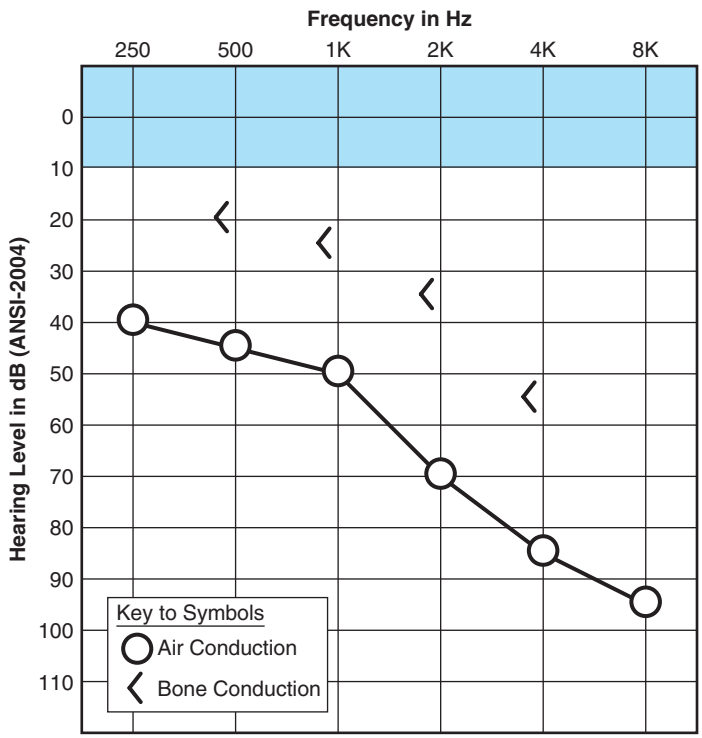


FIGURE 3-5 Audiogram showing a mixed hearing loss.

The **etiology** of a hearing loss is its cause.

hearing loss, due for example to active middle-ear disease, to a longstanding sensorineural hearing loss of unrelated **etiology**. In other cases, the disease process causing middle-ear disorder can also cause cochlear disorder and results in a mixed hearing loss of common origin. The causes of mixed hearing loss will be described in more detail in Chapter 4.

Suprathreshold Hearing Disorder

Although there is a tendency to think of hearing disorder as the sensitivity loss that can be measured on an audiogram, there are other types of hearing disorders that may or may not be accompanied by sensitivity loss. These other disorders result from disease or damage to the central auditory nervous system in adults, or delayed or disordered auditory nervous system development in children.

A disordered auditory nervous system, regardless of cause, will have functional consequences that can vary from subclinical to a substantial, easily measurable auditory deficit. Although the functional consequences may be similar, we tend to divide auditory nervous system disorders into two groups, depending on the nature of the underlying disorder.

1. When a disorder is caused by an active, measurable disease process, such as a tumor or other space-occupying lesion, or from damage due to trauma or stroke, it is often referred to as a retrocochlear disorder. That is, retrocochlear disorders result from structural lesions of the nervous system.
2. When a disorder is due to developmental dysfunction or delay or from diffuse changes such as the aging process, it is often referred to as a auditory processing disorder. That is, auditory processing disorders results from "functional lesions" of the nervous system.

The consequences of both types of disorder can be remarkably similar from a hearing perspective, but they are treated differently because of the consequences of diagnosis and the likelihood of a significant residual communication disorder.

Retrocochlear Hearing Disorder

A retrocochlear disorder is caused by a change in neural structure and function of some component of the peripheral or central auditory nervous system. As a general rule, the more peripheral a lesion, the greater its impact will be on auditory function. Conversely, the more central the lesion, the more subtle its impact will be. One might conceptualize this by thinking of the nervous system as a large oak tree. If you were to damage one of its many branches, overall growth of the tree would be affected only subtly. Damage its trunk, however, and the impact on the entire tree could be significant. A well-placed tumor on the auditory nerve can substantially impact hearing, whereas a lesion in the midbrain is likely to have more subtle effects.

A retrocochlear lesion may or may not affect auditory sensitivity. This will depend on many factors, including lesion size, location, and impact. A tumor on the VIIIth cranial nerve can cause

a substantial sensorineural hearing loss, depending on how much pressure it places on the nerve, the damage that it causes to the nerve, or the extent to which it interrupts cochlear function. A tumor in the temporal lobe, however, is quite unlikely to result in any change in hearing sensitivity. This relationship is shown in Figure 3-6.

Speech recognition is the ability to perceive and identify speech.

More subtle hearing disorders from retrocochlear disease are often noted in measures of suprathreshold function such as **speech recognition** ability. Using various measures that stress the auditory system, the audiologist can detect some of the more subtle changes resulting from retrocochlear lesions.

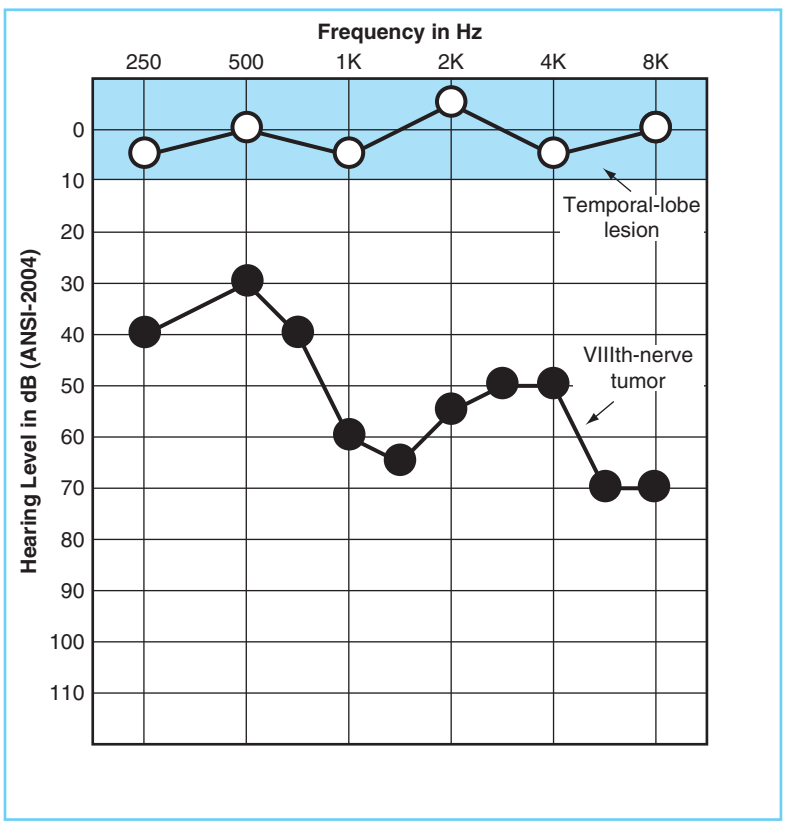


FIGURE 3-6 Representative audiometric outcomes resulting from temporal-lobe and VIIIth-nerve tumors.

Auditory Processing Disorder

Disorders of central auditory nervous system function occur primarily in two populations:

- young children and
- the elderly.

APD in Children. The vast majority of childhood auditory processing disorders do not result from documented **neuropathologic** conditions. Rather, they present as communication problems that resemble hearing sensitivity loss. The specific hearing disorder is related to an **idiopathic** dysfunction of the central auditory nervous system and is commonly referred to as *auditory processing disorder*. Although the auditory symptoms and clinical findings in children with APD may mimic those of children with auditory disorders due to discrete pathology in the central auditory nervous system, they result from no obvious pathological condition that requires medical intervention.

Neuropathologic conditions are those that involve the peripheral or central nervous systems.

When a hearing loss is **idiopathic**, it is of an unknown cause.

APD can be thought of as a hearing disorder that occurs as a result of dysfunction of the central auditory nervous system. Although some children may be **genetically predisposed** to APD, it is more likely to be a developmental delay or disorder, resulting from inconsistent or degraded auditory input during the critical period for auditory perceptual development. APD is **symptomatic** in nature and is often confused with an impairment of hearing sensitivity. It can be an isolated disorder, or it can co-exist with **attention deficit disorders**, **learning disabilities**, and language disorders. Functionally, children with APD act as if they have hearing-sensitivity deficits, although they are usually capable of hearing faint sounds. In particular, they exhibit difficulty in perceiving spoken language or other sounds in **hostile acoustic environments**. Thus, APD is commonly identified early in children's academic lives, when they enter a conventional classroom situation and are unable to understand instructions from the teacher.

When a person is **genetically predisposed**, he or she is susceptible to a heredity condition.

When a person is **symptomatic**, he or she is exhibiting a condition that indicates the existence of a particular disease.

An **attention deficit disorder** results in reduced ability to focus on an activity, task, or sensory stimulus.

A **learning disability** is the lack of skill in one or more areas of learning that is inconsistent with the person's intellectual capacity.

A **hostile acoustic environment** is a difficult listening environment, such as a room with a significant amount of background noise.

As our understanding of APD has progressed, we have begun to better define its true nature and to agree on clinical, operational definitions of the disorder. Consensus is beginning to emerge on a definition of APD that distinguishes it from language processing

disorders and other neuropsychological disorders. One useful classification scheme for categorizing disorder types is shown in Table 3-1. Under this scheme,

- *APD* is defined as an auditory disorder that results from deficits in central auditory nervous system function.
- *Receptive language processing disorders* are defined as deficits in linguistic-processing skills and may affect language comprehension and vocabulary development.
- *Supramodal disorders*, such as auditory attention and auditory memory, are defined as deficits in cognitive ability that cross modalities.

Clearly, overlap exists among these disorders, they may co-exist, and they are often difficult to separate. For example, the change from perception to comprehension must occur on a continuum, and deciding where one ends and the other begins can only be defined operationally. Similarly, the relation of memory and attention to either perception or comprehension is difficult to separate. Nevertheless, distinguishing among these classes of disorders is important clinically because they tend to have different **sequelae** and to be treated differently.

Sequelae are conditions following or occurring as a consequence of another condition.

APD, then, can be thought of as an auditory disorder that occurs as a result of dysfunction in the manipulation and utilization of acoustic signals by the central auditory nervous system.

TABLE 3-1 Classification system for describing types of disorders that can affect the ability to turn sound into meaning

Disorder Type	Nature of Deficit
Auditory processing disorders — speech-in-noise problems — dichotic deficits — temporal processing disorders	Auditory
Receptive language processing disorders — linguistically dependent problems — deficits in analysis, synthesis, closure	Linguistic
Supramodal disorders — attention — memory	Cognitive

It is broadly defined as an impaired ability to process acoustic information that cannot be attributed to impaired hearing sensitivity, impaired language, or impaired intellectual function.

Auditory processing disorders have been characterized based on models of deficits in children and adults with acquired lesions of the central auditory nervous system. Such deficits include reduced ability to understand in background noise, to understand speech of **reduced redundancy**, to localize and **lateralize** sound, to separate **dichotic stimuli**, and to process normal or altered **temporal cues**. Children with APD exhibit deficits similar to those with acquired lesions, although they may be less pronounced in severity and are more likely to be generalized than ear-specific.

Reduced redundancy means less information is available.

To **lateralize** sound means to determine its perceived location in the head or ears.

Dichotic stimuli are different signals presented simultaneously to each ear.

Temporal cues are timing cues.

APD in the Elderly. Changes in structure and function occur throughout the peripheral and central auditory nervous systems as a result of the aging process. Evidence of **neural degeneration** has been found in the auditory nerve, brainstem, and cortex.

Neural degeneration occurs when the anatomic structure degrades.

Whereas the effect of structural change in the auditory periphery is to attenuate and distort incoming sounds, the major effect of structural change in the central auditory nervous system is the degradation of auditory processing. Hearing impairment in the elderly, then, can be quite complex, consisting of attenuation of acoustic information, distortion of that information, and/or disordered processing of neural information. In its simplest form, this complex disorder can be thought of as a combination of peripheral cochlear effects (attenuation and distortion) and central nervous system effects (auditory processing disorder). The consequences of peripheral sensitivity loss in the elderly are similar to those of younger hearing-impaired individuals. The functional consequence of structural changes in the central auditory nervous system is auditory processing disorder.

Auditory processing ability is usually defined operationally on the basis of behavioral measures of speech recognition. Degradation in auditory processing has been demonstrated most convincingly by the use of **sensitized** speech audiometric measures. Age-related changes have been found on degraded speech tests that use both frequency and **temporal alteration**. Tests of dichotic performance have also been found to be adversely affected by aging. In addition, aging listeners do not perform as well as younger listeners on tasks

Sensitized speech audiometric measures are measures in which speech targets are altered in various ways to reduce their informational content in an effort to more effectively challenge the auditory system.

Temporal alteration refers to changing the speed or timing of speech signals.

that involve the understanding of speech in the presence of background noise.

Functional Hearing Loss

Functional hearing loss is the exaggeration or feigning of hearing impairment. Many terms have been used to describe this type of hearing "impairment," including nonorganic hearing loss, pseudohypacusis, malingering, factitious hearing loss, and so on. Since there may be some organicity to the hearing loss, it is probably best considered as an exaggerated hearing loss or a functional overlay to an organic loss. The term functional hearing loss is the general term most commonly used to describe such outcomes.

A better way to understand functional hearing loss is to define it by a patient's motivation (Austen & Lynch, 2004). This is depicted in Figure 3-7. Here motivation is defined by two factors: the *intent*

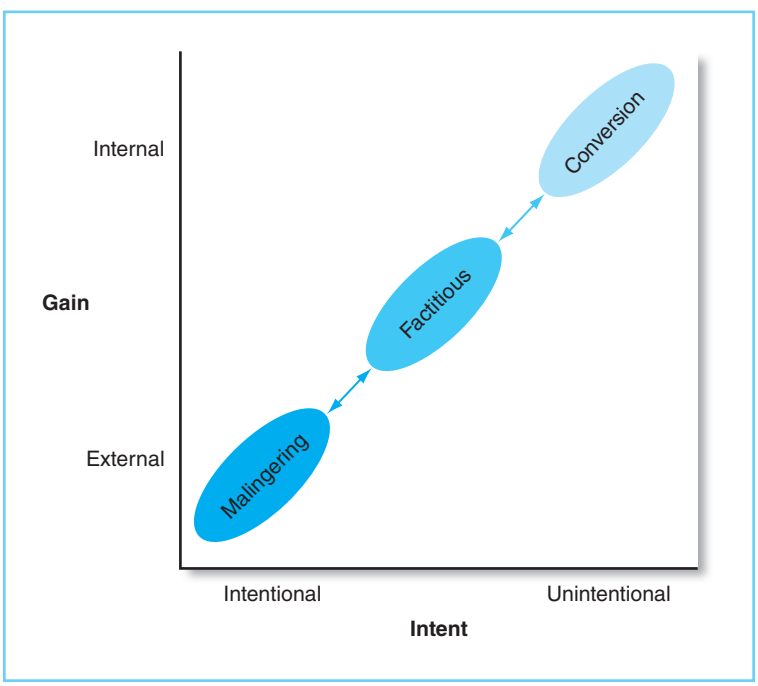


FIGURE 3-7 **Categories of functional hearing loss, defined by motivation.** (Adapted with permission from Taylor & Francis Group. Austen, S., & Lynch, C. (2004). Non-organic hearing loss redefined: Understanding, categorizing and managing non-organic behaviour. *International Journal of Audiology, 43,* 449–457.)

of the person in creating the symptoms and the nature of the *gain* that results. Thinking of functional hearing loss in this way results in a continuum that can be divided into at least three categories: malingering, factitious disorder, and conversion disorder.

Malingering occurs when someone is feigning a hearing loss, typically for financial gain. In many cases of malingering, particularly in adults, an organic hearing sensitivity loss exists but is willfully exaggerated for compensatory purposes. In other cases, often secondary to trauma of some kind, the entire hearing loss will be willfully feigned. Malingering occurs mostly in adults. For example, an employee may be applying for worker's compensation for hearing loss secondary to exposure to excessive sound in the workplace. Or someone discharged from the military may be seeking compensation for hearing loss from excessive noise exposure. Although most patients have legitimate concerns and provide honest results, a small percentage tries to exaggerate hearing loss in the mistaken notion that they will receive greater compensation. There are also those who have an accident or altercation and are involved in a lawsuit against an insurance company or someone else. Some may think that feigning a hearing loss will lead to greater monetary award.

A *factitious* disorder is one in which the feigning of a hearing loss is done to assume a sick role, where the motivation is internal rather than external. Children with functional hearing loss are more likely to have factitious disorder, using hearing impairment as an explanation for poor performance in school or to gain attention. The idea may have emerged from watching a classmate or sibling get special treatment for having a hearing impairment. It may also be secondary to a bout of otitis media and the consequent parental attention paid to the episode.

A *conversion* disorder is a rare case in which the symptom of a hearing loss occurs unintentionally with little or no organic basis. A conversion disorder results following psychological distress of some nature.

IMPACT OF HEARING DISORDER

Defining the impact of a hearing disorder is complicated by the many factors involved in the hearing loss itself and in the patient who has the hearing loss. Hearing sensitivity loss varies in degree from minimal to

profound. Similarly, speech perception deficits vary from mild to severe. The extent to which these problems cause a communication disorder depends on a number of factors, including:

- degree of sensitivity loss,
- audiometric configuration,
- type of hearing loss, and
- degree and nature of a speech perception deficit.

Confounding this issue further are individual patient factors that are interrelated to these auditory factors, including:

- age of onset of loss,
- whether the loss was sudden or gradual, and
- communication demands on the patient.

Congenital means present at birth.

Prelinguistic means occurring before the time of spoken language development.

Prognosis is a prediction of the course or outcome of a disease or treatment.

Postlinguistic means occurring after the time of spoken language development.

Compensatory strategies are skills that a person learns in order to compensate for the loss or reduction of an ability.

Speechreading is the ability to understand speech by watching the movements of the lips and face; also known as lipreading.

Environmental alteration refers to the manipulation of physical characteristics of a room or a person's location within that room to provide an easier listening situation.

Patient Factors

One of the most important factors determining the impact of hearing loss in children is the age of onset. When a hearing loss is **congenital**, it occurs before linguistic development or **prelinguistically**. If the degree of loss is severe enough, and intervention is not implemented early enough, the **prognosis** for developing adequate spoken language is diminished. Conversely, when a hearing loss is acquired after spoken language development, or **postlinguistically**, the prognosis for continued speech and language development is significantly better.

An important factor in the impact of hearing loss on adults is the speed with which a hearing loss occurs. Sudden hearing loss has a significantly greater impact on communication than a gradual hearing loss. Those who develop hearing loss slowly over many years tend to develop **compensatory strategies**, such as **speechreading**, and implement **environmental alteration**. This concept seems to hold even for mild hearing loss. The gradual development of a mild hearing loss has little impact on most patients, and many will not seek treatment for a mild disorder. However, the same mild hearing loss of sudden onset can cause significant communication disorder for that patient.

Another patient factor that influences the impact of hearing loss is the communication demands a patient faces in everyday life. Two pa-

tients with the same type, degree, and configuration of hearing loss will have significantly different perceptions of the impact of the hearing loss if their communication demands are substantially different. The active businesswoman who spends most of her days in meetings and on the telephone will find the impact of a moderate hearing loss to be much greater than the retired person who lives alone.

Although these patient factors will influence the extent of impairment, there are, nevertheless, some general rules about the impact of degree, configuration, and type of hearing loss on communication ability.

Degree and Configuration of Hearing Sensitivity Loss

Degree of hearing sensitivity loss is commonly defined on the basis of the audiogram. Table 3-2 provides a general guideline for describing degree of hearing loss. Normal hearing is defined as audiometric zero, plus or minus two standard deviations of the mean. Thus, normal sensitivity ranges from −10 to +10 dB HL. All other classifications are based on generally accepted terminology.

These terms might be used to describe the pure-tone thresholds at specific frequencies, or they might be used to describe the **pure-tone average** or threshold for speech recognition. In this way, the audiogram in Figure 3-8 might be described as a mild hearing loss through 1000 Hz and a moderate hearing loss above 1000 Hz, or, based on the pure-tone average, a moderate hearing loss for the **speech frequencies**. It is important to remember that these

Pure-tone average is the mean of thresholds at 500, 1000, and 2000 Hz.

The term **speech frequencies** generally refers to 500, 1000, and 2000 Hz.

TABLE 3-2 | General guideline for describing degree of hearing loss

Degree of loss	Range in dB HL
Normal	−10 to 10
Minimal	11 to 25
Mild	26 to 40
Moderate	41 to 55
Moderately severe	56 to 70
Severe	71 to 90
Profound	>90

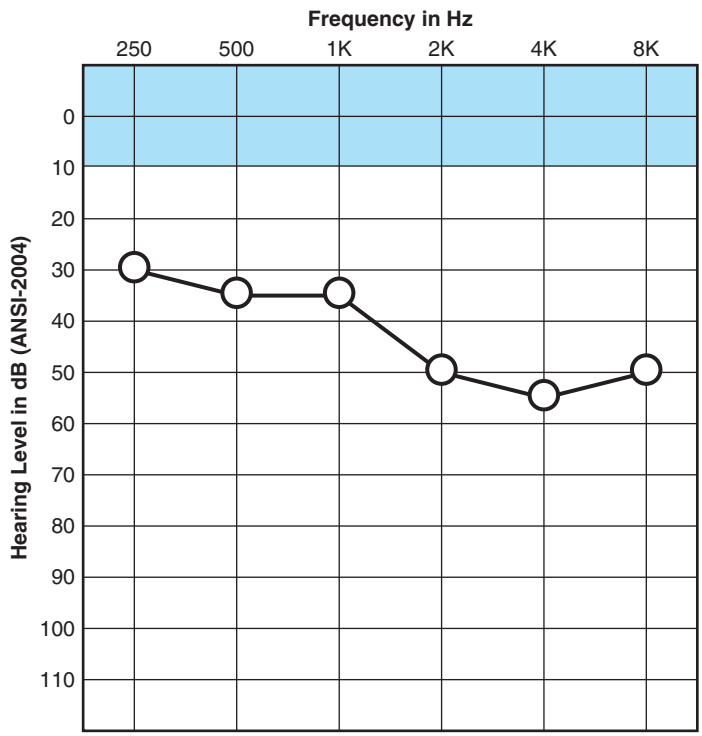


FIGURE 3-8 Audiogram showing a mild hearing loss through 1000 Hz and a moderate hearing loss above 1000 Hz.

descriptions are just words and that "mild is in the ear of the listener." What might truly be a mild problem to one individual with a mild loss can be a severe communication problem for another patient with the same mild degree of sensitivity loss. Nevertheless, these terms serve as a means for consistently describing the degree of sensitivity loss across patients.

In terms of communication, the degree of hearing loss might be considered as follows:

Minimal	difficulty hearing faint speech in noise
Mild	difficulty hearing faint or distant speech, even in quiet

Moderate	hears conversational speech only at a close distance
Moderately-severe	hears loud conversational speech
Severe	cannot hear conversational speech
Profound	may hear loud sounds; hearing is not the primary communication channel

Another important aspect of the audiogram is the shape of the audiometric configuration. In general, shape of the audiogram can be defined in the following terms:

Flat	thresholds are within 20 dB of each other across the frequency range
Rising	thresholds for low frequencies are at least 20 dB poorer than for high frequencies
Sloping	thresholds for high frequencies are at least 20 dB poorer than for low frequencies
Low-frequency	hearing loss is restricted to the low-frequency region of the audiogram
High-frequency	hearing loss is restricted to the high-frequency region of the audiogram
Precipitous	steeply sloping high-frequency hearing loss of at least 20 dB per octave

Examples of these various configurations are shown in Figure 3-9.

The shape of the audiogram combined with the degree of the loss provides a useful description of hearing sensitivity. How a particular hearing loss might affect communication can begin to be understood by assessing the relationship of the pure-tone audiogram to the intensity and frequency areas of speech sounds during normal conversations. Figure 3-10 shows an example. Here, **phonetic** representations of speech sounds spoken at normal

Phonetic refers to an individual speech sound.

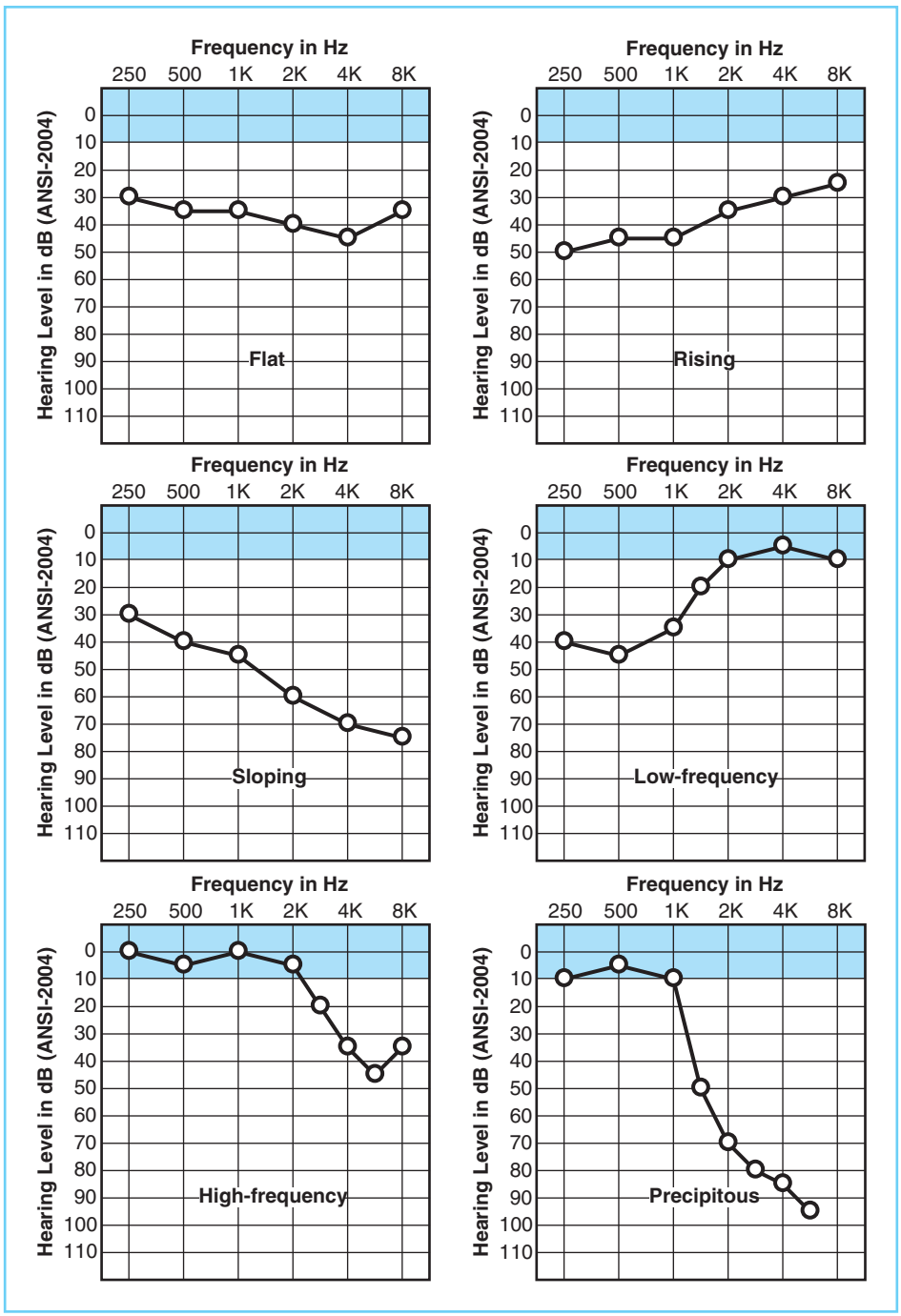


FIGURE 3-9 | Audiometric configurations.

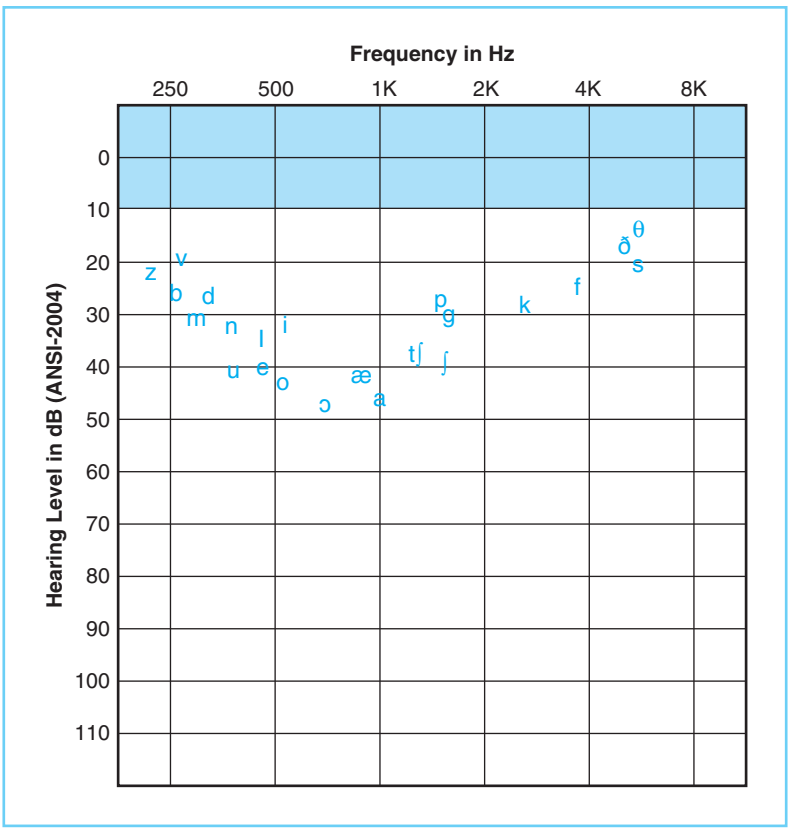


FIGURE 3-10 Generalized phonetic representations of speech sounds occurring at normal conversational levels plotted on an audiogram.

conversational levels are plotted as a function of frequency and intensity on an audiogram. Next, three examples of audiograms are superimposed on these symbols.

Figure 3-11 shows a mild, low-frequency hearing loss. In this case, nearly all the speech sounds would be **audible** to the listener. Some of the lower frequency sounds, such as the vowels, may be less audible, but because they do not carry nearly as much meaning as consonant sounds, suprathreshold speech perception should not be affected.

Audible is "hearable."

Figure 3-12 shows a moderately severe, flat hearing loss. In this example, none of the speech signals of normal conversational speech

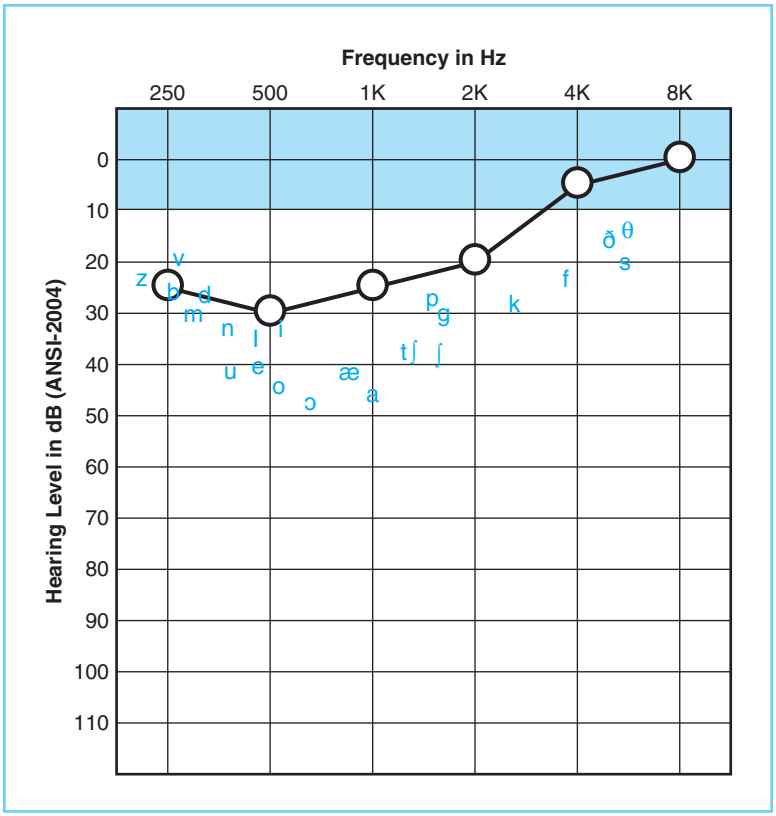


FIGURE 3-11 The audibility of speech sounds in the presence of a mild, rising audiometric configuration.

would be perceived. In order for perception of speech sounds to occur, the intensity of the speech sounds would have to be increased by moving closer to the sound source or by amplifying the sound.

Figure 3-13 shows a moderate high-frequency hearing loss. In this case, low-frequency sounds are perceived adequately, but high-frequency sounds are imperceptible. Again, because the high-frequency sounds are consonant sounds, and because consonant sounds carry much of the meaning in the English language, this patient would be at a disadvantage for perceiving speech adequately.

It is not quite this simple, of course. Perception of speech in the real world is made easier by built-in redundancy of information.

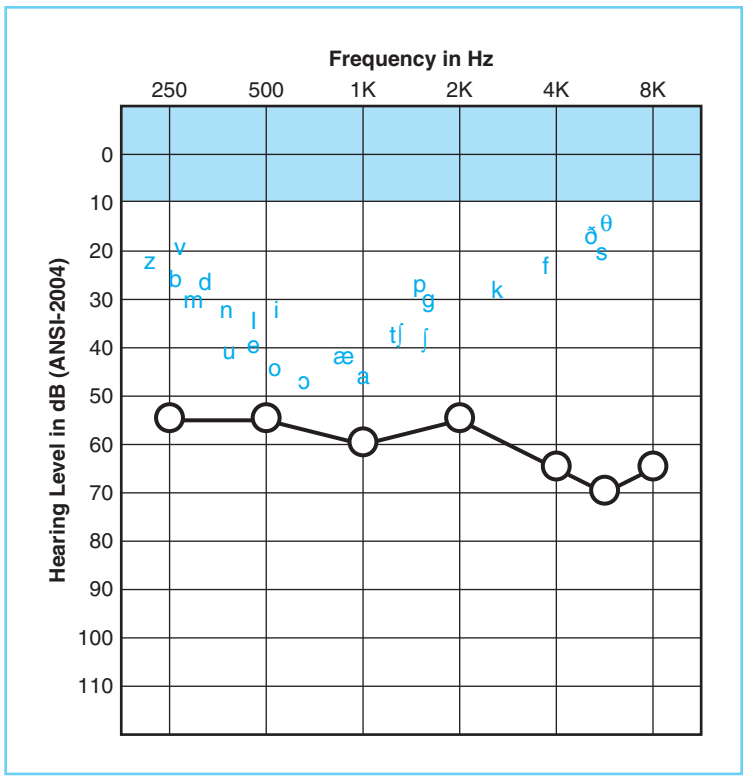


FIGURE 3-12 The inaudibility of speech sounds in the presence of a moderately severe, flat audiometric configuration.

For example, **co-articulation** from one sound to the other can provide enough information about the next sound that the listener does not even need to hear it to accurately perceive what is being said. As another example, many consonant sounds are visible on the speaker's lips, so that the combination of hearing some frequencies of speech and seeing others can provide enough information for adequate understanding.

Co-articulation refers to the influence of one speech sound on the next.

Although redundancy in the communication process makes perception easier, noise and **reverberation** make it more difficult. Those important high-frequency consonant sounds have the least acoustic energy of any speech sounds. As a consequence, noise of any kind is likely to cover up or mask those signals first. Add a high-frequency sensitivity loss to the mix, and the most important speech sounds are the least likely to be perceived.

Reverberation is the prolongation of a sound by multiple reflections, more commonly termed an echo.

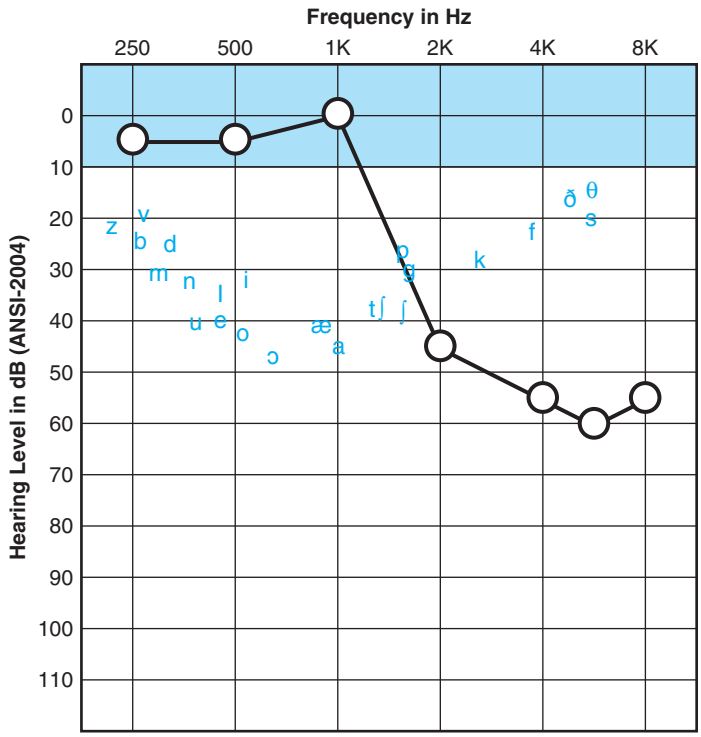


FIGURE 3-13 The selective audibility of speech sounds in the presence of a moderate, high-frequency audiometric configuration.

Type of Hearing Loss

The type of hearing loss is also a factor in the impact that a hearing loss has on communication ability. For example, the simple attenuation created by a conductive hearing loss has less of an impact than the more complex impairment that can result from a retrocochlear disorder.

Conductive Hearing Loss

The effects of conductive hearing loss are probably the easiest to understand. The configuration of a conductive hearing loss is generally either flat or low-frequency in nature. In addition, conductive hearing loss has a maximum limit of approximately 60 dB HL. This represents the loss due to both the lack of impedance-matching function of the middle ear and additional mass and stiffness components related to the nature of the disorder.

As a general rule, a conductive hearing loss simply reduces the volume of the incoming signal. Although too much attenuation makes the hearing of speech difficult, it can be fairly easily overcome by increasing the intensity level of the speech. At suprathreshold level, the ear with a conductive hearing loss acts quite normally. As long as sound can be made sufficiently loud, hearing will be normal.

Most conductive hearing loss results from auditory disorders that can be treated medically. As a result, conductive loss is seldom of a longstanding duration. Thus, its impact on communication is usually **transient**. Under some circumstances, however, conductive hearing loss can have a more long-term effect. Occasionally, a patient will have chronic middle-ear disorder that has gone untreated. In some cases, this will lead to permanent conductive hearing loss that can only be treated with hearing aid amplification.

In this context, **transient** means short-lived or not long term.

But there is also a more **insidious** effect of conductive hearing loss. Some children have chronic middle-ear disorder that results in fluctuating conductive hearing loss throughout much of their early lives. Evidence suggests that some children who experience this type of inconsistent auditory input during their formative years will not develop appropriate auditory and listening skills. Such children may be at risk for later learning and achievement problems.

When something is more dangerous than seems evident, it is **insidious**.

Sensorineural Hearing Loss

As you learned earlier, a sensorineural hearing loss has at least three fundamentally important effects on hearing: a reduction in the cochlear sensitivity, a reduction in frequency resolution, and a reduction in the dynamic range of the hearing mechanism. In many ways, the reduction in hearing sensitivity can be thought of as having the same effects as a conductive hearing loss in terms of reducing the audibility of speech. That is, a conductive hearing loss and a sensorineural hearing loss of the same degree and configuration will have the same effect on audibility of speech sounds. The difference between the two types of hearing loss occurs at suprathreshold levels.

One of the consequences of sensorineural hearing loss is *recruitment*, or abnormal loudness growth. Recall from Figure 3-4 that loudness grows more rapidly than normal at intensity levels just

above threshold in an ear with sensorineural hearing loss. This recruitment results in a reduced dynamic range from the threshold level to the discomfort level.

Reduction in frequency resolution and in dynamic range affect the perception of speech. In most sensorineural hearing loss, this effect on speech understanding is predictable from the audiogram and is poorer than would be expected from a conductive hearing loss of similar magnitude. At the extreme end of the audiogram the reduction in frequency resolution and dynamic range can severely limit the usefulness of **residual hearing**.

Residual hearing refers to the remaining hearing ability in a person with a hearing loss.

Retrocochlear Hearing Loss

In general, hearing loss from retrocochlear disorder is distinguishable from cochlear or conductive hearing loss by the extent to which it can adversely affect speech perception. Conductive loss impacts speech perception only by attenuating it. Cochlear hearing loss adds distortion, but it is reasonably minimal and predictable. Retrocochlear disorder can cause severe distortion of incoming speech signals in a manner that limits the usefulness of hearing.

In addition to speech-recognition deficits, other suprathreshold abnormalities can occur. Loudness growth can be abnormal in patients with retrocochlear disorder. Instead of the abnormally rapid growth of loudness characteristic of cochlear hearing loss, retrocochlear disorder can show no recruitment or *decruitment*, an abnormally slow growth in loudness with increasing intensity. Another abnormality that can occur as a result of retrocochlear disorder is abnormal *auditory adaptation*. The normal auditory system tends to adapt to ongoing sound, especially at near-threshold levels, so that, as adaptation occurs, an audible signal becomes inaudible. At higher intensity levels, ongoing sound remains audible without adaptation. However, in an ear with retrocochlear disorder, the audibility may diminish rapidly due to excessive auditory adaptation, even at higher intensity levels.

The impact of retrocochlear disorder often depends on the level in the auditory nervous system at which the disorder is occurring. A disorder of the VIIIth nerve may have a significant impact on the audiogram and on speech perception. A disorder of the brainstem

may spare the audiogram and negatively influence only hearing of speech in noisy or other complex listening environments.

Auditory Processing Disorder

Consequences of APD can range from mild difficulty understanding a teacher in a noisy classroom to substantial difficulty understanding speech in everyday listening situations at home and school. One of the most important deficits in children with APD is difficulty understanding in background noise. In an acoustic environment that would be adequate for other children, a child with APD may have substantial difficulty understanding what is being said. Thus, parents will often complain that the child cannot understand them when the television is on, while riding in the car, or when the parents are speaking from another room. The teacher will complain of the child's inability to follow directions, distractibility, and general unruliness. In effect, the complaints will be similar to those expressed by parents or teachers of children with impairments of hearing sensitivity. In a quiet environment, with one-on-one instruction, a child with APD may thrive in a manner consistent with his or her academic potential. In a more adverse acoustic environment, a child with APD will struggle.

In general, children with APD will act as if they have a hearing sensitivity loss, even though most will have normal audiograms. They will ask for repetition, fail to follow instructions, and so on, particularly in the presence of background noise or other factors that reduce the redundancy of the acoustic signal. To the extent that such difficulties result in frustration, secondary problems may develop related to their behavior and motivation in the classroom. Some children with APD will have **concomitant** speech and language deficits, learning disabilities, and attention deficit disorders. Thus, APD may be accompanied by distractibility, attention problems, memory deficits, language comprehension deficits, restricted vocabulary, and reading and spelling problems.

Concomitant means together with or accompanying.

In general, elderly patients with APD will experience substantially greater difficulty hearing than would be expected from their degree and configuration of hearing loss. This difficulty will be exacerbated in the presence of background noise or competition. As a result, disorders in auditory processing may adversely impact benefit from conventional hearing aid use.

Summary

- Hearing disorders are of two major types: hearing sensitivity loss and suprathreshold hearing disorders.
- The major cause of hearing disorder is a loss of hearing sensitivity. A loss of hearing sensitivity means that the ear is not as sensitive as normal in detecting sound. Hearing sensitivity losses are of three types: conductive, sensorineural, and mixed.
- A conductive hearing loss is caused by an abnormal reduction or attenuation of sound as it travels from the outer ear to the cochlea. A sensorineural hearing loss is caused by a failure in the cochlear transduction of sound from mechanical energy in the middle ear to neural impulses in the VIIIth nerve. A mixed hearing loss results when sound being delivered to an impaired cochlea is attenuated by a disordered outer or middle ear.
- Auditory nervous system disorders are of two types, depending on the nature of the underlying disorder: retrocochlear disorders and auditory processing disorders.
- Retrocochlear disorders result from structural lesions of the nervous system, such as a tumor or other space-occupying lesions or damage due to trauma or stroke.
- Auditory processing disorders result from "functional lesions" of the nervous system, such as developmental disorder or delay or diffuse changes such as those related to the aging process.
- Functional hearing loss is the exaggeration or feigning of hearing impairment. In many cases of functional hearing loss, particularly in adults, an organic hearing sensitivity loss exists but is willfully exaggerated.
- The impact of hearing disorder on communication depends on factors such as age of onset of loss, whether the loss was sudden or gradual, and communication demands on the patient.
- The impact of hearing disorder on communication also depends on hearing-loss factors, including degree of sensitivity loss, audiometric configuration, type of hearing loss, and degree and nature of speech perception deficits.

Short Answer Questions

1. Type of hearing loss is related to _____ of disorder within the auditory system. Degree of hearing loss is related to the _____ that the disorder is impacting normal function.
2. The two major types of hearing loss include hearing _____ loss and _____ hearing disorders.
3. The time of _____ refers to when a hearing loss first occurs. A _____ hearing loss refers to one that is present at birth, while _____ and _____ hearing losses are obtained after birth.
4. When describing the ear specificity of a hearing loss, a _____ hearing loss, pertaining to one ear only, has _____ impact on communication that a _____ hearing loss, in which both ears are involved.
5. A _____ hearing loss is a reduction of hearing sensitivity due to disorder of outer or middle ear. The functional problem of this type of hearing loss is an _____of sound energy as it travels from outer ear to cochlea. It is demonstrated by the presence of an _____-_____ gap.
6. The _____, or shape, of a hearing loss varies depending on attenuating characteristics of physical obstruction. Disorders adding mass to the system affect _____ frequencies. Disorders affecting stiffness affect _____ frequencies.
7. A _____ hearing loss results from an inner-ear disorder. The configuration of the hearing loss depends on the location along the _____ _____ of hair cell loss or other damage.
8. The outcomes of sensorineural hearing loss can include reduction in _____ of cochlear receptor cells, reduction in _____-resolving capability of the cochlea, and reduction in the _____ _____ of the hearing mechanism.
9. A _____ hearing loss has both _____ and _____ components, whose etiologies may or not be the same.

10. A _____ hearing disorder may be either a _____ hearing disorder, caused by an active, measurable disease process, or an _____ _____ disorder, caused by developmental disorder or delay.
11. Characteristics of auditory processing disorders in children often include: a reduced ability to understand in _____ noise; reduced ability to understand speech of reduced _____; reduced ability to _____ and _____ the source of sound; reduced ability to separate _____ stimuli (different signals presented simultaneously to each ear); and reduced ability to process normal or altered_____ (timing) cues.
12. A _____ hearing loss is an exaggeration of fabrication of a hearing loss. It often co-occurs with an _____ hearing loss of some degree.
13. The time of _____ of a hearing loss has important implications for the impact of the disorder on functioning. Hearing loss can be described relative to the timing of language development. A _____ hearing loss occurs prior to the onset of spoken language development, while a _____ hearing loss occurs following the majority of language acquisition.
14. With a gradual onset of hearing loss, _____ strategies are often developed, which allow the individual to cope with their reduction in ability. Strategies such as _____, where the individual with hearing loss relies on visual cues from the face and lips, and _____ alterations, where the individual manipulates characteristics of the auditory environment or location to facilitate easier listening, are examples of compensation.
15. The _____ of hearing sensitivity loss has implications for communication ability, with greater amounts of loss generally resulting in greater communication difficulty.
16. The _____ of hearing loss describes its shape. A _____ configuration occurs when all thresholds are within 20 dB of each other. In a _____ configuration, the lower frequency thresholds are at least 20 dB poorer than the higher frequencies. Conversely, for a _____

configuration, the higher frequency thresholds are at least 20 dB poorer than the lower frequencies. A _____ hearing loss has a steeply sloping shape with high-frequency thresholds much poorer than low frequency.

17. The prolongation of sound due to reflections of sound from surfaces in a room, known as _____, contributes to decreased ability to perceive speech by adding _____ to the acoustic signal.
18. A _____ hearing loss, which changes over time, commonly occurs with conductive hearing losses, and causes _____ auditory input during speech and language learning.
19. A _____ hearing loss has numerous consequences for hearing including: reduction in cochlear sensitivity; reduction in _____ resolution; and reduction in the _____ range of the hearing mechanism.
20. Consequences of a _____ hearing loss can include severe distortion of incoming auditory signals, _____ (an abnormally slow growth of loudness with increasing intensity), and abnormally excessive auditory _____ (diminished audibility).

Discussion Questions

1. How might the transient nature of conductive losses have implications for the development of auditory and listening skills? How might hearing loss and patient factors contribute to poorer outcomes in these areas?
2. How might the consequences of auditory processing disorders in children make it initially difficult for parents and teachers to distinguish it from other disorders such as attentional disorders, language impairment, and learning disabilities?
3. The primary function of a hearing aid is to make sound louder, to make the auditory signal audible for a person with a hearing impairment. How might the consequences of a sensorineural hearing loss impact on the outcomes of hearing aid use?

4. Discuss the roles of gain and intent in defining the motivation for a functional hearing loss.
5. How might a mild hearing loss result in significant functional impact for an individual?

Resources

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4

CAUSES OF HEARING DISORDER

Learning Objectives

Auditory Pathology

Conductive Hearing Disorders
- Congenital Outer- and Middle-Ear Anomalies
- Impacted Cerumen
- Other Outer-Ear Disorders
- Otitis Media with Effusion (OME)
- Complications of OME
- Otosclerosis
- Other Middle-Ear Disorders

Sensory Hearing Disorders
- Congenital and Inherited Sensory Hearing Disorders
- Acquired Sensory Hearing Disorders

Neural Hearing Disorders
- Auditory Neuropathy
- VIIIth Nerve Tumors and Disorders
- Brainstem Disorders
- Temporal-Lobe Disorders
- Other Nervous System Disorders

Vestibular Disorders
- Benign Paroxysmal Positional Vertigo
- Superior Canal Dehiscence
- Vestibulotoxicity
- Vestibular Neuritis
- Ménière's Disease

Summary

Short Answer Questions

Discussion Questions

Resources
- Articles and Books
- Web Sites

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- Describe the different categories of pathology or influences that can adversely affect the auditory system.
- Identify and describe the various outer-, middle-, and inner-ear anomalies that contribute to hearing loss.
- Identify the various infections, both maternal and acquired, that cause hearing loss.
- Explain the mechanism causing otitis media and describe its effect on hearing.
- Explain how hereditary factors are related to hearing loss, including syndromic and nonsyndromic disorders.
- Describe the effects of ototoxic drugs on acquired and congenital hearing loss.
- Explain how trauma and noise exposure contribute to the occurrence of hearing loss.
- Identify and describe common vestibular disorders.

THERE are a number of causes of hearing disorder, some affecting the growing embryo, some the newborn and young child, others adults and the elderly. Some of the causes affect the outer- or middle-ear conductive mechanisms. Others affect only the sensory system of the cochlea or the auditory nervous system. Still others can affect the entire auditory mechanism. This section provides a brief overview of the various pathologies that can cause auditory disorder.

Toxins are poisonous substances.

Vascular disorders are disorders of blood vessels.

Neoplastic pertains to a mass of newly formed tissue or tumor.

If only one gene of a pair is needed to carry a genetic characteristic or mutation, the gene is **dominant**.

If both genes of a pair are needed to carry a genetic characteristic or mutation, the gene is **recessive**.

Maternal prenatal infections are infections such as rubella that a pregnant mother contracts that can cause abnormalities in her unborn fetus.

Teratogenic drugs are drugs that if ingested by the mother during pregnancy can cause abnormal embryologic development.

AUDITORY PATHOLOGY

There are several major categories of pathology or noxious influences that can adversely affect the auditory system, including developmental defects, infections, **toxins**, noise exposure and trauma, **vascular disorders**, neural disorders, immune-system disorders, bone disorders, aging, and tumors and other **neoplastic** growths.

Potential developmental defects are numerous, and many of them are inherited. Hereditary disorders, both **dominant** and **recessive**, are a significant cause of sensorineural hearing loss. Some inherited disorders result in congenital hearing loss; others result in progressive hearing loss later in life. Other developmental defects result from certain **maternal prenatal infections** such as maternal rubella, or from maternal ingestion of **teratogenic drugs**, such as thalidomide or accutane. A number of other outer-, middle-, and

inner-ear anomalies can occur in isolation during embryologic development or as part of a genetic syndrome.

Infections are a common cause of outer- and middle-ear disorder and, in some cases, can result in sensorineural hearing loss. Bacterial infections of the external ear and tympanic membrane are not uncommon, though usually treatable and of little consequence to hearing. Infections of the middle ear are quite common. Although treatable, chronic middle-ear infections can have a long-lasting impact on hearing ability. Bacterial infections of the brain lining, or **meningitis**, can affect the **cochlear labyrinth**, resulting in severe sensorineural hearing loss. Viral and other infections, resulting in measles, mumps, cytomegalovirus, and syphilis can all result in substantial and permanent sensorineural hearing loss.

Meningitis is a bacterial or viral inflammation of the membranes covering the brain and spinal cord that can cause significant hearing loss.

Cochlear labyrinth is another term for inner ear.

Certain types of bone disorders can affect the auditory system. **Otosclerosis** is a common cause of middle-ear disorder and may also cause sensorineural hearing loss. Other bone defects, both developmental and progressive, can impact on auditory function.

Otosclerosis is a disorder characterized by new bone formation around the stapes and oval window, resulting in stapes fixation and related conductive hearing loss.

Certain drugs and environmental toxins can cause temporary or permanent sensorineural hearing loss. A group of antibiotics known as aminoglycosides are ototoxic, or toxic to the ear. Other drugs including aspirin, quinine, and lasix are associated with ototoxicity. Certain solvents used for industrial purposes and additives used in commercial products can be toxic to the ear of a person exposed to high levels. In addition, certain components of the drugs used in chemotherapy treatment of cancer are ototoxic.

Exposure to excessive levels of sound and other trauma to the auditory system, both physical and acoustic, can cause temporary or permanent damage to hearing. Excessive noise exposure is a common cause of permanent sensorineural hearing loss. Physical trauma can cause tympanic membrane perforation, ossicular disruption, and fracture of the temporal bone. Trauma to the hearing mechanism can also occur because of changes in air pressure that occur when rapidly ascending or descending during diving or flying. Hearing can also be affected by radiation trauma used in the treatment of cancer.

Hearing loss can occur from vascular disorders. Interruption or diminution of blood supply to the cochlea can cause a loss of hair cell function, resulting in permanent sensorineural hearing loss. Causes of blood supply disruption include stroke, **embolism**, other occlusion, or diabetes mellitus.

An **embolism** is an occlusion or obstruction of a blood vessel by a transported clot or other mass.

Immune system disorders have been associated with hearing loss. Hearing disorder due specifically to autoimmune disease has been described. Other hearing disorders that occur secondarily to systemic autoimmunity, such as AIDS, have also been described.

Neural disorders can affect the auditory system. Auditory neuropathy is a hearing disorder that interferes with the synchronous transmission of signals from cochlear hair cells to the VIIIth cranial nerve. Neoplasms, or tumors, can also affect the auditory system. One of the more common neoplasms, the cochleovestibular schwannoma or acoustic tumor, is an important cause of retrocochlear hearing disorder. **Neuritis**, or inflammation of the auditory nerve can cause a temporary or permanent hearing disorder. Other disorders, such as **multiple sclerosis** or **brainstem gliomas**, can also affect hearing function.

Neuritis is inflammation of a nerve with corresponding sensory or motor dysfunction.

Multiple sclerosis (MS) is a demyelinating disease in which plaques form throughout the white matter of the brain, resulting in diffuse neurologic symptoms, including hearing loss and speech recognition deficits.

A **brainstem glioma** is any neoplasm derived from neuroglia (non-neuronal supporting tissues of the nervous system) located in the brainstem.

Other hearing disorders are of unknown origin. Idiopathic endolymphatic hydrops is an excessive collection of endolymph in the cochlea of unknown origin. It is the underlying cause of Ménière's disease and can result in permanent sensorineural hearing loss. Other **idiopathic** disorder, particularly sudden hearing loss, is not an uncommon finding clinically.

When a hearing loss is **idiopathic**, it is of an unknown cause.

CONDUCTIVE HEARING DISORDERS

Disorders of the outer and middle ear are commonly of two types, either structural defects due to embryologic malformations or structural changes secondary to infection or trauma. Another common abnormality, otosclerosis, is a bone disorder.

Congenital Outer- and Middle-Ear Anomalies

Microtia and atresia are **congenital** malformations of the auricle and external auditory canal. *Microtia* is an abnormal smallness of the auricle. It is one of a variety of **auricular** malformations.

Congenital is present at birth.

Auricular pertains to the outer ear or auricle.

Others that fall into the general category of congenital auricular malformations include:

accessory auricle:	an additional auricle or additional auricular tissue
anotia:	congenital absence of an auricle
auricular aplasia:	anotia
cleft pinna:	congenital **fissure** of the auricle
coloboma lobuli:	congenital fissure of the earlobe
macrotia:	congenital excessive enlargement of the auricle
melotia:	congenital displacement of the auricle
low-set ears:	congenitally displaced auricles
polyotia:	presence of an additional auricle on one or both sides
preauricular pits:	small hole of variable depth lying anterior to the auricle
preauricular tags:	small appendage lying anterior to the auricle
scroll ear:	auricular deformity in which the rim is rolled forward and inward

A **fissure** is a narrow slit or opening.

Microtia in isolation may not affect hearing in any substantial way. The auricle serves an important purpose in horizontal sound localization and in providing certain resonance to incoming signals. But the absence of auricles, or the presence of auricles that are deformed, does not in itself create a significant communication disorder for patients. Ears with microtia or other deformities will often be surgically corrected at an early age.

Atresia is the absence of an opening of the external auditory meatus. An ear is said to be atretic if the ear canal is closed at any point. Atresia is a congenital disorder and may involve one or both ears. *Bony atresia* is the congenital absence of the ear canal due to a wall of bone separating the external auditory meatus from the middle ear. *Membranous atresia* is the condition in which a dense soft tissue plug is obstructing the ear canal.

Atresia is the congenital absence or pathologic closure of a normal anatomical opening.

Although atresia can occur in isolation, the underlying embryologic cause of this malformation can also affect surrounding structures. So it is not unusual for atresia to be accompanied by microtia or other auricular deformity. Atresia can also occur with middle-ear malformations, depending on the cause.

Atresia causes a significant conductive hearing loss, which can be as great as 60 dB. An example of an audiogram obtained from an atretic ear is shown in Figure 4-1. The additional bone or membranous plug adds mass and stiffness to the outer ear system, resulting in a relatively flat conductive hearing loss.

Middle-ear anomalies include malformed ossicles (ossicular dysplasia), malformed openings into the cochlea (fenestral malformations), and congenital cholesteatoma. Ossicular dysplasia can result in fixation of the bones, deformity of the bones, and disarticulation of the bones, especially the incus and stapes. In cases of congenital stapes fixation, the stapes footplate is fixed into the bony wall of the cochlea at the oval window. Lack of oval window development is an example of fenestral malformation. Congenital cholesteatoma is a cyst that is present in the middle-ear space at birth.

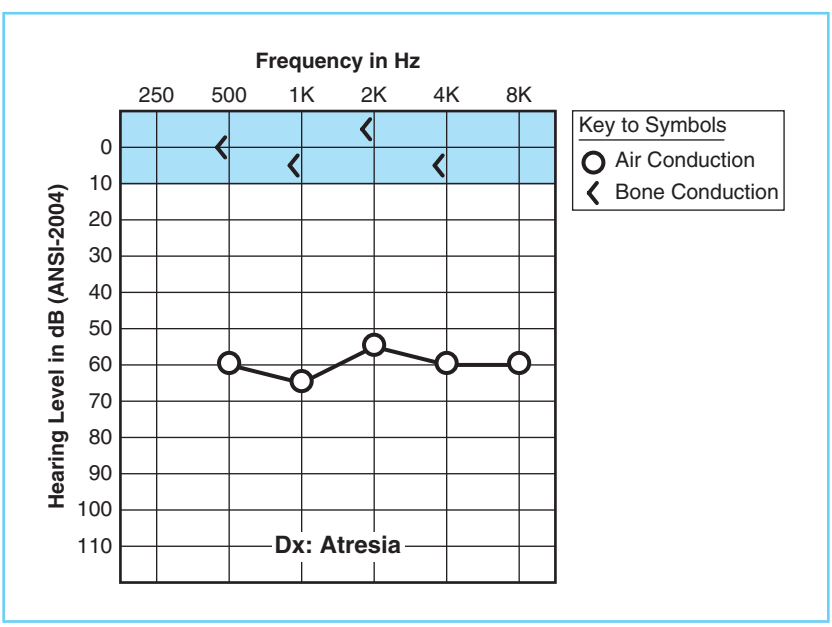


FIGURE 4-1 An audiogram representing the effect of atresia.

There are a number of causes of microtia, atresia, and other malformations of the outer and middle ears. They often occur as part of genetic syndromes, associations, or anomalies that are inherited.

Impacted Cerumen

One common cause of transient hearing disorder is the accumulation and impaction of cerumen in the external auditory canal. As you learned earlier, the ear canal naturally secretes cerumen as a mechanism for protecting the ear canal and tympanic membrane. Cerumen has a natural tendency to migrate out of the ear canal and, with proper aural hygiene, seldom interferes with hearing.

In some individuals, however, cerumen is secreted excessively, a condition known as **ceruminosis**. In these patients, routine ear canal cleaning may be required to forestall the effects of excessive cerumen accumulation.

Ceruminosis is the excessive accumulation of cerumen (wax) in the external auditory meatus (ear canal).

Regardless of whether a patient experiences ceruminosis, occasionally excessive cerumen can accumulate in the ear canal and become impacted. The problem can occur gradually, and the impaction can become fairly significant before a patient will seek treatment.

Figure 4-2 demonstrates the effect of a moderate level of impacted cerumen on hearing sensitivity. Not unlike atresia, the effect is one of both mass and stiffness, resulting in **attenuation** across the frequency range, giving a flat audiogram.

Attenuation means to reduce or decrease in magnitude.

Although impacted cerumen often results in only a mild conductive hearing loss, the loss can have a significant impact on children in a classroom or on patients with preexisting hearing loss.

Sometimes cerumen is pushed down into the ear canal and onto the tympanic membrane without **occluding** the ear canal. This results in an increase in the mass of the tympanic membrane, resulting in a high-frequency conductive hearing loss, as shown in Figure 4-3.

When something is **occluding**, it is blocking or obstructing.

Impacted cerumen is often managed first by a course of eardrops to soften the impaction, followed by irrigation of the ear canal to remove it.

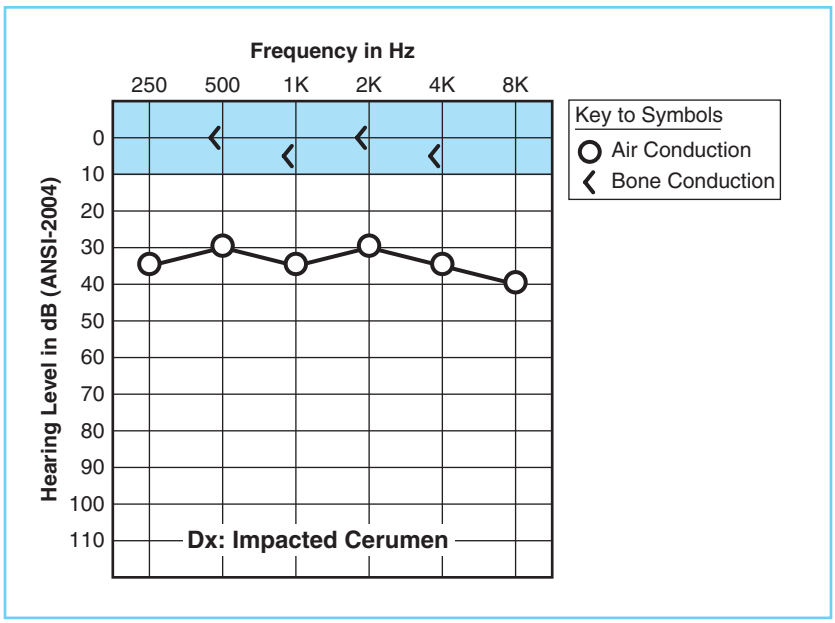


FIGURE 4-2 An audiogram representing the effect of impacted cerumen.

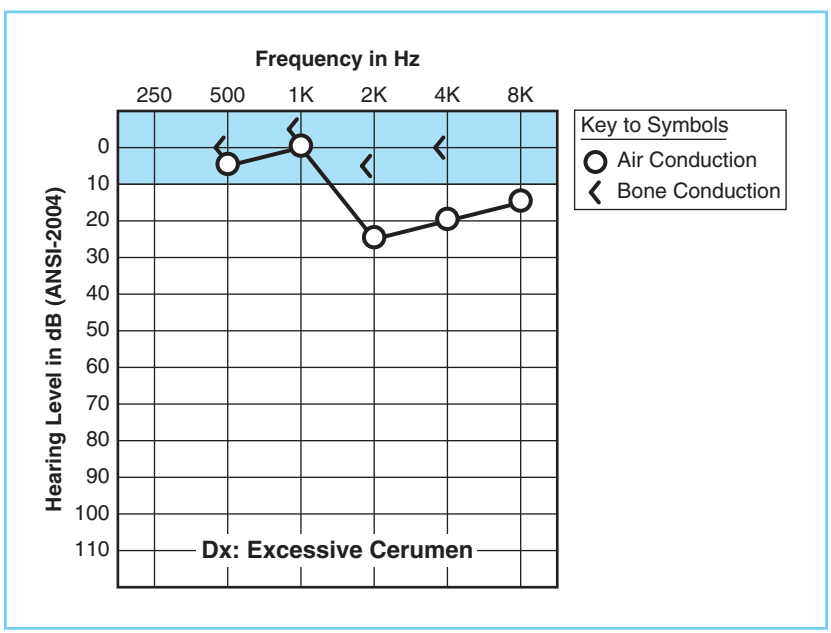


FIGURE 4-3 An audiogram representing the effect of cerumen resting on the tympanic membrane, increasing its mass and resulting in a high-frequency conductive hearing loss.

Other Outer-Ear Disorders

Other disorders of the outer ear are caused by infections, cancer, and other neoplastic growths. In general, outer-ear disorders do not impact hearing ability unless they result in ear canal **stenosis** or blockage.

Stenosis is a narrowing of the diameter of an opening or canal.

Infections of the ear canal or auricle are referred to collectively as **otitis externa**, or inflammation of the external ear. They are often caused by bacterium, virus, or fungus cultivated in the external ear canal. One common type is known as *swimmer's ear*, or acute diffuse **external otitis**, and is characterized by diffuse reddened pustular lesions surrounding hair follicles in the ear canal due to a gram-negative bacterial infection during hot, humid weather and often initiated by swimming.

External otitis is an inflammation of the external auditory meatus, also called **otitis externa**.

Carcinoma of the auricle is not uncommon. **Basal-cell**, **epidermoid**, and **squamous-cell carcinoma** can all occur around the auricle and external auditory meatus. In addition, tumors of various types can proliferate around the external auditory meatus and auricle.

Basal-cell carcinoma is a slow-growing malignant skin cancer that can occur on the auricle and external auditory meatus.

Epidermoid carcinoma is a cancerous tumor of the auricle, external auditory canal, middle ear, and/or mastoid.

Squamous-cell carcinoma is the most common malignant (cancerous) tumor of the auricle.

Otitis Media with Effusion

The most common cause of transient conductive hearing loss in children is *otitis media* with **effusion**. Otitis media is inflammation of the middle ear. It is caused primarily by Eustachian tube dysfunction. When it is accompanied by middle-ear effusion, otitis media often causes conductive hearing loss.

Effusion is the escape of fluid into tissue or a cavity.

Edema = swelling

Recall that the Eustachian tube is a normally closed passageway that permits pressure equalization between the middle ear and the atmosphere. Sometimes the Eustachian tube is restricted from opening by, for example, an upper respiratory infection that causes **edema** of the **mucosa** of the nasopharynx. When this occurs, oxygen that is trapped in the middle-ear space begins to be absorbed by the mucosa of the middle-ear cavity. This creates a relative vacuum in the cavity and results in significant negative pressure in the middle ear. The lining of the middle ear then becomes inflamed. If allowed to persist, the inflamed tissue begins the process of **transudation** of fluid through the mucosal walls into the middle-ear cavity. Once this fluid is sufficient to impede

Mucosa is any epithelial lining of an organ or structure, such as the tympanic cavity, that secretes mucus; also called the mucous membrane.

The passage of a body fluid through a membrane or tissue surface is called **transudation**.

normal movement of the tympanic membrane and ossicles, a conductive hearing loss occurs.

Eustachian tube dysfunction is a common problem in young children. The opening to the Eustachian tube is surrounded by the large adenoid tissue in the nasopharynx. An upper respiratory infection or inflammation causes swelling of this tissue and can block Eustachian tube function. The inflammation can also travel across the mucosal lining of the tube. Children seem to be particularly at risk because their Eustachian tubes are shorter, more horizontal, and more compliant.

There are a number of ways to classify otitis media, including by type, effusion type, and duration. Various descriptions are provided in Table 4-1. *Otitis media without effusion* is just that, inflammation that does not result in exudation of fluid from the mucosa. *Adhesive otitis media* refers to inflammation of the middle ear caused by prolonged Eustachian tube dysfunction, resulting in severe retraction of the tympanic membrane and obliteration of the middle-ear space. *Otitis media with effusion* has already been described, although there are a number of types of effusion.

Serous effusion is a common form of effusion and is characterized as thin, watery, sterile fluid. *Purulent* effusion contains pus. *Suppurative* is a synonym of purulent. *Nonsuppurative* refers to serous fluid or mucoid fluid. *Mucoid* refers to fluid that is thick, viscid, and mucuslike. *Sanguineous* fluid contains blood.

Otitis media is also classified by its duration. The following may be used as a general guideline. *Acute* otitis media is a single bout lasting fewer than 21 days. *Chronic* otitis media refers to that which persists beyond 8 weeks or results in permanent damage to the middle-ear mechanism. *Subacute* refers to an episode of otitis media that lasts from 22 days to 8 weeks. Otitis media is considered *unresponsive* if it fails to resolve after 48 hours of antibiotic therapy, and *persistent* if it fails to resolve after 6 weeks. *Recurrent* otitis media is often defined as three or more acute episodes within a 6-month period. Finally, someone is said to be *otitis prone* if otitis media occurs before the age of 1 year or if six bouts occur before the age of 6 years.

76 to 95% of all children have one episode of **otitis media** by 6 years of age.

Otitis media is a common middle-ear disorder in children. Estimates are that from **76 to 95% of all children** have one episode

TABLE 4-1 | Various descriptions of otitis media, based on type, effusion type, and duration

Description	Definition
otitis media	inflammation of the middle ear, resulting predominantly from Eustachian tube dysfunction
otitis media, acute	inflammation of the middle ear having a duration of fewer than 21 days
otitis media, acute serous	acute inflammation of middle-ear mucosa with serous effusion
otitis media, acute suppurative	acute inflammation of the middle ear with infected effusion containing pus
otitis media, adhesive	inflammation of the middle ear caused by prolonged Eustachian tube dysfunction resulting in severe retraction of the tympanic membrane and obliteration of the middle-ear space
otitis media, chronic	persistent inflammation of the middle ear having a duration of greater than 8 weeks
otitis media, chronic adhesive	longstanding inflammation of the middle ear caused by prolonged Eustachian tube dysfunction resulting in severe retraction of the tympanic membrane and obliteration of the middle-ear space
otitis media, chronic suppurative	persistent inflammation of the middle ear with infected effusion containing pus
otitis media, mucoid	inflammation of the middle ear, with mucoid effusion
otitis media, mucosanguinous	inflammation of the middle ear with effusion consisting of blood and mucus
otitis media, necrotizing	persistent inflammation of the middle ear that results in tissue necrosis
otitis media, nonsuppurative	inflammation of the middle ear with effusion that is not infected, including serous and mucoid otitis media
otitis media, persistent	middle-ear inflammation with effusion for 6 weeks or longer following initiation of antibiotic therapy
otitis media, purulent	inflammation of the middle ear with infected effusion containing pus; synonym: suppurative otitis media
otitis media, recurrent	middle-ear inflammation that occurs 3 or more times in a 6-month period
otitis media, secretory	otitis media with effusion, usually referring to serous or mucoid effusion
otitis media, serous	Inflammation of middle-ear mucosa, with serous effusion
otitis media, subacute	inflammation of the middle ear ranging in duration from 22 days to 8 weeks

continues

Table 4-1 *continued*

otitis media, suppurative	inflammation of the middle ear with infected effusion containing pus
otitis media, unresponsive	middle-ear inflammation that persists after 48 hours of initial antibiotic therapy, occurring more frequently in children with recurrent otitis media
otitis media with effusion	inflammation of the middle ear with an accumulation of fluid of varying viscosity in the middle-ear cavity and other pneumatized spaces of the temporal bone; synonym: seromucinous otitis media
otitis media without effusion	inflammation of the middle ear

of **otitis media** by 6 years of age. The prevalence of otitis media is highest during the first 2 years and declines with age. Approximately 50% of those children who have otitis media before the age of 1 year will have 6 or more bouts within the ensuing 2 years. Otitis media is more common in males, and its highest occurrence is during the winter and spring months. Certain groups appear to be more at risk for otitis media than others, including children with cleft palate or other craniofacial anomalies, children with Down syndrome, children with learning disabilities, Native populations, children who live in the inner city, those who attend day-care centers, and those who are passively exposed to cigarette smoking.

One of the consequences of otitis media with effusion is conductive hearing loss. An illustrative example of an audiogram is shown in Figure 4-4. The degree and configuration of the loss depends on the amount and type of fluid and its influence on functioning of the tympanic membrane and ossicles. This hearing loss is transient and resolves along with the otitis media. In cases of chronic otitis media, damage to the middle-ear structures can occur, resulting in more permanent conductive and/or sensorineural hearing loss.

Recurrent or chronic otitis media can also have a far reaching impact on communication ability. For example, in studies of children with auditory processing disorders or children with learning disabilities, there is evidence of a higher prevalence of chronic otitis media. It appears likely that children who have **aperiodic** disruption in auditory input during the critical period

Aperiodic means occurring at irregular intervals.

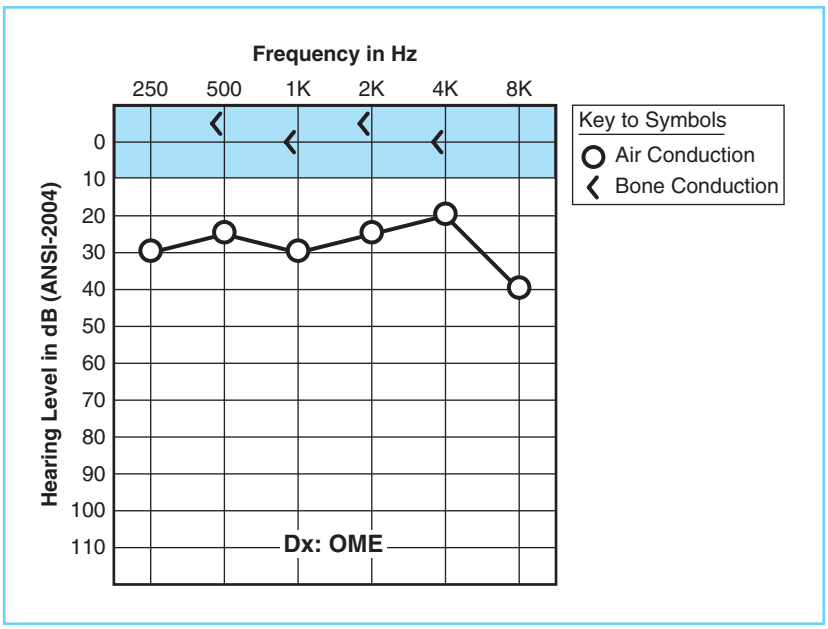


FIGURE 4-4 An audiogram representing the effects of otitis media with effusion.

for auditory development may be at risk for developing auditory processing disorder or language and psychoeducational delays.

Otitis media is usually treated with antibiotic therapy If it is unresponsive to such treatment, then surgical **myringotomy** and **pressure-equalization tube** placement is a likely course of action. In myringotomy, an incision is made in the tympanic membrane and the effusion is removed by suctioning. A tube is then placed through the opening to serve as a temporary replacement of the Eustachian tube in its role as middle-ear pressure equalizer.

Myringotomy involves an incision through the tympanic membrane to remove fluid from the middle ear.

PE tube, or pressure equalization tube, is a small tube inserted in the tympanic membrane following myringotomy to provide equalization of air pressure within the middle-ear space as a substitute for a non-functional Eustachian tube.

Complications of OME

Tympanic-Membrane Perforation

Perforation of the tympanic membrane is a common complication of middle-ear infection. Sometimes, in the later stages of an acute attack of otitis media, the fluid trapped in the middle-ear space is so excessive that the membrane ruptures to relieve the pressure. In other cases, chronic middle-ear infections erode portions of the tympanic membrane, weakening it to the point that a perforation forms.

The tympanic membrane can also be perforated by trauma. *Traumatic perforation* can occur when a foreign object is placed into the ear canal in an unwise effort to remove cerumen. It can also occur with a substantial blow to the side of the head.

The **pars tensa** is the larger and stiffer portion of the tympanic membrane.

The **pars flaccida** is the smaller and more compliant portion of the tympanic membrane, located superiorly.

Perforations of the tympanic membrane are of three types, defined by location. A *central perforation* is one of the **pars tensa** portion of the tympanic membrane, with a rim of the membrane remaining at all borders. An *attic perforation* is one of the **pars flaccida** portion. A *marginal perforation* is one located at the edge or the margin of the membrane.

A perforation in the tympanic membrane may or may not result in hearing loss, depending on its location and size. In general, if a perforation causes a hearing loss, it will be a mild, conductive hearing loss. An example of an audiogram from an ear with a perforation is shown in Figure 4-5.

Regardless of type, most perforations heal spontaneously. Those that do not are usually too large or are sustained by recurrent

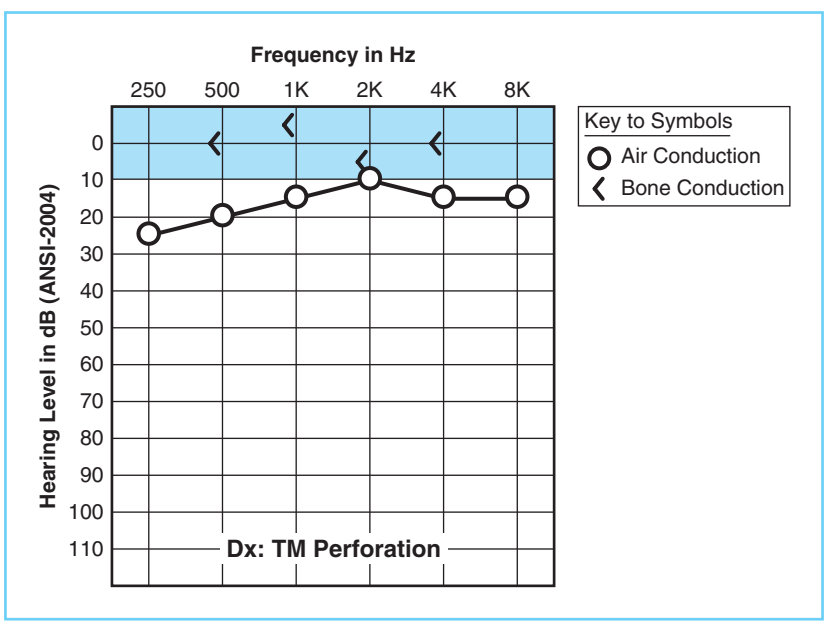


FIGURE 4-5 An audiogram representing the effects of a tympanic membrane perforation.

infection. In such cases, surgery may be necessary to repair or replace the membrane.

Cholesteatoma

Following chronic otitis media, a common pathologic occurrence is the formation of a *cholesteatoma*. A cholesteatoma is an **epithelial** pocket that forms, usually in the **epitympanum**. Typically, a weakened portion of the tympanic membrane becomes retracted into the middle-ear space. The outer layer of the membrane then sheds the cells naturally, and they become entrapped in the pocket formed by the retraction, resulting in growth of the cholesteatoma. As the cholesteatoma grows, it can begin to erode adjacent structures with which it has contact. The result can be substantial erosion of the ossicles and even invasion of the bony labyrinth.

Epithelial pertains to cell layer covering skin.

The attic of the middle-ear cavity is called the **epitympanum**.

Depending on the location of cholesteatoma growth, the magnitude of conductive hearing loss can vary from nonexistent to substantial. Typically, the cholesteatoma will impede the ossicles, resulting in a significant conductive hearing loss. An illustrative example of a hearing loss caused by cholesteatoma is shown in Figure 4-6.

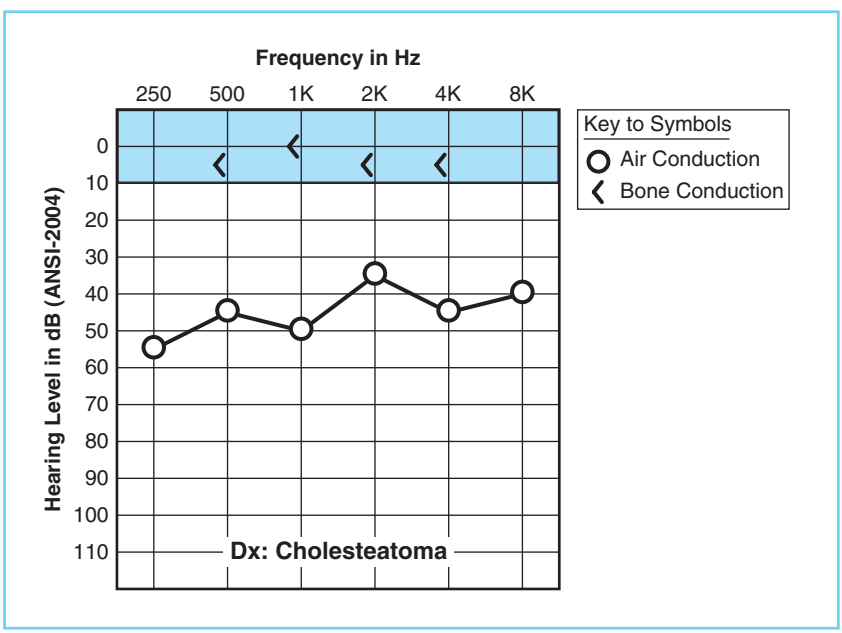


FIGURE 4-6 An audiogram representing the effects of cholesteatoma.

Cholesteatoma, once detected, is removed surgically, with or without ossicular replacement, depending on the disease process.

Tympanosclerosis

Another consequence of chronic otitis media, is tympanosclerosis. *Tympanosclerosis* is the formation of whitish plaques on the tympanic membrane, with **nodular** deposits in the mucosal lining of the middle ear. These plaques can cause an increased stiffening of the tympanic membrane and ossicles and even fixation of the ossicular chain in rare cases. Conductive hearing loss can occur, depending on the severity and location of the deposits.

Nodular means a small knot or rounded lump.

Otosclerosis

Otosclerosis is a disorder of bone growth that affects the stapes and the bony labyrinth of the cochlea. The disease process is characterized by resorption of bone and new spongy formation around the stapes and oval window. Gradually the stapes becomes fixed within the oval window, resulting in conductive hearing loss.

Otosclerosis is a common cause of middle-ear disorder. A family history of the disease occurs in over half of the cases. Women are more likely to be diagnosed with otosclerosis than men, and its onset can be related to pregnancy.

When a disorder involves both ears, it is **bilateral**.

Otosclerosis usually occurs **bilaterally**, although the time course of its effect on hearing may differ between ears. The primary symptom of otosclerosis is hearing loss and the degree of loss appears to be directly related to the amount of fixation.

An audiogram characteristic of otosclerosis is shown in Figure 4-7. The degree of the conductive hearing loss varies with the progression of fixation, but the configuration of the bone-conduction thresholds is almost a signature of the disease. Note that the bone-conduction threshold dips slightly at 2000 Hz, reflecting the elimination of factors that normally contribute to bone-conducted hearing due to the fixation of the stapes into the wall of the cochlea. This 2000 Hz notch is often referred to as "Carhart's notch," named after Raymond Carhart who first described this characteristic pattern.

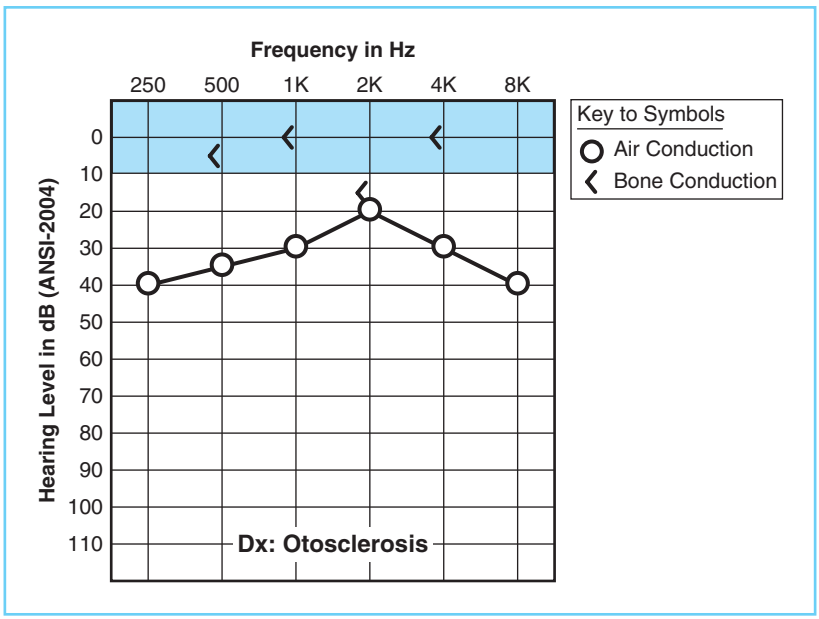


FIGURE 4-7 An audiogram representing the effects of otosclerosis.

Otosclerosis is usually treated surgically. The surgical process frees the stapes and replaces it with some form of prosthesis to allow the ossicular chain to function adequately again.

Other Middle-Ear Disorders

Physical *trauma* can cause middle-ear disorder. One consequence of trauma is a partial or total disarticulation of the ossicular chain. *Ossicular discontinuities* include partial fracture of the incus with separation of the **incudostapedial joint**, complete fracture of the incus, fracture of the crura of the stapes, and fracture of the malleus. Any of these types of ossicular disruptions can result in substantial conductive hearing loss. An example of an audiogram from an ear with a disarticulated ossicular chain is shown in Figure 4-8. A complete disarticulation terminates the impedance-matching capabilities of the middle ear by eliminating the stiffness component. In addition, the remaining unattached ossicles add mass to the system, resulting in a maximum, flat conductive hearing loss.

The point of articulation of the incus and stapes is called the **incudostapedial joint**.

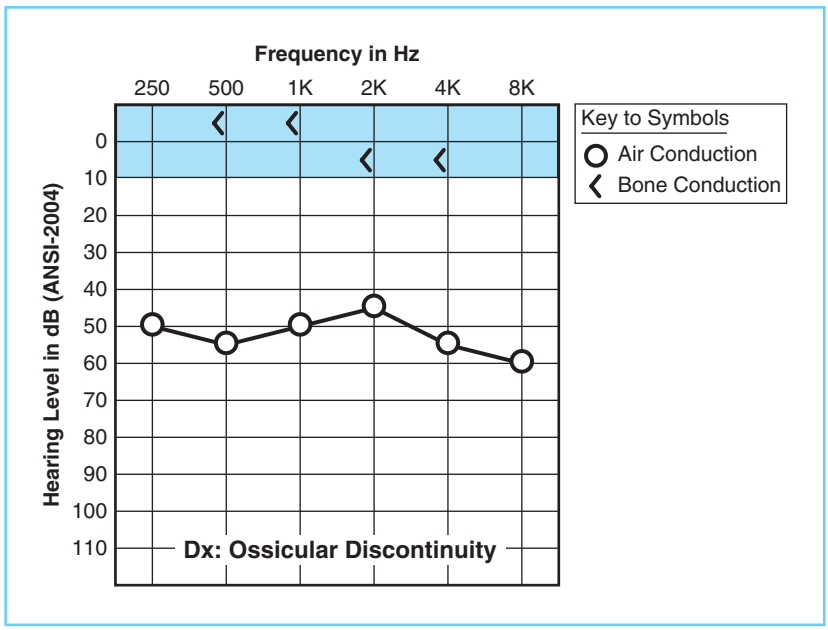


FIGURE 4-8 An audiogram representing the effects of a disarticulated ossicular chain.

Barotrauma is a traumatic injury caused by a rapid marked change in atmospheric pressure resulting in a significant mismatch in air pressure in the air-filled spaces of the body.

Another form of insult to the middle ear results from **barotrauma**, or trauma related to a sudden, marked change in atmospheric pressure. This often occurs when an airplane descends from altitude too fast without proper airplane cabin pressure equalization or when a diver ascends too rapidly in the water. It can also occur under more normal ascending and descending conditions if a person's Eustachian tube is not providing adequate pressure equalization. Under both circumstances, a severe negative air pressure is created in the middle-ear space due to failure of the Eustachian tube to open adequately. If air pressure changes are sudden and intense, the tympanic membrane may rupture. If not, it is stretched medially, followed by increased blood flow, swelling, and bruising of the mucosal lining of the middle ear. Effusion then forms within the middle ear from the traumatized tissue.

Glomus tumors are small neoplasms of paraganglionic tissue with a rich vascular supply located near or within the jugular bulb.

Vascular pertains to blood vessels.

Tumors may also occur within the middle ear. One neoplasm commonly found in the middle ear is a **glomus tumor**, or *glomus tympanicum*. A glomus tumor is a mass of cells with a rich **vascular** supply. It arises from the middle ear and can result in significant

conductive hearing loss. One distinctive symptom of this tumor is that it often causes **pulsatile tinnitus**. An untreated glomus tumor can encroach on the cochlea, resulting in mixed hearing loss.

Pulsatile tinnitus is the perception of a pulsing sound in the ear that results from vascular abnormalities.

SENSORY HEARING DISORDERS

Sensory hearing disorders result from impaired cochlear function. *Congenital* disorders are present at birth and result from structural and functional defects of the cochlea, secondary to embryologic malformation. Congenital disorders are a common form of sensorineural hearing loss in infancy. *Inherited* hearing disorders can be present at birth or can manifest in adulthood. *Acquired* sensory auditory disorders occur later in life and are caused by excessive noise exposure, trauma, infections, ototoxicity, endolymphatic hydrops, presbyacusis, and other influences.

Congenital and Inherited Sensory Hearing Disorders

Congenital sensory hearing disorders are present at birth. There are a number of causes, both exogenous and endogenous, of congenital disorders. *Exogenous* conditions are those that are not necessarily intrinsic to the genetic makeup of an individual. The teratogenic effects on the developing infant of certain maternal infections or drug ingestion are examples. *Endogenous* conditions are those that are inherited. The actual change in cochlear structure or function may be identical, whether the cause is exogenous or endogenous. In this section, we will first review the actual anomalies of the inner ear, followed by a summary of teratogenic causes. Endogenous causes are separated into two categories, those inherited disorders that occur in syndromes and those inherited disorders that appear as hearing loss alone.

Inner-Ear Anomalies

Inner-ear malformations occur when development of the membranous and/or bony labyrinth is arrested during fetal development. Although in many cases the arrest of development is due to genetic cause, some cases are the result of teratogenic influences during pregnancy, including viral infections such as rubella, drugs such as thalidomide, and fetal radiation exposure. Inner-ear malformations can be divided into those in which both the

osseous and membranous labyrinths are abnormal and those in which only the membranous labyrinth is abnormal. Anomalies of the bony labyrinth are better understood because they can be readily identified with scanning techniques.

Malformations of both membranous and osseous labyrinths are:

- complete labyrinthine aplasia (Michel deformity),
- common cavity defect,
- cochlear aplasia and hyopaplasia, and
- Mondini defect.

Michel deformity is a very rare malformation characterized by complete absence of membranous and osseous inner-ear structures, resulting in total deafness. The common-cavity malformation is one in which the cochlea is not differentiated from the vestibule, usually resulting in substantial hearing loss. Cochlear aplasia is a rare malformation consisting of complete absence of the membranous and osseous cochlea, with no auditory function, but presence of semicircular canals and vestibule. Cochlear hypoplasia is a malformation in which less that one full turn of the cochlea is developed. Mondini malformation, an incomplete partition of the cochlea, is a relatively common inner-ear malformation, in which the cochlea contains only about 1.5 turns, and the osseous spiral lamina is partially or completely absent. The resulting hearing loss is highly variable.

Other abnormalities of both the osseous and membranous labyrinth include anomalies of the semicircular canals, the internal auditory canal, and the cochlear and vestibular aqueducts. One example of the latter is large vestibular aqueduct syndrome, a malformation of the temporal bone that is associated with early onset hearing loss and vestibular disorders. Hearing loss is usually progressive, profound, and bilateral. Large vestibular aqueduct syndrome is often associated with Mondini malformation.

Malformations limited to the membranous labyrinth are:

- complete membranous labyrinth dysplasia (Bing Siebenmann),
- cochleosaccular dysplasia (Scheibe), and
- cochlear basal turn dysplasia (Alexander).

The Bing Siebenmann malformation is a rare malformation resulting in complete lack of development of the membranous labyrinth. Scheibe aplasia, or cochleosaccular dysplasia, is a common inner-ear abnormality in which there is failure of the organ of Corti to fully develop. Alexander aplasia is an abnormal development of the basal turn of the cochlea, with normal development in the remainder of the cochlea, resulting in low-frequency residual hearing.

Teratogenic Factors

Sensorineural hearing loss can result from teratogenic effects of congenital infections on a mother during embryologic development of a fetus.

Congenital infections most commonly associated with sensorineural hearing loss include:

- **cytomegalovirus** (CMV),
- human immunodeficiency virus (HIV),
- rubella,
- syphilis, and
- toxoplasmosis.

Cytomegalovirus (CMV) is a viral infection usually transmitted in utero, which can cause central nervous system disorder, including brain damage, hearing loss, vision loss, and seizures.

CMV is the leading cause of nongenetic congenital hearing loss in infants and young children. CMV is a type of herpes virus that can be transmitted in utero. Infants with congenital CMV infections are most often asymptomatic at birth. In those who develop hearing loss, the loss is usually of delayed onset, often **asymmetric**, progressive, and sensorineural. Other complications can include neurodevelopmental deficits, including **microcephaly** and mental retardation.

If a person has a moderate hearing loss in one ear and a severe hearing loss in the other, the hearing is **asymmetric**. If the degree of hearing loss is the same in both ears it is considered symmetric.

Microcephaly is an abnormal smallness of the head.

HIV is the virus that causes *acquired immunodeficiency syndrome* (AIDS). Congenital HIV infections are increasingly common and can result in substantial neurodevelopmental deficits. Hearing is at risk mostly from opportunistic infections such as meningitis that are secondary to the disease or from ototoxic drugs used to treat the infections.

Rubella, or German **measles**, is a viral infection. Prior to vaccination against the disease, congenital infections resulted in tens of thousands of children born with congenital rubella syndrome,

Measles is a highly contagious viral infection, characterized by fever, cough, conjunctivitis, and a rash, which can cause significant hearing loss.

with characteristic features including cardiac defects, congenital cataracts, and sensorineural hearing loss. In the 1960s and 1970s, it was the leading nongenetic cause of hearing loss. In countries where vaccinations are routine, rubella has been nearly eliminated as a causative factor.

A **spirochete** is a slender, spiral, motile microorganism that can cause infection.

Syphilis is a venereal disease, caused by the **spirochete** Treponema pallidum, that can be transmitted from an infected mother to the fetus. Although most children with congenital syphilis will be asymptomatic at birth, a late form of the disease, occurring after 2 years of age, can result in progressive sensorineural hearing loss.

Toxoplasmosis is caused by a parasite infection, contracted mainly through contaminated food or close contact with domestic animals carrying the infection. Congenital toxoplasmosis can result in retinal disease, **hydrocephalus**, mental retardation, and sensorineural hearing loss.

Hydrocephalus is the excessive accumulation of cerebrospinal fluid in the subarachnoid or subdural space of the brain.

In addition to infections, some drugs have a teratogenic effect on the auditory system of the developing embryo when taken by the mother during pregnancy. Ingestion of these drugs, especially early in pregnancy, can result in multiple developmental abnormalities, including profound sensorineural hearing loss. These drugs include **accutane**, dilantin, quinine, and **thalidomide**.

Accutane is a retinoic acid drug prescribed for cystic acne that can have a teratogenic effect on the auditory system of the developing embryo.

Thalidomide is a tranquilizing drug that can have a teratogenic effect on the auditory system of the developing embryo.

Syndromic Hereditary Hearing Disorder

Hereditary factors are common causes of sensorineural hearing loss. Hearing loss of this nature is one of two types. *Syndromic hearing disorder* occurs as part of a constellation of other medical and physical disorders that occur together commonly enough to constitute a distinct clinical entity. *Nonsyndromic hearing disorder* is an autosomal recessive or dominant genetic condition in which there is no other significant feature besides hearing loss.

Genetic inheritance is either related to non-sex-linked (autosomal) chromosomes or is linked to the X-chromosome. In *autosomal dominant* inheritance, only one gene of a pair must carry a genetic characteristic or mutation in order for it to be expressed; in *autosomal recessive* inheritance, both genes of a pair must share the characteristic. *X-linked hearing disorder* is a

genetic condition that occurs due to a faulty gene located on the X chromosome.

Some of the more common *syndromic disorders* that can result in congenital hearing loss in children are:

- *Alport syndrome*: genetic syndrome characterized by progressive kidney disease and sensorineural hearing loss, probably resulting from X-linked inheritance through a gene that codes for **collagen**;
- *Branchio-oto-renal syndrome*: autosomal dominant disorder consisting of **branchial clefts**, **fistulas**, and cysts, **renal** malformation, and conductive, sensorineural, or mixed hearing loss;
- *Cervico-oculo-acoustic syndrome*: congenital branchial arch syndrome, occurring primarily in females, characterized by fusion of two or more cervical vertebrae, with retraction of eyeballs, lateral gaze weakness, and hearing loss;
- *CHARGE association*: genetic association featuring **coloboma**, *h*eart disease, *a*tresia choanae (nasal cavity), *r*etarded growth and development, *g*enital **hypoplasia**, and *e*ar anomalies and/or hearing loss that can be conductive, sensorineural, or mixed;
- *Jervell and Lange-Nielsen syndrome*: autosomal recessive cardiovascular disorder accompanied by congenital bilateral profound sensorineural hearing loss;
- *Pendred syndrome*: autosomal recessive endocrine metabolism disorder resulting in goiter and congenital, symmetric, moderate-to-profound sensorineural hearing loss;
- *Usher syndrome*: autosomal recessive disorder characterized by congenital sensorineural hearing loss and progressive loss of vision due to **retinitis pigmentosa**;
- *Waardenburg syndrome*: autosomal dominant disorder characterized by lateral displacement of the medial canthi, increased width of the root of the nose, multicolored iris, white forelock, and mild-to-severe sensorineural hearing loss.

Although these syndromes are commonly associated with hearing loss, there are over 400 syndromes identified that claim auditory disorder as a component.

Collagen is the main protein of connective tissue, cartilage, and bone, the age-related loss of which can reduce auricular cartilage strength and result in collapsed ear canals.

Branchial clefts are a series of openings between the embryonic branchial arches. Branchial arches are a series of five pairs of arched structures in the embryo that play an important role in the formation of head and neck structures.

An abnormal passage or hole formed within the body by disease, surgery, injury, or other defect is called a **fistula**.

Renal pertains to the kidneys.

A **coloboma** is a congenital fissure (cleft or slit).

Hypoplasia is the incomplete development or underdevelopment of tissue or an organ.

Retinitis pigmentosa is a chronic progressive disease characterized by retinal-tissue degeneration and optic-nerve atrophy.

Nonsyndromic Hereditary Hearing Disorder

Approximately 30 percent of hereditary hearing disorders occur as part of a syndrome; the other 70 percent are nonsyndromic. In fact, nonsyndromic hereditary hearing loss is a primary cause of sensorineural hearing loss in infants and young children and probably contributes substantially to much of the acquired hearing loss in aging patients.

The genetic basis for nonsyndromic sensorineural hearing loss is becoming increasingly well understood. A number of genes have been identified as being associated with hearing loss. Despite sizeable genetic heterogeneity, however, one gene locus, known as GJB2 or connexin 26, has been implicated in up to half of prelinguistic, nonsyndromic sensorineural hearing loss.

Hereditary hearing disorder may be present at birth, or it may have a delayed onset and be progressive in nature. The majority of nonsyndromic hereditary hearing disorders are autosomal recessive, and the hearing loss is predominantly sensorineural in nature. An example of a hereditary hearing loss is shown in Figure 4-9.

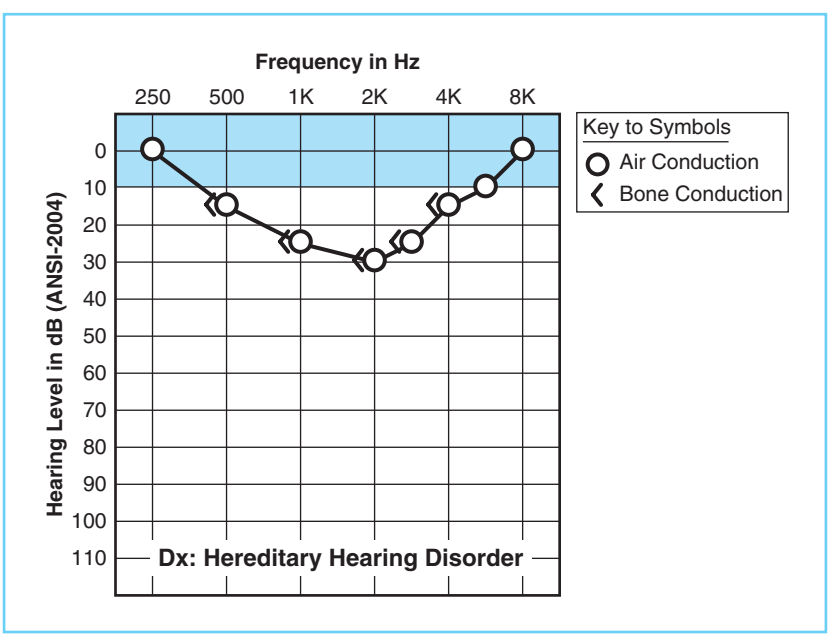


FIGURE 4-9 An audiogram representing congenital sensorineural hearing loss.

Although not all hereditary hearing losses have this classic configuration, when this pattern is encountered in the clinic it can most often be attributable to a congenital loss of genetic origin.

Nonsyndromic hearing disorders can be classified in a number of ways. Following are general patterns of hereditary hearing loss:

- *Dominant hereditary hearing loss*: hearing loss due to transmission of a genetic characteristic or mutation in which only one gene of a pair must carry the characteristic in order to be expressed, and both sexes have an equal chance of being affected;
- *Dominant progressive hearing loss*: genetic condition in which sensorineural hearing loss gradually worsens over a period of years, caused by dominant inheritance;
- *Progressive adult-onset hearing loss*: autosomal recessive nonsyndromic hearing loss with onset in adulthood, characterized by progressive, symmetric sensorineural hearing loss;
- *Recessive hereditary sensorineural hearing loss*: most common inherited hearing loss, in which both parents are carriers of the gene but only 25% of offspring are affected, occurring in either nonsyndromic or syndromic form;
- *X-linked hearing disorder*: hereditary hearing disorder due to a faulty gene located on the X chromosome, such as that found in Alport syndrome.

Acquired Sensory Hearing Disorders

Perinatal Factors

Infants who have a traumatic perinatal period are at a significant risk for hearing loss. The underlying cause of the hearing loss may be unknown, but hearing loss has been associated with a history of low birth weight, hypoxia, hyperbilirubinemia, and exposure to potentially ototoxic drugs. Indeed, mere length-of-stay in the intensive care nursery (ICN), with all the various potential adverse influences on the auditory system, has been associated with increased risk for hearing loss. Of all factors, one that has been clearly linked to hearing loss is severe respiratory distress at birth.

Persistent pulmonary hypertension of the newborn (PPHN) is a condition in which an infant's blood flow bypasses the lungs,

thereby eliminating oxygen supply to the organs of the body. PPHN is associated with perinatal respiratory problems such as meconium aspiration or pneumonia. Sensorineural hearing loss is a common complication of PPHN and has been found in approximately one third of surviving children. Hearing losses range from high-frequency unilateral loss to severe-to-profound bilateral loss and are progressive in many cases.

PPHN is treated by administration of oxygen or oxygen and nitric oxide via a mechanical ventilator. Extracorporeal membrane oxygenation (ECMO) is a treatment for PPHN that involves diverting blood from the heart and lungs to an external bypass where oxygen and carbon dioxide are exchanged before the blood is reintroduced to the body. When ECMO is applied as part of respiratory management, it has been associated with hearing loss in up to 75% of cases. Hearing loss is often progressive.

Noise-induced Hearing Loss

Noise-induced hearing loss (NIHL) is the most common cause of acquired sensorineural hearing loss other than presbyacusis. NIHL can be temporary or permanent. Exposure to excessive sound results in a change in the threshold of hearing sensitivity or a threshold shift. If a noise-induced hearing loss is temporary, it is referred to as a *temporary threshold shift* or TTS. If the hearing loss is permanent, it is called a *permanent threshold shift* or PTS.

You have probably experienced TTS. It is a common occurrence following exposure to loud music at a concert or following exposure to nearby firing of a gun or explosion of fireworks. The experience is usually one of sound seeming to be muffled, often accompanied by tinnitus. If you listen to your radio or MP3 player while you have TTS, you may notice that it just does not sound right.

If the loud sounds to which you were exposed were not of sufficient intensity, or the duration of your exposure was not excessive, your hearing loss will be temporary, and hearing sensitivity will return to normal over time. However, if the signal intensity and the duration of exposure were of a sufficient magnitude, your hearing loss will be permanent. Repeated exposure will result in a progression of the hearing loss.

PTS is typically a gradual hearing loss that occurs from repeated exposure to excessive sound. It occurs as a result of outer hair cell loss in the cochlea due to metabolic changes from repeated exhaustion of the cells. PTS caused by acoustic trauma from a single exposure results from mechanical destruction of the organ of Corti by excessive pressure waves.

There are several important acoustic factors that make sound potentially damaging to the cochlea:

- the intensity of the sound,
- the frequency composition of the sound, and
- the duration of exposure to the sound.

In general, higher frequency sounds are more damaging than lower frequency sounds. Whether or not a particular intensity of sound is damaging to an ear depends on the duration of exposure to that sound. For example, a **broad-spectrum noise** with an intensity of 100 **dBA** is not necessarily dangerous if the duration of exposure is below 2 hours per day. However, exposure duration of greater than that can result in permanent damage to the ear.

Broad-spectrum noise is a noise comprised of a broad band of frequencies.

dBA is decibels expressed in sound pressure level as measured on the A-weighted scale of a sound level meter filtering network.

Damage-risk criteria have been established as guidelines for this tradeoff between exposure duration and signal intensity. An example of commonly accepted damage risk criteria for industry is shown in Table 4-2. Exposure above these levels over prolonged periods in the workplace will most likely result in significant PTS. Exposure to sound below these levels is considered safe by these standards.

Other factors also influence the risk of permanent noise-induced hearing loss. For example, some individuals are more susceptible than others, so that safe damage risk criteria for the population in general will not be safe levels for some individuals who are unusually susceptible. Also, the damaging effects of a given noise can be exacerbated by simultaneous exposure to certain ototoxic drugs and industrial chemicals.

The most common type of permanent hearing loss from noise exposure is a slowly progressive high-frequency hearing loss that occurs from repeated exposure over time. An example of a noise-induced hearing loss is shown in Figure 4-10. Typically, with TTS

TABLE 4-2 Damage-risk criteria expressed as the maximum permissible noise exposure for a given duration during a workday. Sound level is expressed in dBA, a weighted decibel scale that reduces lower frequencies from the overall decibel measurement

Duration per Day (in hours)	Sound Level (in dBA)
8.0	90
6.0	92
4.0	95
3.0	97
2.0	100
1.5	102
1.0	105
0.5	110
0.25	115

Note: Criteria based on the U.S. Occupational Safety and Health Act 1983 regulations.

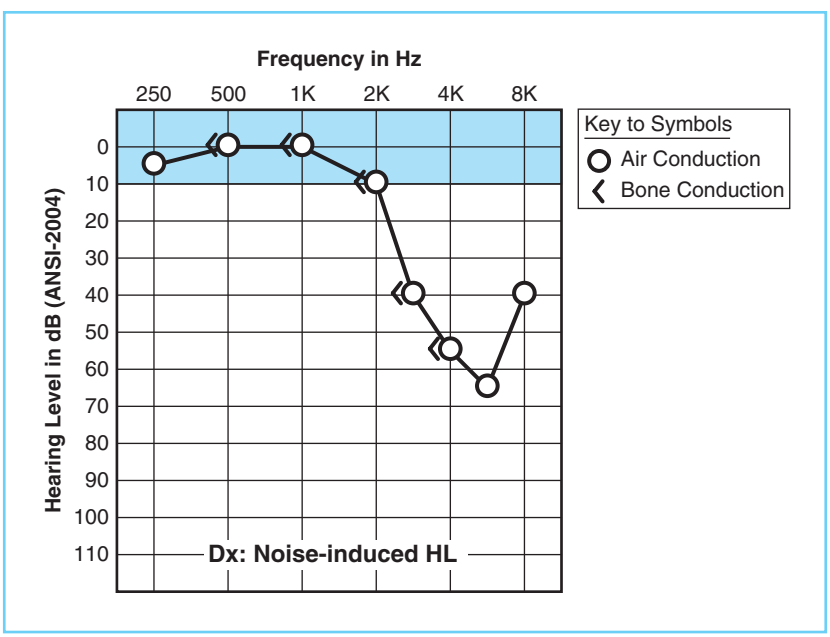


FIGURE 4-10 An audiogram representing the effects of excessive noise exposure.

or with PTS in its early form, the configuration will have a notch that peaks in the 4000 to 6000 Hz region of the audiogram. This is sometimes referred to as a *noise notch* or a *4K notch*, consistent with exposure to excessive noise. As additional exposure occurs, the threshold in this region will worsen, followed by a shift in threshold at progressively lower frequencies. Figure 4-11 shows the progression of hearing loss from industrial noise exposure over a period of four decades.

Hearing loss that occurs from acoustic trauma as a result of a single exposure to excessive sound may resemble the noise-induced hearing loss from prolonged exposure, or it may result in a flatter audiometric configuration. The audiogram shown in Figure 4-12

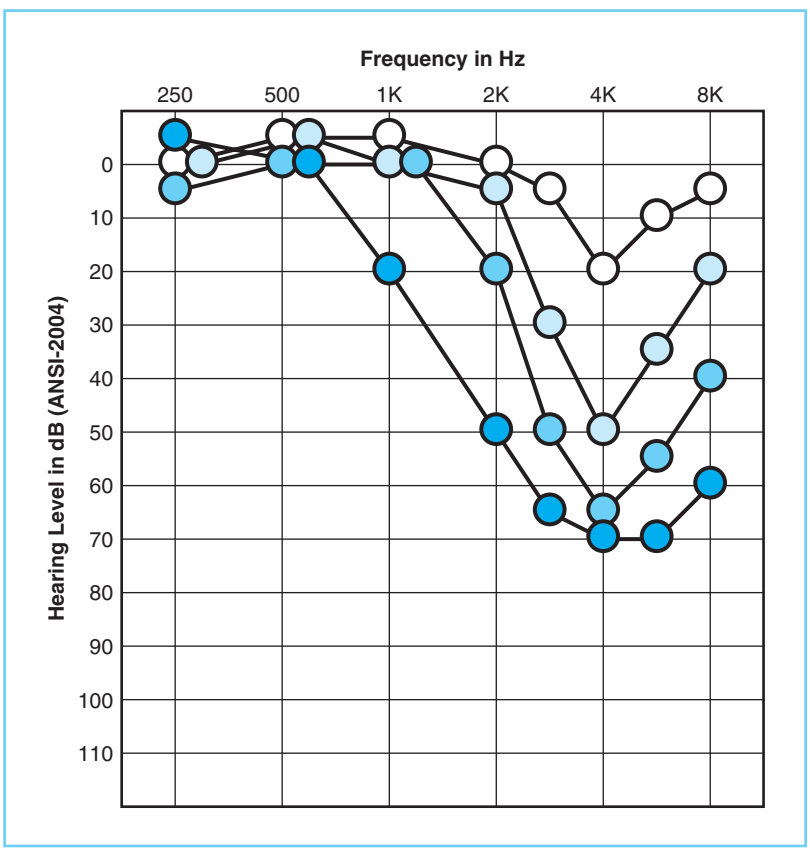


FIGURE 4-11 The progression of hearing loss from industrial noise exposure over a period of four decades.

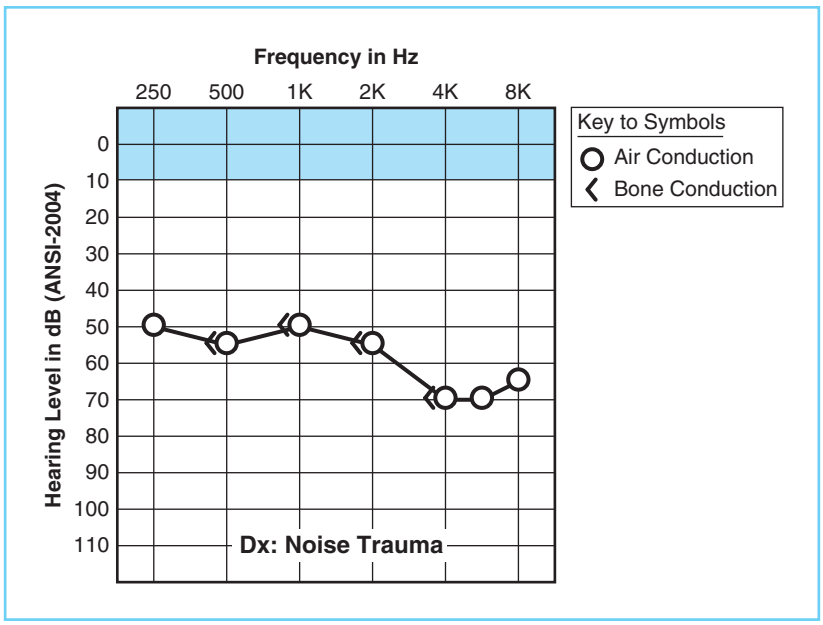


FIGURE 4-12 An audiogram representing the effect of a single exposure to an early cordless telephone that rang in close proximity to the user's ear.

resulted from a single exposure to an early cordless telephone that rang as the user held the phone up to his ear. The level of the sound was estimated to be over 140 dB SPL, resulting in a relatively flat, moderate sensorineural hearing loss.

Trauma

In addition to acoustic trauma, other insults to the auditory system can cause significant hearing loss. Physical trauma that results in a **transverse fracture** of the temporal bone can cause extensive destruction of the membranous labyrinth. This type of trauma is often caused by a blow to the occipital region of the skull. Recall that a **longitudinal** fracture can result in damage to the middle-ear structures, but seldom to the cochlea. Conversely, a transverse fracture tends to spare the middle ear and damage the cochlea. Depending on the extent of the labyrinthine destruction, the sensorineural hearing loss can be quite severe.

Transverse means a slice in the horizontal plane.

Longitudinal means lengthwise.

When tissue dies due to excessive exposure to radiation it is called **radionecrosis**, which in the auditory system may occur immediately following exposure or have a later onset.

Another form of trauma occurs as a result of **radionecrosis**, or the death of tissue due to excessive exposure to radiation. Injury to the auditory system secondary to X-ray irradiation occurs as

a result of **atrophy** of the spiral and annular ligaments causing degeneration of the organ of Corti. Hearing loss of this nature is sensorineural, progressive, and usually has a delayed onset. X-ray irradiation injury is increasingly common as radio-surgery is used in an effort to irradiate acoustic tumors.

Atrophy is the wasting away or shrinking of a normally developed organ or tissue.

Infections

Sensorineural hearing loss can result from acquired infections, the pathogens from which can directly insult the membranous labyrinth of children or adults.

Infections from bacteria, viruses, and fungi can cause sensorineural hearing loss. Bacterial infections can cause inflammation of the membranous labyrinth of the cochlea, or labyrinthitis, through several routes. Serous or toxic labyrinthitis is an inflammation of the labyrinth caused by bacterial contamination of the tissue and fluids, either by invasion through the middle ear *(otogenic)* or via the **meninges** *(meningogenic)*. *Serous labyrinthitis* may be transient, resulting in mild hearing loss and dizziness. In more severe forms, however, it can be toxic to the sensory cells of the cochlea, causing substantial sensorineural hearing loss. Serous labyrinthitis sometimes occurs secondary to serous otitis media, presumably from the bacterial toxins traveling through the membranes of the oval or round windows. It may also occur secondary to meningitis, with the inflammation traveling along the brain's linings to the membranous labyrinth of the cochlea.

The three membranes of the brain and spinal cord, the arachnoid, dura mater, and pia mater, are called the **meninges**.

Bacterial infections can also cause otogenic *suppurative labyrinthitis*. In this type of infection, bacteria invade the cochlea from the temporal bone. The pus formation in the infection can cause permanent and severe damage to the cochlear labyrinth, resulting in substantial sensorineural hearing loss.

Meningitis is an inflammation of the membranes that surround the brain and spinal cord caused by bacteria or viruses. The greatest frequency of hearing loss occurs in cases of bacterial meningitis, with estimates ranging from 5 to 35% of cases. Other common signs and symptoms of bacterial meningitis include fever, seizures, neck stiffness, and altered mental status. Hearing disorder ranges from mild to profound sensitivity loss or

total deafness and may be progressive. Cochlear osteoneogenesis, or bony growth in the cochlea, may occur following meningitis.

Some of the more common acquired viral infections that can cause sensorineural hearing loss include herpes zoster oticus, mumps, and measles.

Herpes zoster oticus, or Ramsay Hunt syndrome, is caused by a virus that also causes chicken pox. The virus, often acquired during childhood, can lie dormant for years in the central nervous system. At some point in time, due to changes in the immune system or to the presence of systemic disease, the virus is reactivated, causing burning pain around the ear, skin eruptions in the external auditory meatus and concha, facial nerve paralysis, dizziness, and sensorineural hearing loss. Hearing loss is of varying degree and often has a high-frequency audiometric configuration.

Mumps is a contagious systemic viral disease, characterized by painful enlargement of the parotid glands, fever, headache, and malaise, that can cause sudden, permanent, profound unilateral sensorineural hearing loss.

The **parotid glands** are the salivary glands near the ear.

Encephalitis is inflammation of the brain.

Mumps, or epidemic parotitis, is an acute systemic viral disease, most often occurring in childhood after the age of 2 years. Depending on severity, it usually causes painful swelling of the **parotid glands** and can cause a number of complications related to **encephalitis**. Despite the systemic nature of the disease, hearing loss is peculiar in that it is almost always unilateral in nature. Because of this, it often goes undiagnosed until later in life. Mumps is probably the single most common cause of unilateral sensorineural hearing loss, and the loss is usually profound.

Measles is a highly contagious viral illness that characteristically causes symptoms of rash, cough, fever, conjunctivitis, and white spots in the mouth. Hearing loss is a common complication of the measles virus. Prior to widespread vaccination in the United States, measles accounted for 5 to 10% of all cases of profound, bilateral, sensorineural hearing loss. Measles is still a significant cause of hearing loss and deafness in other parts of the world.

Syphilis is a congenital or acquired disease caused by a spirochete, which in its secondary and tertiary stages can cause auditory and vestibular disorders.

Tertiary means third in order.

Another cause of hearing loss from acquired infection is **syphilis**, a venereal disease that can also cause congenital hearing loss. Syphilis is usually described in terms of clinical stages, from primary infection, through secondary involvement of other organs, to tertiary involvement of the cardiovascular and nervous systems. Hearing loss from *otosyphilis* occurs in the secondary or **tertiary** stages and

results from membranous labyrinthitis associated with acute meningitis or **osteitis** of the temporal bone. Hearing loss from syphilis is not unlike that from Ménière's disease, characterized by fluctuation attacks and progression in severity. An example of a hearing loss from otosyphilis is shown in Figure 4-13. Besides the fluctuation and progression, another common finding is disproportionately poor speech recognition ability.

Osteitis is inflammation of the bone.

Ototoxicity

Certain drugs and chemicals are toxic to the cochlea. Ototoxicity can be acquired or congenital. *Acquired ototoxicity* results from the ingestion of certain drugs that are administered for medical purposes, such as in the treatment of infections and cancer. Ototoxicity can also result from excessive exposure to certain environmental toxins. *Congenital ototoxicity*, as discussed earlier, results from the teratogenic effects of drugs administered to the mother during pregnancy.

The *aminoglycosides* are a group of antibiotics that are often ototoxic. They are used primarily against bacterial infections.

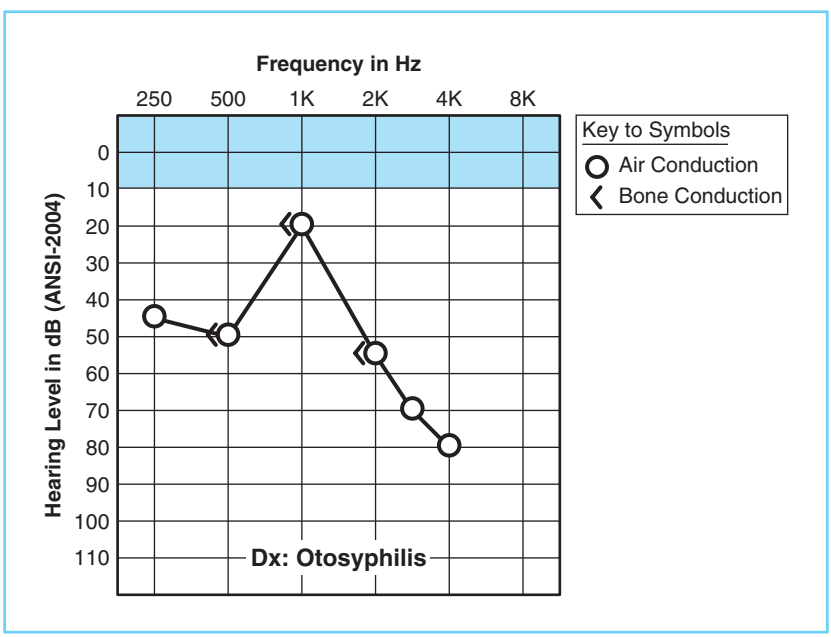


FIGURE 4-13 An audiogram representing the effects of otosyphilis.

Predilection means a partiality or preference.

Some of the aminoglycosides have a **predilection** for hair cells of the cochlea (*cochleotoxic*), while others have a predilection for hair cells of the vestibular end-organs *(vestibulotoxic)*. Most of these antibiotics can be used in smaller doses to effectively fight infection without causing ototoxicity. Sometimes, however, the infections must be treated aggressively with high doses, resulting in significant sensorineural hearing loss. Ototoxic antibiotics include:

- amikacin,
- dihydrostreptomycin,
- garamycin,
- gentamicin,
- kanamycin,
- neomycin,
- netilmicin,
- streptomycin,
- tobramycin, and
- viomycin.

Antineoplastic refers to an agent that prevents the development, growth, or proliferation of tumor cells.

Other drugs that are ototoxic have been developed in the fight against cancer. *Carboplatin* and *cisplatin* are antimitotic and **antineoplastic** drugs often used in cancer treatment. It is not unusual for patients who undergo chemotherapy regimens that contain either or both of these drugs to develop permanent sensorineural hearing loss.

Hearing loss from ototoxicity is usually permanent, sensorineural, bilateral, and symmetric. The mechanism for damage varies depending on the drug, but, in general, hearing loss results initially from damage to the outer hair cells of the cochlea at its basal end. Thus, the hearing loss typically begins as a high-frequency loss and progresses to lower frequencies with additional drug exposure. An example of a hearing loss resulting from ototoxicity due to cisplatin chemotherapy is shown in Figure 4-14.

Quinine is an antimalarial drug that can have a teratogenic effect on the auditory system of the developing embryo.

Some drugs cause ototoxicity that is reversible. *Antimalarial drugs*, including chloroquine and **quinine**, have been associated with ototoxicity. Typically, the hearing loss from these drugs is temporary. However, in high doses the loss can be permanent.

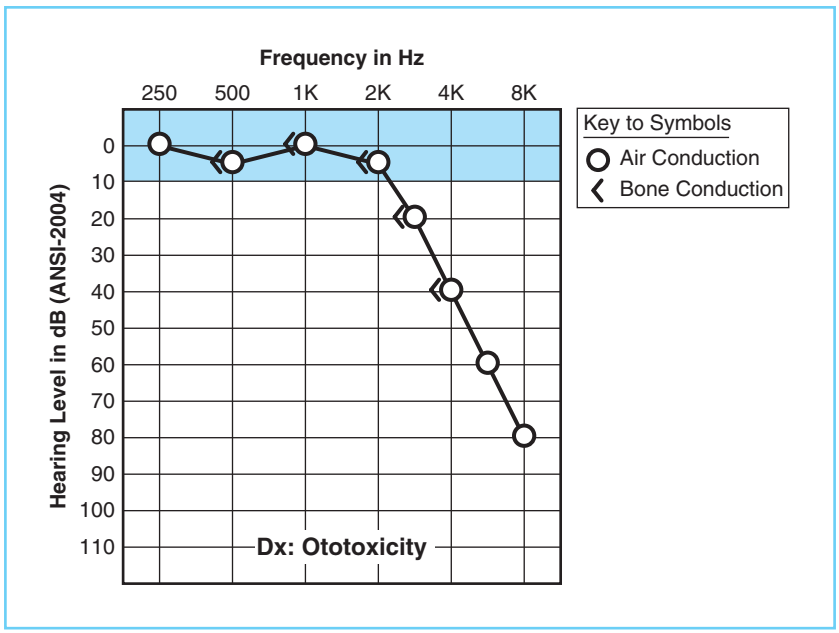


FIGURE 4-14 An audiogram representing the effects of ototoxicity.

Drugs known as *salicylates* can also be ototoxic. Salicylates such as acetylsalicylic acid and aspirin are used as therapeutic agents in the treatment of arthritis and other connective tissue disorders. Hearing loss is usually reversible and accompanied by tinnitus. In the case of salicylate intoxication, the hearing loss often has a flat rather than a steeply sloping configuration. An example is shown in Figure 4-15.

Loop diuretics, including ethacrynic acid, furosemide, and **lasix**, are used to promote the excretion of urine by inhibiting resorption of sodium and water in the kidneys. Hearing loss from loop diuretics may be reversible or permanent.

Lasix is an ototoxic loop diuretic used in the treatment of edema (swelling) or hypertension, which can cause a sensorineural hearing loss secondary to degeneration of the stria vascularis.

Other ototoxic substances include *industrial solvents*, such as styrene, toluene, and trichlorethylene, which can be ototoxic if inhaled in high concentrations over extended periods. Potassium bromate, a chemical neutralizer used in food preservatives and other commercial applications, has also been associated with ototoxicity.

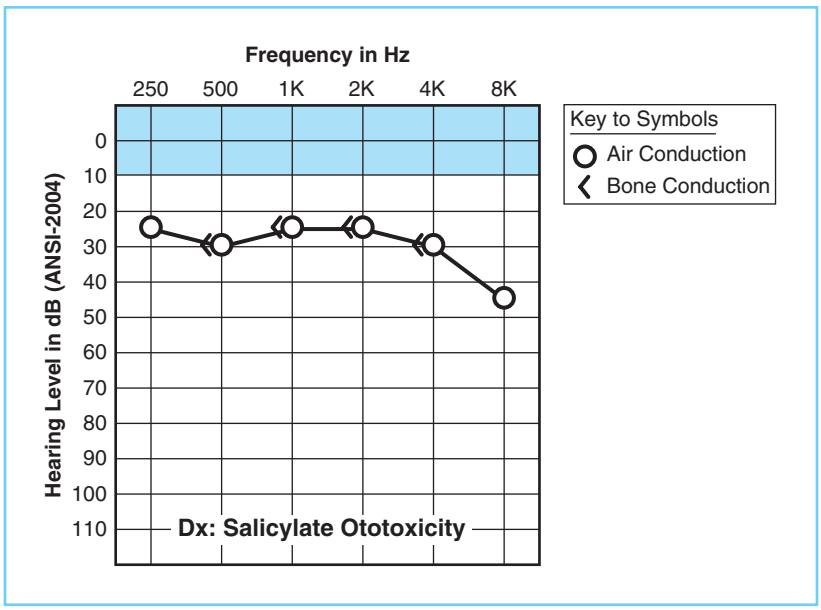


FIGURE 4-15 An audiogram representing the temporary effects of salicylate intoxication.

Ménière's Disease, named after Prosper Ménière, is idiopathic endolymphatic hydrops, characterized by fluctuating vertigo, hearing loss, tinnitus, and aural fullness.

Episodic vertigo is the repeated occurrence of dizziness.

Ménière's Disease

A common disorder of the cochlea is *endolymphatic hydrops*. Endolymphatic hydrops is a condition resulting from excessive accumulation of endolymph in the cochlear and vestibular labyrinths. This excessive accumulation of endolymph often causes **Ménière's disease**, a constellation of symptoms of **episodic vertigo**, hearing loss, tinnitus, and aural fullness. The name of this syndrome is derived from the French scientist, Prosper Ménière, who in 1861 first attributed the diverse symptoms of dizziness, vomiting, and hearing loss to a disorder of the inner ear rather than the central nervous system.

The classic symptoms of Ménière's disease are an attack of vertigo with hearing loss, tinnitus, and pressure in the involved ear. The hearing loss is typically unilateral, fluctuating, progressive, and sensorineural. The feeling of pressure, the sensation of tinnitus, and hearing loss often build up before an attack of vertigo, which is often accompanied by nausea and vomiting. The spells can last from minutes to 2 or 3 hours and often include unsteadiness between spells. In the early stages of the disease, attacks are dominated by vertigo, and recovery can be complete. In the later

stages, attacks are dominated by hearing loss and tinnitus, and permanent, severe hearing loss can occur.

The underlying cause of Ménière's disease is endolymphatic hydrops. The underlying cause of endolymphatic hydrops is most often unknown, although sometimes it can be attributed to allergy, vascular insult, physical trauma, syphilis, acoustic trauma, viral insult, or other causes. In the early stages of Ménière's disease, the buildup of endolymph occurs mainly within the cochlear duct and saccule. Essentially, these structures distend or dilate from an increase in fluid and cause ruptures of the membranous labyrinth.

Although Ménière's disease usually involves both the auditory and vestibular mechanisms, two variant forms exist, so-called *cochlear Ménière's disease* and *vestibular Ménière's disease*. In the cochlear form of the disease, only the auditory symptoms are present, without vertigo. In the vestibular form, only the vertiginous episodes are present, without hearing loss.

Hearing loss from Ménière's disease is most often unilateral, sensorineural, and fluctuating. In the early stages of the disease, the hearing loss configuration is often low frequency in nature. An example is shown in Figure 4-16. After repeated attacks, the loss usually progresses into a flat, moderate-to-severe hearing loss, as shown in Figure 4-17. One common feature of Ménière's disease is poor speech-recognition ability, much poorer than would be expected from the degree of hearing sensitivity loss.

Presbyacusis

Presbyacusis (or *presbycusis*) is a decline in hearing as a part of the aging process. As a collective cause, it is the leading contributor to hearing loss in adults. Estimates suggest that from 25 to 40% of those over the age of 65 years have some degree of hearing loss. The percentage increases to approximately 90% of those over the age of 90 years.

All hearing loss that is present in aging individuals is not, of course, due to the aging process per se. During a lifetime, an individual can be exposed to excessive noise, vascular and systemic disease, dietary influences, environmental toxins, ototoxic drugs, and so on. Add to these any genetic predisposition to hearing loss, and you may begin to wonder how anyone's hearing can be normal in older age. If you

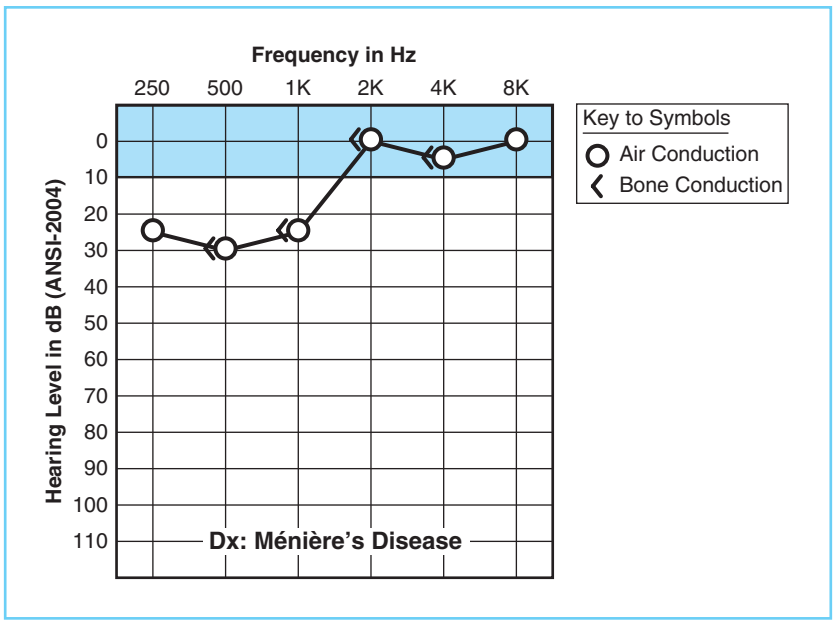


FIGURE 4-16 An audiogram representing the effects of the early stages of Ménière's disease.

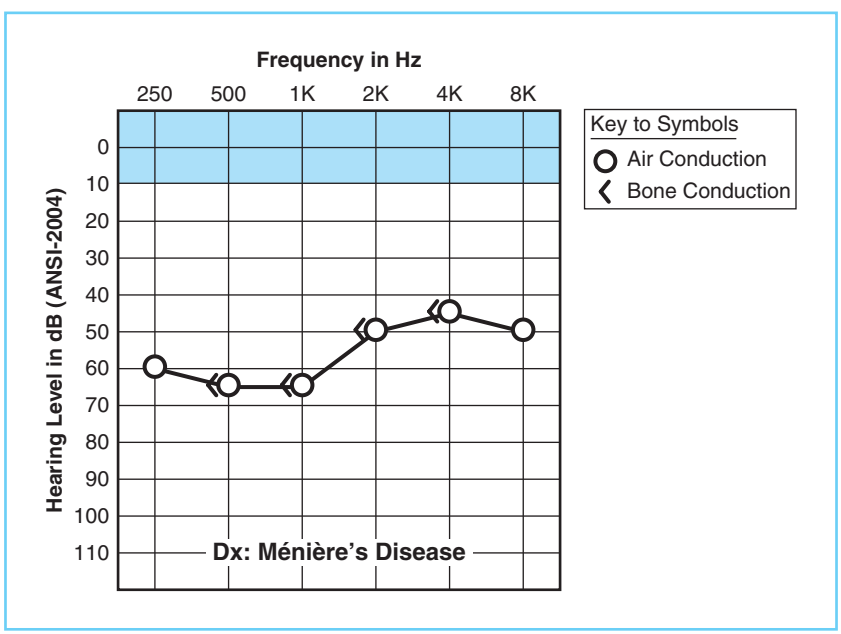


FIGURE 4-17 An audiogram representing the effects of Ménière's disease that has progressed.

were able to restrict exposure to all of these factors, you would be able to study the specific effects of the aging process on the auditory structures. What you would likely find is that a portion of hearing loss is attributable to the aging process, and a portion is attributable to the exposure of the ears to the world for the number of years it took to become old. How much is attributable to each can be estimated, although it will never be truly known in an individual. Regardless, if we think of living as a contributing factor to the aging process, then the hearing loss that occurs with aging, which cannot be attributed to other causative factors, can be considered presbyacusis.

Structures throughout the auditory system degenerate with age. Changes in cochlear hair cells, the **stria vascularis**, the **spiral ligament**, and the cochlear neurons all conspire to create sensorineural hearing loss. Changes in the auditory nerve, brainstem, and cortex conspire to create auditory processing disorder.

Hearing sensitivity loss from presbyacusis is bilateral, usually symmetric, progressive, and sensorineural. An example of the effects of aging is shown in Figure 4-18. The systematic decline

The **stria vascularis** is the highly vascularized band of cells on the internal surface of the spiral ligament, located within the scala media, extending from the spiral prominence to Reissner's membrane.

The **spiral ligament** is the band of connective tissue that affixes the basilar membrane to the outer bony wall, against which lies the stria vascularis within the scala media.

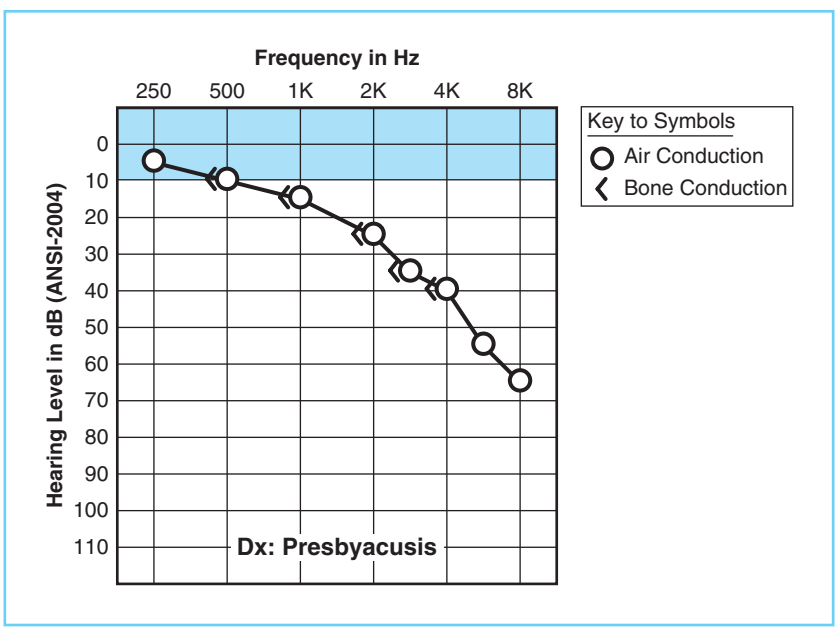


FIGURE 4-18 An audiogram representing the effects of presbyacusis.

in the audiogram is greatest in the higher frequencies, but present across the frequency range. There are some interesting differences in the audiometric configurations of males and females attributable to aging. As shown in Figure 4-19, men tend to have more high-frequency hearing loss, and women tend to have flatter audiometric configurations. When noise exposure is controlled, the amount of high-frequency hearing loss is similar in the two groups, but women tend to have more low-frequency hearing loss.

Presbyacusis is also characterized by decline in the perception of speech that has been sensitized in some manner. Decline in understanding of speech in background competition or speech

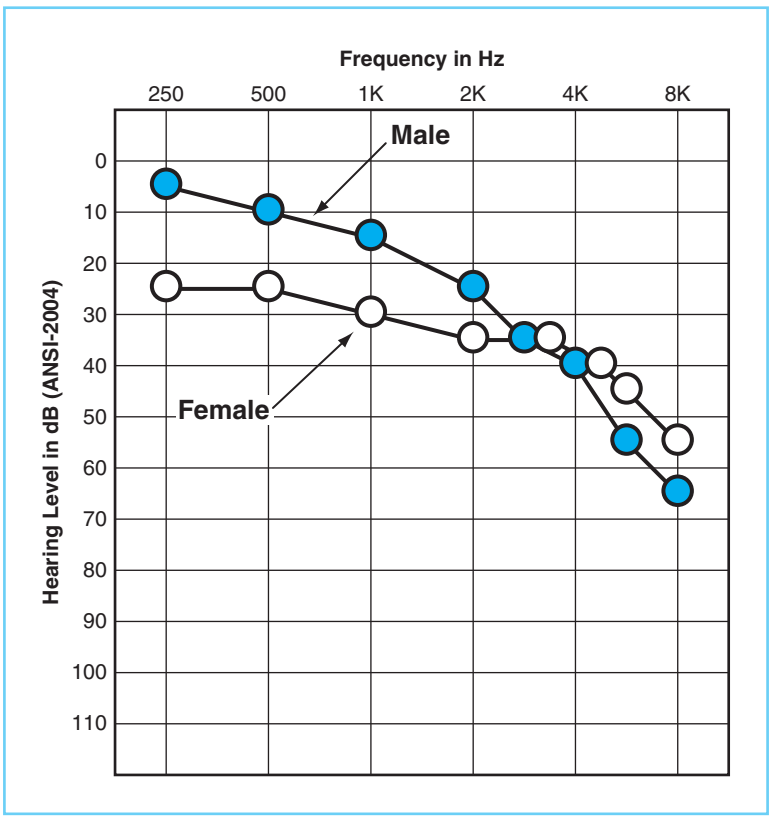


FIGURE 4-19 Generalized representation of the difference in the audiometric configurations of males and females as they age.

that has been temporally altered is consistent with aging changes in the central auditory nervous system. An example is shown in Figure 4-20.

Autoimmune Inner-Ear Disease

Autoimmune inner-ear disease (AIED) is an auditory disorder characterized by bilateral, asymmetric, progressive, sensorineural hearing sensitivity loss in patients who test positively for autoimmune disease. It tends to be diagnosed on the basis of exclusion of other causes, but it is increasingly attributed as the causative factor in progressive sensorineural hearing loss. An example of AIED hearing loss is shown in Figure 4-21. The asymmetry and progression are the signature characteristics of the disorder. The hearing sensitivity loss may be responsive to immunosuppressive drugs, such as steroids.

Autoimmune refers to a disordered immunologic response in which the body produces antibodies against its own tissues.

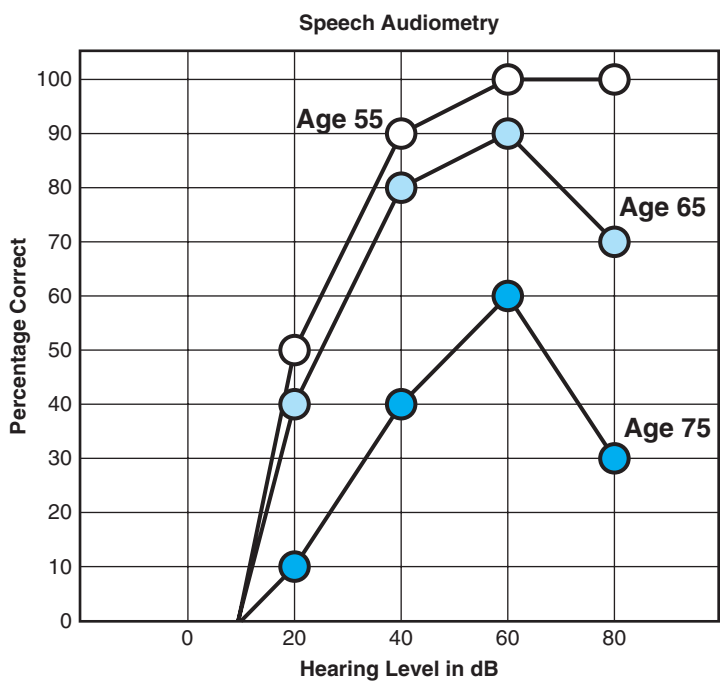


FIGURE 4-20 Decline with age in the ability to recognize speech in a background of competition.

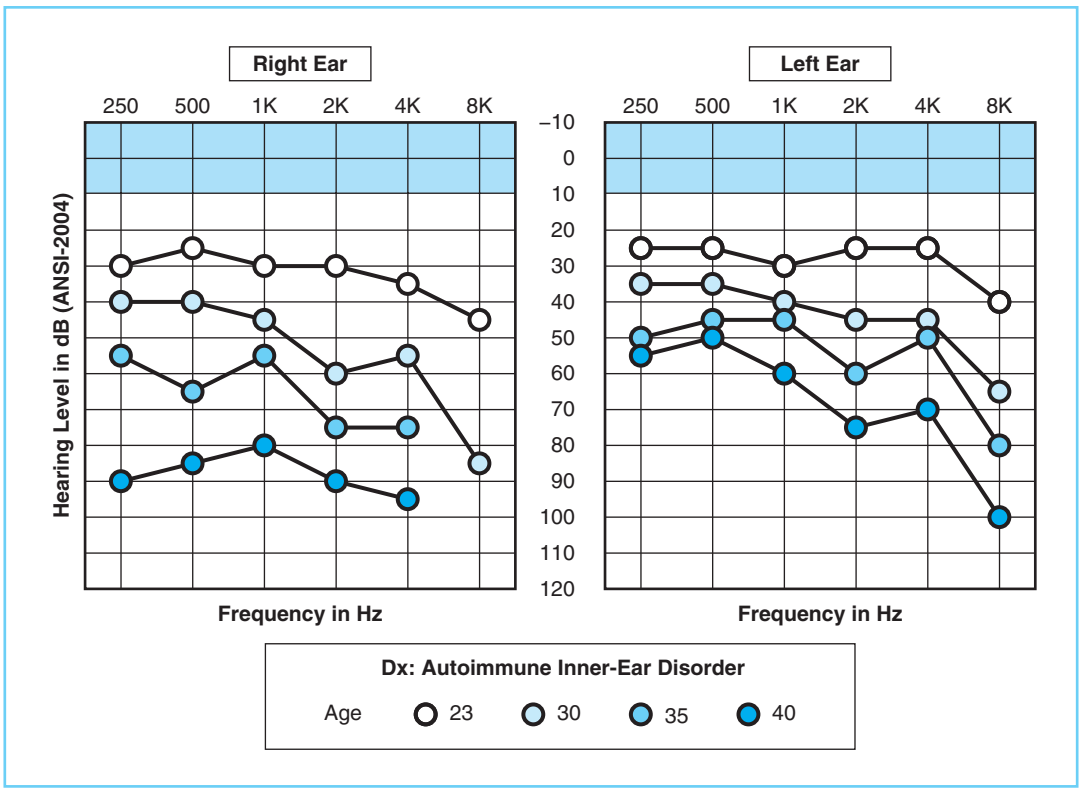


FIGURE 4-21 Illustrative example of the progression of autoimmune hearing loss.

Cochlear Otosclerosis

The same otosclerosis that can fix the stapes footplate into the oval window can occur within the cochlea and result in sensorineural hearing loss. Recall that otosclerosis is a disorder of bone growth that affects the stapes and the bony labyrinth of the cochlea. The disease process is characterized by resorption of bone and new spongy formation around the stapes and oval window. Depending on the extent of cochlear involvement, a sensorineural hearing loss can occur. Although there is some debate about whether a sensorineural hearing loss can occur in isolation, it is certainly theoretically possible. Nevertheless, *cochlear otosclerosis* is commonly accompanied by fixation of the stapes, resulting in a mixed hearing loss. An example of this type of hearing loss is shown in Figure 4-22.

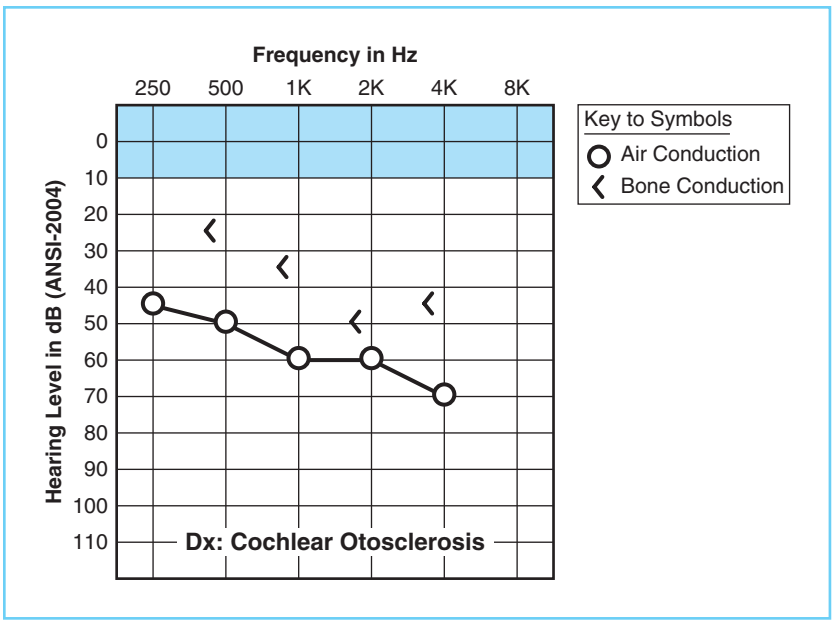


FIGURE 4-22 An audiogram representing the effects of cochlear otosclerosis.

Idiopathic Sudden Sensorineural Hearing Loss

Idiopathic *sudden hearing loss* is a term that is used to describe a sudden, often unilateral, sensorineural hearing loss. Idiopathic sudden hearing loss is often noticed upon awakening and is usually accompanied by tinnitus. The extent of the sensorineural hearing loss ranges from mild to profound. Partial or full recovery of hearing occurs in approximately 75% of patients. The term idiopathic is used because the cause is often unknown, although viral or vascular influences are usually suspected.

Idiopathic is of an unknown cause.

NEURAL HEARING DISORDERS

Any disease or disorder process that affects the peripheral and central nervous system can, of course, result in auditory disorder if the auditory nervous system is involved. Neoplastic growths on the VIIIth nerve or in the auditory brainstem, cranial nerve neuritis, multiple sclerosis, and brain **infarcts** can all cause some form of auditory disorder.

Infarcts are localized areas of ischemic necrosis.

An **infarction** is the sudden insufficiency of blood supply due to occlusion of arterial supply or venous drainage.

The nature of hearing impairment that accompanies central auditory nervous system disorder varies as a function of location of the disorder. A disorder of the VIIIth nerve is likely to result in a sensorineural hearing loss with poor speech understanding. The likelihood of a hearing sensitivity loss diminishes as the disorder becomes more central, so that a brainstem lesion is less likely than an VIIIth nerve lesion to cause a sensitivity loss, and a temporal lobe lesion is quite unlikely to cause such a loss. Similarly, disorders of speech perception become more subtle as the disorder becomes more central.

Auditory Neuropathy

Auditory neuropathy is a term that is used to describe a disorder in the synchrony of neural activity of the VIIIth cranial nerve. It is operationally defined based on a constellation of clinical findings that suggest normal functioning of some cochlear structures and abnormal functioning of the VIIIth nerve and brainstem.

In reality, the term auditory neuropathy as it is defined clinically probably describes two fairly different disorders, one sensory and the other neural. The auditory neuropathy of sensory origin—AN(S)—is a sensory hearing disorder that represents a transduction problem, with the failure of the cochlea to transmit signals to the auditory nerve. The most likely origin of AN(S) is the inner hair cells of the cochlea with normally functioning outer hair cells serving little or no purpose. The hearing loss from AN(S) acts like any other sensitivity loss in terms of its influence on speech and language acquisition and its amenability to hearing aids and cochlear implants.

Auditory neuropathy of neural origin—AN(N)—was first described as a specific disorder of the auditory nerve that results in a loss of synchrony of neural firing. Because of the nature of the disorder, it is also referred to as auditory dys-synchrony. The cause of auditory neuropathy is often unknown, although it may be observed in cases of syndromic peripheral pathologies. The age of onset is usually before 10 years. Hearing sensitivity loss ranges from normal to profound and is most often flat or reverse-sloped

in configuration. The hearing loss often fluctuates and may be progressive. Speech perception is often substantially poorer than what would be expected from the audiogram.

VIIIth Nerve Tumors and Disorders

The most common neoplastic growth affecting the auditory nerve is called a **cochleovestibular schwannoma**. The more generic terms *acoustic tumor* or *acoustic neuroma* are typically referring to a cochleovestibular schwannoma. Other terms used to describe this tumor are *acoustic neurinoma* and *acoustic neurilemoma*.

Cochleovestibular schwannoma is the proper term for acoustic neuroma.

A cochleovestibular schwannoma is a **benign**, encapsulated tumor composed of Schwann cells that arises from the VIIIth cranial nerve. Schwann cells serve to produce and maintain the **myelin** that ensheathes the **axons** of the VIIIth nerve. This tumor arising from the proliferation of Schwann cells is benign in that it is slow growing, is encapsulated, thereby avoiding local invasion of tissue, and does not disseminate to other parts of the nervous system. Acoustic tumors are unilateral and most often arise from the vestibular branch of the VIIIth nerve. Thus, they are sometimes referred to as *vestibular schwannomas*.

When a tumor is **benign**, it is nonmalignant or noncancerous.

The tissue enveloping the axon of myelinated nerve fibers is called **myelin**.

Axons are the efferent processes of a neuron that conduct impulses away from the cell body and other cell processes.

The effects of a cochleovestibular schwannoma depend on its size, location, and the extent of the pressure it places on the VIIIth nerve and brainstem. Auditory symptoms may include tinnitus, hearing loss, and unsteadiness. Depending on the extent of the tumor's impact, it may cause headache, motor incoordination from cerebellar involvement, and involvement of adjacent cranial nerves. For example, involvement of the Vth cranial nerve can cause facial numbness, involvement of the VIIth cranial nerve can cause facial weakness, and involvement of the IVth cranial nerve can cause **diplopia**.

Diplopia means double vision.

Among the most common symptoms of cochleovestibular schwannoma are unilateral tinnitus and unilateral hearing loss. The hearing loss varies in degree depending on the location and size of the tumor. An example of a hearing loss resulting from an acoustic tumor is shown in Figure 4-23. Speech understanding typically is disproportionately poor for the degree of hearing loss.

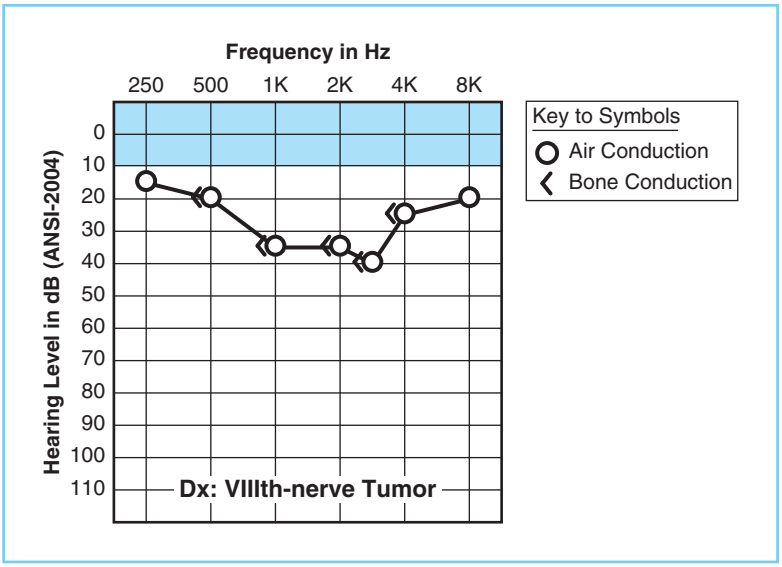


FIGURE 4-23 An audiogram representing the effects of an acoustic or VIIIth-nerve tumor.

One other important form of schwannoma is *neurofibromatosis*. This tumor disorder has two distinct types. *Neurofibromatosis 1* (NF-1), also known as von Recklinghausen's disease, is an autosomal dominant disease characterized by **café-au-lait spots** and multiple **cutaneous tumors**, with associated optic gliomas, peripheral and spinal neurofibromas, and, rarely, acoustic neuromas. In contrast, *Neurofibromatosis 2* (NF-2) is characterized by bilateral cochleovestibular schwannomas. The schwannomas are faster growing and more virulent than the unilateral type. This is also an autosomal dominant disease and is associated with other intracranial tumors. Hearing loss in NF-2 is not particularly different from the unilateral type of schwannoma, except that it is bilateral and often progresses more rapidly.

Café-au-lait spots are brown birthmarklike spots that appear on the skin.

Tumors on the skin are called **cutaneous tumors**.

In addition to cochleovestibular schwannoma, a number of other types of tumors, cysts, and aneurysms can affect the VIIIth nerve and the **cerebellopontine angle**, where the VIIIth nerve enters the brainstem. These other neoplastic growths, such as lipoma and **meningioma**, occur more rarely than cochleovestibular schwannoma. The effect of these various forms of tumor on hearing is usually indistinguishable.

Cerebellopontine angle is the anatomical angle formed by the proximity of the cerebellum and the pons from which the VIIIth cranial nerve exits into the brainstem.

Meningiomas are benign tumors that may encroach on the cerebellopontine angle, resulting in a retrocochlear disorder.

In addition to acoustic tumors, other disease processes can affect the function of the VIIIth nerve. Two important neural disorders are *cochlear neuritis* and *diabetic cranial neuropathy*.

Not unlike any cranial nerve, the VIIIth nerve can develop neuritis, or inflammation of the nerve. Although rare, acute *cochlear neuritis* can occur as a result of a direct viral attack on the cochlear portion of the nerve. This results in degeneration of the cochlear neurons in the ear. Hearing loss is sensorineural and often sudden and severe. It is accompanied by poorer speech understanding than would be expected from the degree of hearing loss. One specific form of this disease occurs as a result of syphilis. *Meningo-neuro-labyrinthitis* is an inflammation of the membranous labyrinth and VIIIth nerve that occurs as a predominant lesion in early congenital syphilis or in acute attacks of secondary and tertiary syphilis.

Diabetes mellitus is a metabolic disorder caused by a deficiency of insulin, with chronic complications including neuropathy and generalized degenerative changes in blood vessels. Neuropathies can involve the central, peripheral, and autonomic nervous systems. When neuropathy from diabetes affects the auditory system, it usually results in vestibular disorder and hearing loss consistent with retrocochlear disorder.

Brainstem Disorders

Brainstem disorders that affect the auditory system include infarcts, gliomas, and multiple sclerosis. *Brainstem infarcts* are localized areas of **ischemia** produced by interruption of the blood supply. Auditory disorder varies depending on the site and extent of the disorder. Two syndromes related to vascular lesions that include hearing loss are *inferior pontine syndrome* and *lateral inferior pontine syndrome*. Inferior pontine syndrome results from a vascular lesion of the pons involving several cranial nerves. Symptoms include ipsilateral facial palsy, ipsilateral sensorineural hearing loss, loss of taste from the anterior two thirds of the tongue, and paralysis of lateral conjugate gaze movement of the eyes. Lateral inferior pontine syndrome results from a vascular lesion of the inferior pons, with symptoms that include facial palsy, loss of taste from the anterior two thirds of the tongue, **analgesia** of the face,

Ischemia results from a localized shortage of blood due to obstruction of blood supply.

Analgesia means the reduction or abolition of sensitivity to pain.

paralysis of lateral conjugate gaze movements, and sensorineural hearing loss.

A *glioma* is a tumor composed of neuroglia, or supporting cells of the brain. It comes in various forms, depending on the types of cells involved, including **astrocytomas**, **ependymomas**, **glioblastomas**, and **medulloblastomas**. Any of these can affect the auditory pathways of the brainstem, resulting in various forms of retrocochlear hearing disorder, including hearing sensitivity loss and speech perception deficits.

Astrocytoma is a central nervous system tumor consisting of astrocytes, which are star-shaped neuroglia cells.

Ependymoma is a glioma derived from undifferentiated cells from the ependyma, the cellular membrane lining the brain ventricles

Glioblastoma is a rapidly growing and malignant tumor composed of undifferentiated glial cells.

Medulloblastoma is a malignant tumor that often invades the meninges.

Multiple sclerosis is a **demyelinating disease**. It is caused by an autoimmune reaction of the nervous system that results in small scattered areas of demyelination and the development of demyelinated plaques. During the disease process, there is local swelling of tissue that exacerbates symptoms, followed by periods of remission. If the demyelination process affects structures of the auditory nervous system, hearing disorder can result. There is no characteristic hearing sensitivity loss that emerges as a consequence of the disorder, although all possible configurations have been described. Speech perception deficits are not uncommon in patients with multiple sclerosis.

A **demyelinating disease** is an autoimmune disease process that causes scattered patches of demyelination of white matter throughout the central nervous system, resulting in retrocochlear disorder when the auditory nervous system is affected.

Temporal-Lobe Disorder

Cerebrovascular accident, or stroke, is caused by an interruption of blood supply to the brain due to aneurysm, embolism, or clot. This results in sudden loss of function related to the damaged portion of the brain. When this occurs in the temporal lobe, audition may be affected, although more typically, receptive language processing is affected while hearing perception is relatively spared. Indeed, hearing ability is seldom impaired except in the case of bilateral temporal lobe lesions. In such cases, "cortical deafness" can occur, resulting in symptoms that resemble **auditory agnosia**.

Agnosia means the lack of sensory-perceptual ability to recognize stimuli.

Other Nervous System Disorders

Any other disease processes, lesions, or trauma that affect the central nervous system can affect the central auditory nervous system. For example, AIDS is a disease that compromises the efficacy of the immune system, resulting in **opportunistic infectious** diseases that can affect central auditory nervous system structures.

Opportunistic Infections are those that take advantage of the opportunity afforded by a weakened physiologic state of the host.

When these structures are affected, auditory disorder occurs, usually resembling retrocochlear or auditory processing disorder.

VESTIBULAR DISORDERS

The auditory and vestibular endorgans are neighbors, housed within the same bony labyrinth of the temporal lobe. By proximity alone, it is easy to understand why a disorder that affects one may affect the other. A number of conditions that cause hearing loss can also cause balance disorders of a vestibular nature. Although the two often occur together, they can occur in isolation.

One of the hallmarks of vestibular disorder is **vertigo**, or the abnormal sensation of motion. Recall from Chapter 2 that the vestibular system serves to orient the head in space by responding to movement. The vestibular system serves as the internal monitor for motion, just as the visual and somatosensory systems serve as the external monitors for movement. A disordered vestibular system either sends signals to the brain of head movement that is not occurring or sends inaccurate signals about the nature and extent of head movement. In either case, the conflict between reality and this misinformation causes a misperception of motion, or an illusion of movement. A patient with a disorder of the vestibular labyrinth is likely to experience true vertigo. Other forms of balance disturbance, such as lightheadedness, loss of balance, and nonspecific dizziness are more likely caused by central or systemic disorders than by vestibular disorders.

Vertigo is the perception of the sensation of spinning or whirling.

Some hearing disorders are accompanied by vestibular disorders. Recall that many of the congenital inner-ear anomalies affect the membranous and bony labyrinths of both the auditory and vestibular systems. Similarly, a number of syndromes with characteristic hearing disorders include a disturbance of the vestibular mechanism. Some acquired etiologies, such as meningitis or syphilis, can affect both auditory and vestibular systems simultaneously.

In other cases, vestibular disorders can occur in isolation. The primary disorders causing vertigo without hearing loss include benign **paroxysmal** positional vertigo (BPPV), semicircular canal

Paroxysmal refers to the abrupt, recurrent onset of a symptom.

Audiologist Profile

Devin L. McCaslin, Ph.D.



Where I Live: Nashville, Tennessee

Where I Work: The Vanderbilt Bill Wilkerson Center (VBWC). The VBWC is located within the Vanderbilt University Medical Center, a large tertiary medical center serving middle Tennessee. The VBWC serves patients with diseases of the ear, nose, throat, head, and neck, and with hearing, speech, language, and related disorders. Thousands of patients are served every year by the VBWC through patient care, professional education, and clinical research. The Center is comprised of Vanderbilt's Department of Otolaryngology and Department of Hearing and Speech Sciences.

What I Do: My primary responsibility is as co-director of the Vanderbilt Bill Wilkerson Balance Disorders Laboratory, which is a diagnostic clinic where I conduct tests, the results of which help physicians determine the cause of dizziness, disequilibrium, and vertigo. I also conduct assessments of patients who may be at risk for falling. Through this assessment, I can determine what factors place a patient most at risk for falls and make recommendations to the referring physician for reducing that risk. I am actively involved in clinical research focusing on patients suffering from dizziness, and I teach graduate classes covering the electrophysiological assessment of the vestibular and auditory systems to audiology doctoral students.

Why Audiology? Two reasons. First, my mother is an audiologist, and early on in life I was afforded the opportunity to see the positive impact that this profession has on people and how helping them resulted in a great deal of personal satisfaction. Secondly, there is always an opportunity to keep learning. Whether your primary interest lies in diagnostics or rehabilitation, there is always more you can learn, whether through reading or observation, to make yourself a better clinician and/or researcher.

Dehiscence is the formation of a separation, slit, or cleft.

dehiscence, vestibulotoxicity, and vestibular neuritis. In addition, Ménière's disease is a significant cause of vestibular disorder with or without accompanying hearing loss.

Benign Paroxysmal Positional Vertigo

BPPV is a disorder characterized by an abrupt onset of vertigo in response to a positional change of the head. It usually occurs in episodes that last only a short duration. It is not uncommon for

the condition to be worse in the morning and be precipitated by turning over in bed, getting out of bed, or walking up stairs. BPPV is by far the most common cause of vertigo of vestibular origin.

In some patients BPPV is transient, lasting several months, and resolves spontaneously. In others, this acute condition occurs intermittently with active and inactive periods over a span of years. BPPV is also chronic in some patients, with symptoms lasting over long durations.

BPPV can result from definable causes, including viral labyrinthitis, otitis media, or head trauma. However, in most cases it occurs spontaneously due to a condition known as canalithiasis. Canalithiasis occurs when free-floating otoconia, dislodged from the utricle, gravitate abnormally to the cupula of the superior semicircular canal. The cupula, which is not normally sensitive to gravitational forces, is stimulated abnormally by the debris with changes in head position. This condition may affect the lateral canal as well.

Superior Canal Dehiscence

Superior canal dehiscence results from erosion of the bone overlying the superior semicircular canal. This has the effect of adding a third window to the inner ear, along with the normal oval and round windows.

Patients with canal dehiscence can experience vertigo in response to loud sound, changes in middle-ear pressure, or changes in intracranial pressure. The window created by the dehiscence acts to transduce these pressure changes into fluid motion in the vestibular membranous labyrinth, resulting in the abnormal perception of movement.

Vestibulotoxicity

As you learned earlier in this chapter, various drugs and chemical agents can be toxic to the hair cells of the auditory or the vestibular system or both. Those that primarily affect the auditory system are known as cochleotoxic, and those that primarily affect the vestibular system are known as vestibulotoxic. Although certain drugs have a predilection for one system or another, those that are

particularly harmful, the aminoglycocide antibiotics, are likely to cause permanent, mixed toxicity if given in high enough doses.

Vestibulotoxicity causes reduced vestibular function bilaterally. Because the disorder is symmetric, it seldom results in vertigo because both sides are responding equally poor. Instead, symptoms usually include **ataxia** and **oscillopsia**.

Ataxia is abnormal gait and balance.

Oscillopsia is a blurring of vision during movement.

Vestibular Neuritis

Vestibular neuritis is an inflammation of the vestibular nerve. The inflammation may have a viral or vascular cause and it most often affects the superior division of the nerve.

Vestibular neuritis is characterized by a sudden onset of vertigo without auditory symptoms. The vertigo is usually severe and prolonged, resulting in nausea and vomiting. Another symptom of vestibular neuritis is postural instability, resulting in an unsteady gait.

Ménière's Disease

As described earlier, Ménière's disease is a disorder of the inner ear caused by excessive buildup of endolymph within the membranous labyrinth. The classic symptoms of the disorder are episodes of vertigo, fluctuating hearing loss, tinnitus, and aural fullness. The auditory symptoms are usually unilateral. Variations of the disorder have been reported that include symptoms isolated to the auditory system, so-called cochlear Ménière's disease, or symptoms isolated to the vestibular system, vestibular Ménière's disease.

The vertigo associated with Ménière's disease is often severe and debilitating. Attacks are frequent and can last for hours. The vertigo is most often rotatory in nature.

Summary

- There are several major categories of pathology or noxious influences that can adversely affect the auditory system, including developmental defects, infections, toxins, trauma, vascular disorders, neural disorders, immune system disorders, bone disorders, aging disorder, tumors and other neoplastic growths, and disorders of unknown or multiple causes.

- Disorders of the outer and middle ear are commonly of two types, either structural defects due to embryologic malformations or structural changes secondary to infection or trauma. Another common abnormality, otosclerosis, is a bone disorder.
- Microtia and atresia are congenital malformations of the auricle and external auditory canal. Microtia is an abnormal smallness of the auricle. It is one of a variety of auricular malformations. Atresia is the absence of an opening of the external auditory meatus.
- One common cause of transient hearing disorder is the accumulation and impaction of cerumen in the external auditory canal.
- The most common cause of transient conductive hearing loss in children is otitis media with effusion. Otitis media is inflammation of the middle ear. It is caused primarily by Eustachian tube dysfunction.
- Otosclerosis is a disorder of bone growth that affects the stapes and the bony labyrinth of the cochlea.
- A cholesteatoma is a growth in the middle ear that forms as a consequence of epidermal invasion through a perforation or a retraction of the tympanic membrane.
- Hereditary factors are common causes of sensorineural hearing loss.
- Acoustic trauma is the most common cause of sensorineural hearing loss other than presbyacusis.
- Congenital infections most commonly associated with sensorineural hearing loss include: cytomegalovirus (CMV), human immunodeficiency virus (HIV), rubella, syphilis, and toxoplasmosis.
- Acquired bacterial infections can cause inflammation of the membranous labyrinth of the cochlea, or labyrinthitis.
- Some of the more common acquired viral infections that can cause sensorineural hearing loss include herpes zoster oticus and mumps.
- Certain drugs and chemicals are toxic to the cochlea. Ototoxicity can be acquired or congenital.
- A common disorder of the cochlea is endolymphatic hydrops, a condition resulting from excessive accumulation of endolymph in the cochlear and vestibular labyrinths, which often causes

Ménière's disease, a constellation of symptoms of episodic vertigo, hearing loss, tinnitus, and aural fullness.

- Presbyacusis is a decline in hearing as a part of the aging process. As a collective cause, it is the leading contributor to hearing loss in adults.
- Other causes of sensorineural hearing loss include autoimmune hearing loss, cochlear otosclerosis, and sudden hearing loss.
- Neoplastic growths on the VIIIth nerve or in the auditory brainstem, cranial nerve neuritis, multiple sclerosis, and brain infarcts can all result in some form of auditory disorder.
- The most common neoplastic growth affecting the auditory nerve is called a cochleovestibular schwannoma.
- Some hearing disorders are accompanied by vestibular disorders. Many of the congenital inner-ear anomalies affect the membranous and bony labyrinths of both the auditory and vestibular systems, and some acquired etiologies, such as meningitis or syphilis, can affect both auditory and vestibular systems simultaneously. In other cases, vestibular disorders can occur in isolation. The primary disorders causing vertigo without hearing loss include benign paroxysmal positional vertigo (BPPV), semicircular canal dehiscence, vestibulotoxicity, and vestibular neuritis.

Short Answer Questions

1. Hereditary disorders are a significant cause of sensorineural hearing loss. A _____ disorder occurs when only one gene of a pair is needed to carry a genetic characteristic or mutation. A _____ disorder occurs when both genes of a pair are needed to carry a genetic characteristic or mutation.
2. Drugs or other nongenetic factors that cause abnormal embryological development are known as _____.
3. Numerous types of physical trauma can cause hearing loss. Another type of trauma is _____, which is a result of excessive noise exposure.
4. A hearing disorder that interferes with the synchronous transmission of signals from cochlear hair cells to the VIIIth cranial nerve is known as _____.

5. A hearing loss is termed _____ when its cause is unknown.
6. The absence of an ear canal, called _____, and the abnormal smallness of the auricle, known as _____, are two examples of congenital outer ear anomalies.
7. Middle-ear congenital anomalies typically cause a _____ hearing loss. An example is congenital _____ fixation, wherein the stapes footplate is attached to the oval window.
8. When an accumulation of ear wax, also called _____ completely occludes the ear canal, it is called an _____. This type of block most typically causes a _____ conductive hearing loss, although high frequencies may be involved if cerumen adheres to the tympanic membrane.
9. A tympanic membrane _____ occurs when damage creates a hole in the eardrum. This is typically found when foreign objects are placed in the ear canal, when a blow to the head occurs, or as a complication of _____ in the middle ear.
10. The term _____ _____ refers to inflammation of the middle-ear space. It is often used in conjunction with the term _____, which describes the escape of fluid into tissue or a cavity.
11. Otitis media with effusion is typically the result of dysfunction of the _____. Failure of this structure to open appropriately results in _____ middle-ear pressure, which ultimately causes the buildup of fluid in the middle-ear space.
12. A consequence of otitis media, known as a _____, occurs when a weakened portion of the tympanic membrane is drawn into the middle-ear space, causing a pocket to form. The _____ lining of this pocket grows into the middle-ear space and can erode the ossicles and invade the bony labyrinth.
13. Sensory hearing disorders can be _____, meaning that they are present at birth; _____, being present at birth or occurring later in life; or _____, occurring only later in life after birth.

14. Causes of sensory disorders may be _____, meaning that the disorder is a characteristic of the inherited traits of the individual, or may be _____, resulting from conditions not necessarily intrinsic to the genetic makeup of the individual.
15. A malformation of the _____ bone, known as enlarged _____ _____ syndrome, is associated with early onset of progressive, profound, bilateral hearing loss and vestibular disorders.
16. In cases of _____ hereditary hearing disorders, there is no other feature besides hearing loss. Some hereditary hearing losses may be present at birth, while others are _____, occurring gradually over time, and still others have onset in adulthood.
17. A very common cause of acquired hearing loss is _____-_____ hearing loss that occurs as a result of traumatic exposure to sound. Such a hearing loss can be temporary in nature, and is demonstrated by a _____ _____ _____ (TTS), or permanent in nature, being demonstrated by a _____ _____ _____ (PTS).
18. Medications that are toxic to the cochlea are called _____.
19. The decline in hearing function that occurs as a consequence of aging is known as _____.
20. Brainstem infarcts, gliomas, and _____ _____, a demyelinating disease, are examples of brainstem disorders that cause neural hearing losses.
21. Vestibular disorders may or may not occur in conjunction with hearing disorders. A hallmark of vestibular disorders is the presence of _____, an abnormal sensation of motion.
22. The most common cause of vestibular vertigo is _____ _____ _____ _____ (BPPV). The typical cause is _____, when free floating otoconia migrate to the superior semicircular canal and stimulate the vestibular system with changes in head position.

Discussion Questions

1. Discuss why it may be important to identify and understand the underlying cause of a hearing loss.
2. Explain Eustachian tube dysfunction and how it contributes to the occurrence of otitis media with effusion. Why is this condition so much more prevalent in children?
3. Compare and contrast syndromic and nonsyndromic inherited disorders.
4. Explain why the effects of presbyacusis on hearing are difficult to determine exactly.
5. Explain the concepts of time-intensity tradeoff and damage-risk criteria and how they relate to noise-induced hearing loss.
6. Discuss how the effects of certain causes of hearing loss are compounded by exposure to ototoxic medications.
7. The underlying cause of "dizziness" is often difficult to determine in patients. Speculate as to why this might be true.

Resources

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Web Sites

American Hearing Research Foundation
www.american-hearing.org

Baylor College of Medicine, Department of Otolaryngology, Head and Neck Surgery
www.bcm.edu/oto

Centers for Disease Control and Prevention, Noise and Hearing Loss Prevention
http://www.cdc.gov/niosh/topics/noise/

eMedicine
Search under Specialties for Otolaryngology and Facial Plastic Surgery
www.emedicine.com

American Academy of Otolaryngology, Head and Neck Surgery
www.entnet.org/index.cfm

Genetics Home Reference, Guide to Genetic Conditions
http://www.ghr.nlm.nih.gov/

Merck & Co., Inc.
Search under the Merck Manual of Diagnosis and Therapy for Ear, Nose, Throat, and Dental Disorders. Under Inner Ear Disorders look up Drug-Induced Ototoxicity
www.merck.com

National Center for Biotechnology Information—Click on OMIM (Online Mendelian Inheritance in Man)
www.ncbi.nlm.nih.gov

National Institute on Deafness and Other Communication Disorders (NIDCD)
www.nidcd.nih.gov

Medline Plus
Search for acoustic neuroma under Health Topics
www.medlineplus.gov



5

INTRODUCTION TO HEARING ASSESSMENT

Learning Objectives

The First Question
- Referral-Source Perspective
- Importance of the Case History

The Audiologist's Challenges
- Evaluating Outer- and Middle-Ear Function
- Estimating Hearing Sensitivity
- Determining Type of Hearing Loss
- Measuring Speech Recognition
- Measuring Auditory Processing
- Measuring the Impact of Hearing Loss
- Screening Hearing Function

Summary

Short Answer Questions

Discussion Questions

Resources
- Articles and Books
- Web Sites

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- Describe the purpose of a hearing evaluation.
- List and explain the questions to be answered during an evaluation and identify tools for obtaining this information.
- Describe procedures for determination of hearing loss characteristics.
- Explain the features of the pure-tone audiogram.
- List and describe suprathreshold measures and explain their purpose.
- Define the terminology related to physical impairment and psychosocial outcomes of hearing dysfunction.
- Explain the purpose of hearing screening and describe how it is applied to various populations.

THE main purpose of a hearing evaluation is to define the nature and extent of hearing disorder. The hearing evaluation serves as a first step in the treatment of hearing loss. Toward this end, there are some common questions to be answered as a part of any audiologic evaluation. They include:

- Why is the patient being evaluated?
- Should the patient be referred for medical consultation?
- What is the patient's hearing sensitivity?
- How well does the patient understand speech?
- How well does the patient process auditory information?
- Does the hearing loss cause a communication problem?

Patients have their hearing evaluated for a number of reasons. The focus of a particular hearing evaluation, as well as the types and nature of tests that are used, will vary as a function of the reason. For example, many patients seek the professional expertise of an audiologist because they feel that they have hearing loss and may need hearing devices. In such cases, the audiologist seeks to define the nature and extent of the disorder, in a thorough manner, with an emphasis on factors that may indicate or contraindicate successful hearing-device use.

As another example, patients may be referred because they are seeking compensation for hearing loss that is allegedly caused

by exposure to noise in the workplace, by an accident, or by other means that may be compensible. In these cases, the audiologist must focus on hearing sensitivity, with suspicion aroused for exaggeration of the hearing impairment. The audiologist must use acceptable cross-checks to verify the extent of identified hearing impairment.

Audiologists are often called upon to evaluate the hearing of young children. In many cases, children are evaluated at an age when they are not able to cooperate with behavioral hearing assessment. In these cases, the audiologist must use **behavioral, electroacoustic,** and **electrophysiologic measures** as cross-checks in identification of hearing sensitivity levels.

Behavioral measures = pure-tone audiometry, speech audiometry.

Electroacoustic measures = immittance audiometry and otoacoustic emissions.

Electrophysiologic measures = auditory brainstem response.

Other children are evaluated not because of suspicion of a hearing sensitivity loss, but because of concerns about problems in the processing of auditory information. Here the emphasis is not on quantification of hearing sensitivity but on careful quantification of speech perception. Because time is often limited with younger children, the approach that is used by the audiologist is critical in terms of focusing on the nature of the concern.

Patients are often evaluated in consultation with otolaryngologists to determine the nature and extent of hearing loss that results from active disease processes. In such cases, the otolaryngologist is likely to treat the disease process with drugs or surgery and is interested in evaluating hearing before and after treatment. Careful quantification of middle-ear function and hearing sensitivity are often important features of the pre- and post-treatment assessment.

Some patients are evaluated simply to assure that they have normal hearing sensitivity. Newborns, children entering school, adults in noisy work environments, and a number of other individuals have their hearing sensitivity screened in an effort to rule out hearing disorder. The focus of the screening is on the rapid identification of those with normal hearing sensitivity, rather than the quantification of hearing loss.

Thus, although the fundamental goal of an audiologic assessment is similar for most patients, the specific focus of the evaluation can vary considerably, depending on the nature of the patient and problem. As a result, a very important aspect of the audiologic evaluation is the first question, *Why is the patient being evaluated?*

THE FIRST QUESTION

Why is the patient being evaluated? It sounds like such a simple question. Yet the answer is a very important step in the assessment process because it guides the audiologist to an appropriate evaluative strategy. There are usually two main sources of information for answering this question. One source is the nature of the referral. This alone often provides sufficient information to understand what the expected outcome of the evaluation will be. The other is the case history.

Referral-Source Perspective

There are many reasons for evaluating hearing and several categories of referral sources from which patients come to be evaluated by audiologists. Referral sources include the patient, the patient's parents, the patient's children, the patient's spouse, otolaryngologists, pediatricians, gerontologists, oncologists, neurologists, speech-language pathologists, other patients, attorneys, teachers, and nurses. The nature of the referral source is often a good indicator of why the patient is being evaluated.

Self-referrals or referrals from family members usually indicate that the patient has a significant communication disorder resulting from hearing loss. If it is a self-referral, the patient probably has been concerned about a problem with hearing for some time and has conceded to the possibility of **hearing-device** use. If it is a family referral, it is likely that the family members have noticed a decline in communication function and have urged the patient to seek professional consultation. In all cases of direct referrals, the audiologic evaluation proceeds by first addressing the issue of whether the disorder is of a nature

Hearing device = hearing aid or assistive listening device.

that can be treated medically. Once established, the evaluation proceeds with a focus on hearing assessment for the potential fitting of hearing devices.

Referrals from physicians and other health-care professionals do not always have as clear a purpose. That may seem unusual, but few days pass by in a busy clinic without some patients expressing that they have no idea why their doctors wanted them to have a hearing evaluation. In these cases, the specialty of the physician making the referral is usually helpful in determining why the patient was referred. For example, an adult referred by a neurologist is likely to be under suspicion of having some type of brain disorder. The neurologist is seeking to determine whether a hearing sensitivity loss exists, either for purposes of additional testing by **auditory evoked potentials** or to address whether the central auditory nervous system is involved in the dysfunction. As another example, a child referred by a speech-language pathologist has probably been referred either to rule out the presence of a hearing sensitivity loss as a contributing factor to a speech and language disorder or to assess auditory processing status. As a final example, when an otolaryngologist refers a patient for a hearing consultation, it will be for one of several reasons including:

An **auditory evoked potential** is a measurable response of the electrical activity of the brain in response to acoustic stimulation.

- the patient has a hearing disorder and entered the health-care system through the otolaryngologist;
- the patient is dizzy or has **tinnitus**, and the physician is concerned about the possibility of a tumor on the VIIIth cranial nerve;
- the patient has ear disease, and the physician is interested in pretreatment assessment of hearing;
- the patient is seeking compensation for a trauma-related incident that has allegedly resulted in a hearing problem, and the physician is interested in the nature and degree of that problem; or
- the physician has determined that the patient has a hearing problem that cannot be corrected medically or surgically and has sent the patient to the audiologist for evaluation and fitting of hearing aid amplification or other treatment as necessary.

The sensation of ringing or other sound heard in the ears or head is called **tinnitus**.

It is important to understand why the patient is being evaluated because it dictates the emphasis of the evaluative process. Occasionally, the interest of the referral source in the outcome of a hearing consultation is not altogether clear, and the audiologist must seek that information directly from the referral source prior to starting an evaluation.

Importance of the Case History

An important starting point of any audiologic evaluation is the case history. Sample adult and child case histories are shown on the pages that follow. An effective case history guides the experienced audiologist in a number of ways. It provides necessary information about the nature of auditory complaints, including whether it is in one ear or both; whether it is acute or chronic; and the duration of the problem. All of this information is important because it helps the audiologist to formulate clinical testing strategies.

Case histories are also important because they shed light on possible factors contributing to the hearing disorder. In adult case histories, questions are asked about exposure to excessive noise, family history of hearing loss, or the use of certain types of medication. This information serves at least three purposes. First, it begins to prepare the audiologist for what is likely to be found during the audiologic evaluation. As you learned in the last chapter, certain types of hearing loss configurations are typical of certain causative factors, and knowledge of the potential contribution of these factors is useful in preparing the clinician for testing. Second, knowledge about preventable factors in hearing loss, particularly noise exposure, will lead to appropriate recommendations about ear protection and other preventive measures. Third, some hearing loss is temporary in nature. Reversible hearing loss may result from recent noise exposure. It may also result from ingestion of high doses of certain drugs, such as aspirin. It is important to know whether the hearing impairment being quantified is temporary in nature or is the residual deficit that remains after reversible changes.

The Case History

Following are examples of case histories, one for adults and one for children. The adult form is for use by the patient; the pediatric form is for use by the parent. Regardless of which form is used, there are some commonalities of purpose:

- to secure proper identifying information;
- to provide information about the nature of auditory complaints; and
- to shed light on possible factors contributing to the hearing impairment.

Adult case histories also include information about:

- warning signs that may lead to medical referral;
- whether and under what circumstances a hearing disorder is restrictive; and
- whether consideration has been given to potential use of hearing aid amplification.

Case histories for children also include information about:

- speech and language development;
- general physical and psychosocial development; and
- academic achievement.

In addition, if the child has a history of otitis media, an in-depth case history into the nature of the disorder may be of interest to both the audiologist and the managing physician.

There are almost as many examples of case histories as there are clinics using them. Some important factors that you should keep in mind when considering a case history form:

- keep it at a simple reading level;
- keep it as concise as possible; and
- translate it into other languages common to your region.

The case history form should be designed not as an end in itself but as a form that will lead you into a discussion of the reasons that the patient is in your office and the nature of the auditory complaint.

Adult Case History

Name: _____ Age: _____ Birthdate: _____

Referred by: _____

Primary complaint: _____

Do you have hearing problems? Yes ____ No ____

Which ear? Right ____ Left ____ Both ____

Has the hearing loss been: Gradual? ____ Sudden? ____ Fluctuating? ____

Do you presently use a hearing device? Yes ____ No ____ For how long? _____

Are you interested in using a hearing device? Yes ____ No ____

Do you hear noises in your ears or head? Yes ____ No ____

Which ear? Right ____ Left ____ Both ____

How often do you hear noises? Constantly ____ Occasionally ____ Rarely ____

Do you ever have a feeling of fullness or stuffiness in your ears? Yes ____ No ____

Do you ever experience facial numbness, weakness, or tingling? Yes ____ No ____

Are you ever dizzy, unsteady, or off-balance? Yes ____ No ____

Is your dizziness accompanied by: Nausea? Yes ____ No ____

Vomiting? Yes ____ No ____

Noises in your ears? Yes ____ No ____

Have you ever had any ear surgery? Yes ____ No ____ Describe: _____

Have you ever been exposed to loud noises? Yes ____ No ____

Describe: _____ How recently? _____

Does anyone in your family have a hearing problem? Yes ____ No ____

Are you currently taking medication? Yes ____ No ____ Describe: _____

What is your occupation? _____

Authorization is hereby granted to this institution to release test findings. Please provide names and addresses of persons or agencies to which you would like this report sent:

1. _____ 2. _____ 3. _____

_____ _____ _____

_____ _____ _____

Signature: _____ Date: _____

Pediatric Case History

Name: _____ Age: _____ Birthdate: _____

Referred by: _____

Primary complaint: _____

Do you think your child has a hearing problem? Yes _____ No _____

Has your child ever had a hearing test before? Yes _____ No _____

Describe the results: _____

Does your child have ear infections? Yes _____ No _____ If so, please answer questions on reverse.

Has your child ever had ear surgery? Yes _____ No _____ Describe: _____

Do you believe your child's speech and language is developing normally? Yes _____ No _____

Do you believe your child's physical ability is developing normally? Yes _____ No _____

Does your child require special services, such as speech therapy or remedial help? Yes ___ No ___

Was the pregnancy normal? Yes _____ No _____

Describe complications: _____

Was the delivery of this child normal? Yes _____ No _____

Describe complications: _____

Has your child had any illnesses or medical conditions? Yes _____ No _____

Describe: _____

Is your child taking medication? Yes _____ No _____ Describe: _____

Does anyone in your family have a hearing problem? Yes _____ No

Is there any additional information that you believe might be helpful? _____

_____

Authorization is hereby granted to this institution to release test findings. Please provide names and addresses of persons or agencies to which you would like this report sent:

1. _____ 2. _____ 3. _____

_____ _____ _____

_____ _____ _____

Signature: _____ Date: _____

Otitis Media
Patient/Parent Questionnaire

Ear infections or middle-ear fluid can result in hearing problems. If your child has had recurrent ear infections or persistent middle-ear fluid, your answers to the following questions will help us to determine the necessary treatment for your child.

At what age did the ear infection or middle-ear fluid first occur?_____

How many ear infections have occurred in the last six months?_____

In the last twelve months? _____

How long has the current middle-ear infection or fluid been present? _____

Has treatment included the use of antibiotics? Yes _____ No _____

If you can, please list the medicines used and the duration of use:

Medicine: _____ Duration of use: _____

_____ _____

_____ _____

_____ _____

_____ _____

Has antibiotic prophylaxis (once-a-day dosage for an extended period) been tried?

Yes _____ No _____ Name of medicine: _____

Has your child had tubes inserted? Yes _____ No _____ How many times? _____

Has your child had a tonsillectomy or adenoidectomy? Yes _____ No _____

How many siblings are at home? _____

Is your child in day care? Yes _____ No _____

Does anyone smoke at home? Yes _____ No _____

Does your child: snore or have difficulty breathing at night? Yes ___ No ___

have recurrent sinusitis or colored nasal drainage? Yes ___ No ___

have recurrent tonsillitis or sore throats? Yes ___ No ___

have clumsiness, balance, or coordination problems? Yes ___ No ___

have difficulty breathing through the nose? Yes ___ No ___

have nasal allergies or food allergies? Yes ___ No ___

Also included on adult case histories are questions relating to general health and to specific problems that can accompany hearing disorder. These questions are important because the audiologist is often the entry point into health care and must be knowledgeable about warning signs that dictate appropriate medical referral. This cannot be understated. As a nonmedical entry point into the health-care system, audiologists must maintain a constant vigil for warning signs of medical problems. Thus, questions are asked about dizziness, numbness, weakness, tinnitus, and other signs that might indicate the potential for otologic, neurologic, or other medical problems.

Another very important aspect of the case history involves questions about communication ability. The goal here is to obtain information about whether the patient perceives that the hearing problem is resulting in a communication disorder and whether the patient has or would consider use of personal amplification. The questions about communication disorder begin to give the audiologist an impression of the extent to which a hearing problem is restrictive in some way and the circumstances under which the patient is experiencing the greatest difficulty. The questions about hearing devices are intended to "break the ice" on the issue and promote discussion of potential options for the first step in the treatment process.

Case histories for children are oriented in a slightly different way. Questions are asked of the parents about the nature and any problems associated with pregnancy and delivery. Case histories for children also include a checklist of known childhood diseases or conditions. These questions about health of the mother and the developing child are aimed at obtaining an understanding of factors that might impact hearing ability. They also provide the clinician with a better understanding of any factors that might influence testing strategies.

Case histories for children must also include inquiries about overall development and, specifically, about speech and language development. Children with hearing disorders of any degree should be considered at risk for speech and language delays or disorders. Screening for speech and language problems during an audiologic evaluation is an important role of the

audiologist, and that screening should begin with the case history. Questions relating to parental concerns and developmental milestones can serve as important aspects of the screening process. In addition, such information can provide the clinician with valuable insight about which test materials might be appropriate linguistically.

Another important aspect of a case history for children relates to academic achievement. Answers to questions about school placement and progress will help the audiologist to orient the evaluation and consequent recommendations toward academic needs.

One main benefit of the case history process is that the interaction with patients can reveal substantial information about their general health and communication abilities. For example, experienced clinicians will observe the extent to which patients rely on lipreading and will notice any speech and language abnormalities. They will also attend carefully to patients' physical appearance and **motoric abilities**.

Motoric abilities are muscle movement abilities.

Once the reason for referral is known and the case history is reviewed with the patient, the evaluative challenge begins. Prepared with a knowledge of why the patient is being evaluated and what information the patient hopes to gain, the audiologist can orient the evaluative strategy appropriately.

THE AUDIOLOGIST'S CHALLENGES

Regardless of the techniques that are used, the audiologist faces a number of clinical challenges during any audiologic evaluation. One of the first challenges is to determine whether the problem is strictly a communication disorder or whether there is an underlying active and/or treatable disease process that requires the patient to be referred for medical consultation. Treatable disorders of the outer and middle ears are common causes of auditory complaints. Thus, the first question in the evaluative process is whether these structures are functioning properly. Following that question, the evaluative strategy includes the determination of hearing sensitivity and type of hearing loss, measurement of speech perception, assessment of auditory processing ability, and estimate of hearing handicap.

Evaluating Outer- and Middle-Ear Function

As you have learned, structural changes in the outer and middle ears can cause functional changes and result in hearing impairment. Problems associated with the outer ear are usually related to obstruction or stenosis (narrowing) of the ear canal. The most common problem is an excessive accumulation or impaction of cerumen. When changes such as this occur, sound can be blocked from striking the tympanic membrane, and a loss in the conduction of sound will occur. The function of the tympanic membrane can also be reduced by either perforation or **sclerotic tissue** adding mass to the membrane. These changes result in a reduction in appropriate tympanic membrane vibration and a consequent loss in conduction of sound to the ossicular chain.

Sclerotic tissue = hardened tissue

The first step in the process of assessing outer- and middle-ear function is inspection of the ear canal. This is achieved with *otoscopy*. Otoscopy is simply the examination of the external auditory meatus and the tympanic membrane with an *otoscope*. An otoscope is a device with a light source that permits visualization of the canal and eardrum. Otoscopes range in sophistication from a handheld speculum like instrument with a light source, as shown in Figure 5-1, to a video otoscope, as shown in Figure 5-2. The ear canal is inspected for any obvious inflammation, growths, foreign objects, or excessive cerumen. If possible, the tympanic membrane is visualized and inspected for inflammation, perforation, or any other obvious abnormalities in structure. If an abnormality is noted during inspection, the patient should be referred for medical assessment following the audiologic evaluation.

If excessive or impacted cerumen is noted, the audiologist may choose to remove it or refer the patient to appropriate medical personnel for cerumen management. Cerumen management involves removal of the excessive or impacted wax in one of three ways:

- mechanical removal,
- suction, or
- irrigation.

Mechanical removal is the most common method and involves the use of small curettes or spoons to extract the cerumen. This is usually done using a speculum to open and straighten the ear



FIGURE 5-1 Photograph of a hand-held otoscope. (Photo courtesy of Welch Allyn, Inc.)

canal. Suction is sometimes used, especially when the cerumen is very soft. Irrigation is commonly used when the cerumen is impacted and is hard and dry. Irrigation involves directing a stream of water from an oral jet irrigator against the wall of the ear canal until the cerumen is loosened and extracted.

Following otoscopic inspection of the structures of the outer ear, the next step in the evaluation process is to assess the function of the outer- and middle-ear mechanisms. Problems in function of



FIGURE 5-2 Photograph of a video otoscope. (Photo courtesy of Welch Allyn, Inc.)

the middle ear can be classified into four general categories. Functional deficits can result from:

- significant negative pressure in the middle-ear cavity,
- an increase in the mass of the middle-ear system,
- an increase in the stiffness of the middle-ear system, and
- a reduction in the stiffness of the middle-ear system.

Negative pressure in the middle-ear space occurs when the Eustachian tube is not functioning appropriately, usually due to some form of upper respiratory blockage. Pressure cannot be equalized, and the trapped air is absorbed by the mucosal lining of the middle ear. This results in a reduction in air pressure in comparison to atmospheric pressure and can reduce the transmission of sound through the middle ear.

Increase in the mass of the middle-ear system usually occurs as a result of a fluid accumulation behind the tympanic membrane. Following prolonged negative pressure, the mucosal lining of the middle ear begins to excrete fluid that can block the effects of the tympanic membrane and ossicular chain. Mass increases also can occur as a result of cholesteatoma and other growths within the middle ear, which can have an influence similar to the presence of fluid. Any increase in the mass of the system can affect transmission of sound, particularly in the higher frequencies.

Increase in the stiffness of the middle-ear system results from some type of fixation of the ossicular chain. Usually this fixation is the result of a **sclerosis** of the bones that results in a fusion of the stapes at the oval window. Increases in stiffness of the ossicular chain can also affect transmission of sound, particularly in the lower frequencies.

Sclerosis is the hardening of tissue.

Decrease in the stiffness can have a similar affect. Abnormal reduction usually results from a break or disarticulation of the ossicular chain, which significantly reduces sound transmission.

It is important to evaluate outer- and middle-ear function for at least two reasons. First, a reduction in function usually occurs as a result of structural changes that are amenable to medical management. That is, the causes of structural and functional changes in the outer and middle ear usually can be treated with drugs or surgical intervention. Second, the changes in function of the outer- and middle-ear structures often lead to conductive hearing impairment. Because the ultimate goal of any hearing assessment is the amelioration of hearing loss, an important early question in the evaluation process is to what extent any disorder is the product of a disease process that can be effectively treated medically. Thus, one of the audiologist's first challenges is to assess outer- and middle-ear function. If conductive function is normal, then any hearing disorder is due to changes in the sensory mechanism. If this function is abnormal, then it remains to quantify the extent to which changes in its function contribute to the overall hearing disorder.

The best means for assessing outer- and middle-ear function is the use of **immittance audiometry**. Immittance audiometry, as you will learn, is an electroacoustic assessment technique that measures the

Immittance audiometry is a battery of measurements that assesses the flow of energy through the middle ear, including static immittance, typanometry, and acoustic reflex thresholds.

extent to which energy flows freely through the outer- and middle-ear mechanisms. Its use in the evaluation of middle-ear function developed during the late 1960s and early 1970s. It has gained widespread application both for screening middle-ear function and for more in-depth assessment. In fact, many clinicians embrace immittance audiometry to the extent that they begin every audiologic assessment with it. They believe that the assessment of outer- and middle-ear function is among the most important first steps in the hearing evaluation process.

Estimating Hearing Sensitivity

One of the best ways to describe hearing ability is by its sensitivity to sound. Similarly, one of the best ways to describe hearing disorder is by measuring a reduction in sensitivity to sound. Hearing sensitivity is usually defined by an individual's **threshold** of audibility of sound. Measurements are made to determine at what intensity level a tone or a word is just barely audible. That level is considered the threshold of audibility of the signal and is an accepted way of describing the sensitivity of hearing.

Threshold is the level at which a stimulus is just audible.

Substantial progress has been made in understanding hearing and in measuring hearing ability over the past half century. Yet to this day, the best single indicator of hearing loss, its impact on communication, and the **prognosis** for successful hearing-device use is the pure-tone audiogram. The audiogram is a graph, which depicts thresholds of hearing sensitivity, determined behaviorally, as a function of pure-tone frequency. It has become the cornerstone of audiologic assessment and, as a consequence perhaps, the generic indicator of what is perceived to be an individual's hearing ability. Because the audiogram is such a pervasive means for describing hearing sensitivity, it has become the icon for hearing sensitivity itself. It has provided a common language with which to describe an individual's hearing. As a result, when we characterize the hearing ability of an individual, we are likely to think in terms of the pure-tone audiogram.

Prognosis is the prediction of the course or outcome of a disease or treatment.

The audiologist's role in assessment of hearing sensitivity is most often determination of the pure-tone audiogram. In some instances,

however, particularly in infants and young children or in individuals who are feigning hearing loss, a reliable pure-tone audiogram cannot be obtained. In these cases, other techniques for estimating hearing sensitivity must be used. Regardless, even in these cases, the challenge remains to try to "predict the audiogram."

The measurement of hearing sensitivity provides a means for describing degree and configuration of hearing loss. If normal listeners have hearing thresholds at one level and the patient being tested has thresholds at a higher level, then the difference is considered the amount of hearing loss compared to normal. By its nature then, a pure-tone audiogram provides a depiction of the amount of hearing loss.

Measurements of sensitivity provide a substantial amount of information about hearing ability. Estimates are made of degree of hearing loss, providing a general statement about the severity of sensitivity impairment. Estimates are also made of degree of loss as a function of frequency, or configuration of hearing loss. The configuration of a hearing loss is a critical factor in speech understanding and in fitting personal amplification.

There are several ways to measure hearing sensitivity. Typically, sensitivity assessment begins with the behavioral determination of a threshold for speech recognition. This speech threshold provides a general estimate of sensitivity of hearing over the **speech frequencies**, generally described as the pure-tone average of thresholds at 500, 1000, and 2000 Hz. Sensitivity assessment proceeds with behavioral pure-tone audiometry for determination of the audiogram. Pure-tone thresholds provide estimates of hearing sensitivity at specific frequencies.

The **speech frequencies** are 500, 1000, and 2000 Hz.

In some cases, behavioral testing cannot be completed. In these instances, estimates can be made via auditory evoked potential measurements. Auditory evoked potentials are responses of the brain to sound. Electrical activity of the nervous system that is evoked by auditory stimuli can be measured at levels very close to behavioral thresholds. Thus, for infants or those who will not or cannot cooperate with behavioral testing, these electrophysiologic estimates of hearing sensitivity provide an acceptable alternative.

Determining Type of Hearing Loss

Another challenge to the audiologist is the determination of the type of hearing loss. If a loss occurs as a result of changes in the outer or middle ear, it is considered a loss in the conduction of sound to the cochlea, or a **conductive hearing loss**. If a loss occurs as a result of changes in the cochlea, it is considered a loss in function at the sensory-neural junction, or a **sensorineural hearing loss**. If a loss occurs as a result of changes in both the outer or middle ear and the cochlea, it will have both a conductive and a sensory component and be considered a **mixed hearing loss**. Finally, if a loss occurs as a result of changes to the VIIIth nerve or auditory brainstem, it is considered a **retrocochlear disorder**.

A **conductive hearing loss** is one that occurs as a result of outer- or middle-ear disorder.

A **sensorineural hearing loss** is one that occurs as a result of cochlear disorder.

A **mixed hearing loss** is one that has both a conductive and sensorineural component.

A **retrocochlear disorder** is one that occurs as a result of VIIIth nerve or auditory brainstem disorder.

Determination of the type of hearing loss is an important contribution of the audiologic assessment. A crucial determination is whether a conductive hearing loss is present. Although the function of outer- and middle-ear structures is readily determined by immittance audiometry, the extent that a disorder in function results in a measurable hearing loss is not. Therefore, one important aspect of the audiologic assessment is measurement of the degree of conductive and sensorineural components of the hearing loss. As stated earlier, knowledge of this is valuable because conductive loss is caused by disorders of the outer or middle ear, most of which are treatable medically. Knowledge of the extent to which a loss is conductive will provide an estimate of the residual sensorineural deficit following medical management. For example, if the loss is entirely conductive in nature, then treatment is likely to return hearing sensitivity to normal. If the loss is partially conductive and partially sensorineural, then a residual sensorineural deficit will remain following treatment. If the loss is entirely sensorineural, then medical treatment is unlikely to be of value.

As you learned in Chapter 3, to evaluate the type of hearing loss, hearing sensitivity is measured by presenting sounds in two ways. The most common way is to present sound through an earphone to assess hearing sensitivity of the entire auditory mechanism. This is referred to as **air-conduction** testing. The other way to present sound to the ear is by placing a vibrator in contact with the skin, usually behind the ear or on the forehead. Sound is then directed to the vibrator, which transmits signals directly to the

The transmission of sound through the outer and middle ear to the cochlea is by **air conduction**.

cochlea via **bone conduction**. Direct bone-conduction stimulation virtually bypasses the outer and middle ears to assess sensitivity of the auditory mechanism from the cochlea and beyond. The difference between hearing sensitivity as determined by air conduction and the sensitivity as determined by bone conduction represents the contribution of the function of the outer and middle ear. If sound is being conducted properly by these structures, then hearing sensitivity by air conduction is the same as hearing sensitivity by bone conduction. If a hearing loss is present, that loss is attributable to changes in the sensory mechanism of the cochlea or neural mechanism of the auditory nervous system and is referred to as a sensorineural hearing loss. If sound is not being conducted properly by the outer and middle ear, then air-conduction thresholds will be poorer than bone-conduction thresholds (i.e., an *air-bone gap* will be present), reflecting a loss in conduction of sound through the outer and middle ears, or a conductive hearing loss.

The transmission of sound to the cochlea by vibration of the skull is by **bone conduction**.

One other question about type of hearing loss relates to whether the site of disorder is in the cochlear or retrocochlear structures. Retrocochlear disorders result from tumors or other changes in the auditory peripheral and central nervous systems. The underlying disease processes that result in nervous system disorders are often life-threatening. For example, as you learned in Chapter 4, one of the more common retrocochlear disorders results from a tumor growing on the VIIIth cranial nerve, referred to as a **cochleovestibular schwannoma**. A cochleovestibular schwannoma is a benign growth that often emerges from the vestibular branch of the VIIIth nerve. As it grows, it begins to challenge the nerve for space within the internal auditory canal, resulting in pressure on the nerve that can affect its function. As it grows into the brainstem, it begins to compete for space, which results in pressure on other cranial nerves and brainstem structures. If an acoustic tumor is detected early, the prognosis for successful surgical removal and preservation of hearing function is good. Delay in detection can result in substantial permanent neurologic disorder and reduces the prognosis for preservation of hearing.

A **cochleovestibular schwannoma** is a benign tumor of the VIIIth cranial (auditory and vestibular) nerve.

Neurologic disorders of the peripheral and central auditory nervous system may result in hearing loss or other auditory complaints such as tinnitus or dizziness. It is not uncommon for a patient with

an acoustic tumor to report a loss of hearing sensitivity, muffled sound, vertigo, or tinnitus as a first symptom of the effects of the tumor. That patient may seek assistance from a physician or from an audiologist. Thus, the audiologist's responsibility in all cases of patients with auditory complaints is to be alert for factors that may indicate the presence of a retrocochlear disorder. If the audiologic evaluation reveals results that are consistent with retrocochlear site of disorder, the audiologist must make the appropriate referral for medical consultation.

On most of the measures used throughout the audiologic evaluation, there are indicators that can alert the audiologist to the possibility of retrocochlear disorder. Acoustic reflex thresholds, symmetry of hearing sensitivity, configuration of hearing sensitivity, and measures of speech recognition all provide clues as to the nature of the disorder. Any results that arouse suspicion about the integrity of the nervous system should serve as an immediate indicator of the need for medical referral.

Prior to the advent of sophisticated imaging and radiographic techniques, specialized audiologic assessment was an integral part of the differential diagnosis of auditory nervous system disorders. Behavioral measures of differential sensitivity to loudness, loudness growth, and auditory adaptation were designed to assist in the diagnostic process. As imaging and radiographic techniques improved, the ability to visualize ever-smaller lesions of the auditory nervous system was enhanced. These smaller lesions were less likely to have an impact on auditory function. As a result, the sensitivity of the behavioral audiologic techniques diminished.

For a number of years in the late 1970s and early 1980s, auditory evoked potentials were used as a very sensitive technique for assisting in the diagnosis of neurologic disorders. For a time, these measures of neurologic function were thought to be even more sensitive than radiographic techniques in the detection of lesions. However, the advent of magnetic resonance imaging (MRI) techniques, permitting the visualization of even smaller lesions, reduced the sensitivity of these functional measures once again.

Today, auditory evoked potentials, particularly the auditory brainstem response, remains a valuable indicator of VIIIth nerve and

auditory brainstem function. Audiologists are often consulted to carry out evoked-potential testing as a first screen in the process of neurologic diagnosis. Many neurologists and otologists continue to seek an assessment of **neural function** by evoked potentials to supplement the assessment of **structure** provided by the MRI procedures.

Evoked potentials assess **neural function**.

MRI assesses **neural structure**.

Measuring Speech Recognition

Once a patient's hearing thresholds have been estimated, it is important to determine **suprathreshold** function, or function of the auditory system at intensity levels above threshold. Threshold assessment provides only an indicator of the sensitivity of hearing, or the ability to hear faint sounds. Suprathreshold measures provide an indicator of how the auditory system deals with sound at higher intensity levels.

An intensity level that is above threshold is termed **suprathreshold**.

The most common suprathreshold measure in an audiologic evaluation is that of **speech recognition**. Measures of speech recognition provide an estimate of how well an individual uses residual hearing to understand speech signals. That is, if speech is of sufficient intensity, can it be recognized appropriately?

The ability to perceive and identify speech is called **speech recognition**.

Measurement of speech recognition is important for at least two reasons. The most important reason is that it provides an estimate of how well a person will hear speech at suprathreshold levels, thereby providing one of the first estimates of how much a person with a hearing loss might benefit from a hearing device. In general, if an individual has a hearing sensitivity loss and good speech-recognition ability at suprathreshold levels, the prognosis for successful hearing-aid use is good. If an individual has poor speech-recognition ability at suprathreshold levels, then making sound louder with a hearing device is unlikely to provide as much benefit.

Measurement of speech recognition is also important as a screen for retrocochlear disorder. In most cases of hearing loss of cochlear origin, speech-recognition ability is predictable from the degree and configuration of the audiogram. That is, given a hearing sensitivity loss of a known degree and configuration, the ability to recognize speech is roughly equivalent among individuals and

nearly equivalent between ears within an individual. Expectations of speech-recognition ability, then, lie within a certain predictable range for a given hearing loss of cochlear origin. In many cases of hearing loss of retrocochlear origin, however, speech-recognition ability is poorer than would be expected from the audiogram. Thus, if performance on speech-recognition measures falls below that which would be expected from a given degree and configuration of hearing loss, suspicion must be aroused that the hearing loss is due to retrocochlear rather than cochlear disorder.

Monosyllabic word tests are tests that consist of one-syllable words typically containing speech sounds that occur with similar frequency as those of conversational speech.

Phonetic pertains to an individual speech sound.

Speech-recognition ability is usually measured with **monosyllabic word tests**. Several tests have been developed over the years. Most use single-syllable words in lists of 25 or 50. Lists are usually developed to resemble, to some degree, the **phonetic** content of speech in a particular language. Word lists are presented to patients at suprathreshold levels, and the patients are instructed to repeat the words. Speech recognition is expressed as a percentage of correct identification of words presented.

Measuring Auditory Processing

Auditory processing is how the auditory system utilizes acoustic information.

Another suprathreshold assessment is the evaluation of **auditory processing** ability. Auditory processing ability is usually defined as the process by which the central auditory nervous system transfers information from the VIIIth nerve to the auditory cortex. The central auditory nervous system is a highly complex system that analyzes and processes neural information from both ears and transmits that processed information to other locations within the nervous system.

Much of our knowledge of the way in which the brain processes sound has been gained from studying systems that are abnormal due to neurologic disorders. The central auditory nervous system plays an important role in comparing sound at the two ears for the purpose of sound localization. The central auditory nervous system also plays a major role in extracting a signal of interest from a background of noise. While signals at the cochlea are analyzed exquisitely in the frequency, amplitude, and temporal domains, it is in the central auditory nervous system where those fundamental analyses are eventually perceived as speech or some other meaningful nonspeech sound.

If we understand the role of audiologic evaluation as the assessment of hearing, then we can begin to understand the importance of evaluating more than just the sensitivity of the ears to faint sounds and the ability of the ear to recognize single-syllable words presented in quiet. Although both measures provide important information to the audiologic assessment, they stop short of offering a complete picture of an individual's auditory ability. Certainly, as we think of the complexity of auditory perception, the ability to follow a conversation in a noisy room, the effortless ability to localize sound, or even the ability to recognize someone from the sound of footsteps, we begin to understand that the rudimentary assessments of hearing sensitivity and speech recognition do not adequately characterize what it takes to hear. Neither do they adequately describe the possible disorders that a person might have.

Techniques that were once used to assist in the diagnosis of neurologic disease are now used in the assessment of communication problems that occurs as a result of auditory processing disorder. Speech audiometric measures that are sensitized in certain ways are now commonly used to evaluate auditory processing ability. A typical battery of tests might include:

- the assessment of speech recognition across a range of signal intensities;
- the assessment of speech recognition in the presence of **competing signals**; and
- the measurement of **dichotic listening**, which is the ability to process two different signals presented simultaneously to the two ears.

Competing signal is background noise.

Listening to different signals presented to each ear simultaneously is called **dichotic listening**.

Results of such an assessment provide an estimate of auditory processing ability and a more complete profile of a patient's auditory abilities and impairments. Such information is often useful in providing guidance regarding appropriate amplification strategies or other rehabilitation approaches.

Measuring the Impact of Hearing Loss

Assessment of hearing sensitivity, measurement of speech understanding, and estimates of auditory processing abilities are all measures of a patient's hearing ability or hearing disorder. The question

that remains to be asked is whether a hearing sensitivity loss, reduction in speech understanding, or auditory processing disorder is having an impact on communication ability. Asked another way, is a hearing disorder causing limitations on a patient's activity or restrictions on that patient's involvement in life activities?

Impairment refers to abnormal or reduced function.

Disability refers to a functional limitation imposed by an impairment.

Handicap refers to the obstacles to psychosocial function resulting from a disability.

The traditional approach to describing the impact of hearing loss is in terms of impairment, disability, and handicap. A hearing **impairment** is the actual dysfunction in hearing that is described by the various measures of hearing status. Hearing **disability** can be thought of as the functional limitations imposed by the hearing impairment. Hearing **handicap** can be thought of as the obstacles placed on psychosocial functions imposed by the disability.

A more modern approach to describing the impact that hearing loss is having on communication is in terms of how changes in structure and function (impairment) limit activities (disability) or restrict participation in activities (handicap). In these terms, reduced hearing function constitutes a disorder. The impact of that disorder can be described in three components. The disorder is caused by a problem in body structure and function, resulting in an impairment. The impairment may result in **activity limitations**, or difficulties a person has in executing activities. The impairment may also result in **participation restrictions**, or problems a person has in involvement in life situations. Perhaps a simple example will help to clarify the terminology. If a person has a sensorineural hearing loss (impairment), it will cause difficulty hearing soft sounds (activity limitation) and may cause a problem with the ability to interact with grandchildren (participation restriction).

Activity limitations are difficulties an individual has in executing activities.

Participation restrictions are problems an individual experiences in involvement in life situations.

Audiologists know that the mere presence of hearing loss does not necessarily result in activity limitations or participation restrictions. Although there is a relationship between degree of loss and activity limitation or participation restriction, it is not necessarily a close one in individual patients. For example, a mild hearing sensitivity loss of gradual onset may not result in activity limitations for an 80-year-old with limited communication demands. The same mild sensitivity loss of sudden onset in a person whose livelihood is tied to verbal communication could impose substantial activity limitations and participation restrictions. Thus, the presence of

a mild disorder can impose a significant handicap to one person, whereas the presence of a substantial impairment may be only mildly restrictive to another.

Because of the disparity among impairment, activity limitation, and participation restriction, it is important to assess the extent of limitation and restriction that results from impairment. Such an assessment often leads to a clear set of goals for the treatment process. If the goal of audiologic assessment is to define hearing disorder for the purpose of providing appropriate strategies for amelioration of the resultant communication limitations and restrictions, then there is no better way to complete the assessment process than with an evaluation of the nature and extent of the consequences of the disorder.

The most efficacious way of measuring activity limitations and participation restrictions is by self-assessment scales. Several scales have been developed that are designed to assess both the extent of hearing disability and the social and emotional consequences of hearing loss. That is, the scales were designed to determine the extent to which an auditory disorder is causing a hearing problem and the extent to which the hearing problem is affecting quality of life. Generally, these scales consist of a series of questions designed to provide a profile of the nature and extent of activity limitation and participation restriction. The patient is typically asked to complete the questionnaire prior to the audiologic evaluation. These scales have also been used following hearing aid fitting in an effort to assess the impact of hearing aids on the limitation or restriction. Audiologists also use these scales with spouses or other significant individuals in the patient's life as a way of assessing the impact of the disorder on family and other social interactions. An example of a self-assessment scale is shown in Figure 5-3. Scales have also been developed to assess handicap related to tinnitus and dizziness.

Screening Hearing Function

One other challenge that an audiologist faces involves the screening of hearing function. Hearing screening is designed to separate those with normal auditory function from those who need additional testing. The challenge of the audiologist in the screening process is usually different than the challenges faced in the conventional audiologic assessment. Typical screening measures are simplified to

Question:	Response
1. Does a hearing problem cause you to feel embarrassed when meeting new people?	yes sometimes no
2. Does a hearing problem cause you to feel frustrated when talking to members of your family?	yes sometimes no
3. Do you have difficulty hearing when someone speaks in a whisper?	yes sometimes no
4. Do you feel handicapped by a hearing problem?	yes sometimes no
5. Does a hearing problem cause you difficulty when visiting friends, relatives, or neighbors?	yes sometimes no
6. Does a hearing problem cause you to attend religious services less often than you would like?	yes sometimes no
7. Does a hearing problem cause you to have arguments with family members?	yes sometimes no
8. Does a hearing problem cause you difficulty when listening to TV or radio?	yes sometimes no
9. Do you feel that any difficulty with your hearing limits or hampers your personal or social life?	yes sometimes no
10. Does a hearing problem cause you difficulty when in a restaurant with relatives or friends?	yes sometimes no

yes = 4 points; sometimes = 2 points; no = 0 points

Scores range from 0 to 40, with higher scores indicating greater perceived handicap

FIGURE 5-3 An example of a self-assessment scale, the Hearing Handicap Inventory for the Elderly, administered to determine the impact of hearing loss. (From The Hearing Handicap Inventory for Adults: A New Tool, by I. Ventry and B. Weinstein, *1982, Ear and Hearing, 3,*128-134. Reprinted with permission.)

an extent that the actual procedures can be carried out by technical personnel. The audiologist's role includes education and training of technical staff, continual monitoring of screening results, and follow-up audiologic evaluation of screening referrals.

Audiologist Profile

Jennifer Sherwood, M.A., FAAA



Where I Live: The San Francisco Bay Area

Where I Work: The California Newborn Hearing Screening Program. The Newborn Hearing Screening Program (NHSP) in California is under the Children's Medical Services Branch of the California Department of Health Care Services.

What I Do: I am the program audiologist for the NHSP. My position is different from many audiologists in that I no longer have direct patient contact. While I enjoyed clinical practice, and pediatrics in particular, my current position has a greater impact on the early identification of infants with hearing loss than I was making in my clinical role. As the program audiologist, I create statewide policies for both the NHSP and ongoing audiologic care for children with hearing loss through the California Children's Services (CCS) Program. I work one-on-one with audiologists throughout the state to ensure that infants are receiving the current standard of care for audiology. I act as a liaison between hospital screening programs, audiology providers, and the county CCS program staff. I represent the NHSP at local, state, and national meetings and conferences. The position has afforded me the opportunity to meet clinicians, researchers, and state-level audiologists from around the country that I wouldn't have met otherwise. I could not have asked for a better opportunity.

Why Audiology? I wanted a career in which I felt like I was making a difference. I have found both my clinical and administrative experiences to be very rewarding. Audiology is one of the few professions in which you can actually see the positive impact that your interactions can have on an individual or family.

Screening programs are usually aimed at populations of individuals who are at risk for having hearing disorder or individuals whose undetected hearing disorder could have a substantive negative effect on communication ability. There are three major groups that undergo hearing screening:

- newborns,
- school-age children, and
- adults in occupations that expose them to potentially dangerous levels of noise.

Newborn Hearing Screening

The goal of newborn hearing screening is to identify any child with a significant sensorineural, permanent conductive, or neural hearing loss and to initiate treatment by 6 months of age. To achieve this goal, the hearing of newborns is screened before they leave the hospital.

Newborn hearing screening became fairly common in the 1970s and 1980s for infants who were determined to be at risk for potential hearing loss. Risk factors, or indicators, presented in Table 5-1, place an infant in a category that requires hearing screening and follow-up.

Although these early programs were effective in identifying at-risk infants with hearing disorder, it became apparent that as many as half of all infants with significant sensorineural hearing loss do not have any of the risk-factor indicators. As of the early 1990s, the average age of identification of children with significant hearing loss was estimated to be an alarming 2.5 years in many areas of the United States. Because of the failure of the system to identify half of the children with hearing loss and because of the extent of delay in identifying those children who were not detected early, comprehensive, or universal, newborn hearing screening programs were implemented. Today, early hearing detection and intervention (EHDI) systems exist throughout the United States. Newborn hearing screening is now common practice and is compulsory in many states.

Newborn screening has as its goal the hearing screening of all children, at birth, before discharge from the hospital. Infant hearing screening is usually carried out by technicians, volunteers, or nursing personnel, under the direction of hospital-based audiologists.

An **ABR** or **auditory brainstem response** is an electrophysiological response to sound, consisting of five to seven identifiable peaks that represent neural function of auditory pathways.

The screening of newborns requires the use of techniques that can be carried out without active participation of the patient. Two techniques have proven to be most useful. The **auditory brainstem response (ABR)** is an electrophysiologic technique that is used successfully to screen the hearing of infants. It involves attaching electrodes to the infant's scalp and recording

TABLE 5-1 The Joint Committee on Infant Hearing has identified the following indicators that place an infant into a category of being at risk for significant sensorineural hearing loss, thereby requiring hearing screening and follow-up

Indicators for Those Not Screened at Birth
48 or more hours in an intensive care nursery
Stigmata or findings associated with a syndrome known to include hearing loss
Family history of childhood sensorineural hearing loss
Craniofacial anomalies
Inutero infection, including CMV, herpes, toxoplasmosis, or rubella
Indicators for Those at Risk for Late-onset or Progressive Hearing Loss
Parental concern regarding hearing, speech, or language delay
Family history of permanent hearing loss
Stigmata or findings associated with a syndrome known to include hearing loss
Post-natal infection, including bacterial meningitis
In utero infection, including CMV, herpes, toxoplasmosis, syphilis, or rubella
Neonatal indicators, including:
hyperbilirubinemia with exchange transfusion
persistent pulmonary hypertension with mechanical ventilation
use of extracorporeal membrane oxygenation
Syndromes associated with progressive hearing loss, including:
Neurofibromatosis
Osteopetrosis
Usher syndrome
Neurodegenerative disorders such as Hunter syndrome
Sensory motor neuropathies, including:
Friedreich ataxia
Charcot-Marie-Tooth syndrome
Head trauma
Recurrent or persistent OME for at least 3 months.

Principles of Universal Newborn Hearing Screening

- All infants have access to hearing screening using a physiologic measure by 1 month of age. Newborns who receive routine care have access to hearing screening during their hospital birth admission. Newborns in alternative birthing facilities, including home births, have access to and are referred for screening before 1 month of age. All newborns or infants who require neonatal intensive care receive hearing screening before discharge from the hospital.
- All infants who do not pass the birth admission screen and any subsequent rescreening begin appropriate audiologic and medical evaluations to confirm the presence of hearing loss before 3 months of age.
- All infants with confirmed permanent hearing loss receive services before 6 months of age in interdisciplinary intervention programs.
- EHDI systems should be family centered, and families should have access to information about all forms of intervention and treatment.
- The child should have immediate access to all forms of hearing technology, including hearing aids, cochlear implants, and other assistive devices.
- All infants and children, regardless of screening outcome or risk indicators, should be monitored for hearing loss in the *medical home*. This monitoring should include regular surveillance of developmental milestones, auditory skills, parental concerns, and middle-ear status. The medical home concept refers typically to the pediatrician or other primary-care physician.

(From the Joint Committee on Infant Hearing, 2007, Year 2007 position statement: Principles and guidelines for early hearing detection and intervention programs, *Pediatrics*, *120*, 898–921.)

electrical responses of the brain to sound. It is a reliable measure that is readily recorded in newborns. For screening purposes, the technique is often automated (automated ABR or AABR) to limit testing interpretation errors. Another technique is the measurement of **otoacoustic emissions (OAEs)**. OAEs are small-amplitude sounds that occur in response to stimuli being delivered to the ear. A sensitive microphone placed into the ear canal is used to monitor the presence of the response following stimulation. OAEs are reliably recorded in most infants who have normal cochlear function. There are various advantages and disadvantages to these two techniques. Most successful programs have developed strategies to incorporate both techniques in the screening of all newborns.

Otoacoustic emissions (OAEs) are measurable echoes emitted by the normal cochlea related to the function of the outer hair cells.

School-Age Screening

Not all children who have significant hearing disorder are born with it. Some develop it early in childhood and will be missed by the early screening process. As a result, for many years efforts have been made to screen the hearing of children as they enter school. School screening programs are aimed at identifying children who develop hearing loss later in childhood or whose hearing disorder is mild enough to have escaped early detection. School screenings are usually carried out by nursing or other school personnel under the direction of an educational audiologist. It is not uncommon for screenings to occur upon entry into school, annually from kindergarten through grade 3, and then again at grades 7 and 11.

Screening the hearing of children in schools is usually accomplished with behavioral pure-tone audiometry techniques. Typically, the intensity level of the audiometer is fixed at 20 to 30 dB, depending on the acoustic environment, and responses are screened across the audiometric frequency range. Children who do not pass the screening are referred to the audiologist for a complete audiologic evaluation. Most screening of school-age children also includes an assessment of middle-ear function. Because young children are at risk for developing middle-ear diseases, some of which can go undetected, efforts

are made to evaluate middle-ear status with immittance audiometry screening.

Workplace Screening

Screening programs have also been developed for adults who are at risk for developing hearing loss, usually due to noise exposure. Two such groups are:

- individuals who are entering the military or
- employees who are starting jobs in work settings that will expose them to potentially damaging levels of noise.

An initial audiogram obtained for comparison with later audiograms to quantify any change in hearing sensitivity is called a **baseline audiogram**.

These people are usually subjected to preenlistment or preemployment determination of **baseline audiograms**. In addition, they are reevaluated periodically in an effort to detect any changes that may be attributable to noise exposure in the workplace.

Screening of adults is usually accomplished by automated audiometry. Automated screening makes use of computer-based instruments that are programmed to establish hearing sensitivity thresholds across the audiometric frequency range. These automated instruments have proven to be effective when applied to adult populations with large numbers of individuals who have normal hearing sensitivity.

The audiologist's role is usually to coordinate the program, ensure the validity of the automated screening, and follow up on those who fail the screening and those whose hearing has changed on reevaluation.

Summary

- The main purpose of a hearing evaluation is to define the nature and extent of hearing disorder.
- The hearing evaluation serves as a first step in the treatment of hearing loss that results from the disorder.
- Although the fundamental goal of an audiologic assessment is similar for most patients, the specific focus of the evaluation can vary considerably, depending on the nature of the patient and problem.

- The answer to the question *Why is the patient being evaluated?* is an important step in the assessment process because it guides the audiologist to an appropriate evaluative strategy. The nature of the referral source is often a good indicator of why the patient is being evaluated.
- An important starting point of any audiologic evaluation is the case history. An effective case history guides the experienced audiologist in a number of ways.
- One of the first challenges an audiologist faces is to determine whether a patient's problem is strictly a communication disorder or if there is an underlying disease process that requires medical consultation.
- The audiologic evaluation strategy includes determination of hearing sensitivity and type of hearing loss, measurement of speech understanding, assessment of auditory processing ability, and estimate of communication limitations and restrictions.
- The best single indicator of hearing loss, its impact on communication, and the prognosis for successful hearing aid use is the pure-tone audiogram.
- Suprathreshold measures provide an indicator of how the auditory system deals with sound at higher intensity levels. The most common suprathreshold measure in an audiologic evaluation is that of speech recognition.
- Another suprathreshold assessment is the evaluation of auditory processing ability, or the process by which the central auditory nervous system transfers information from the VIIIth nerve to the auditory cortex.
- Because of the disparity among impairment, disability, and handicap, it is important to assess the degree of activity limitation and participation restriction that results from the impairment. The most efficacious way of measuring limitation and restriction is by self-assessment scales.
- One other challenge that an audiologist faces involves the screening of hearing function of newborns, children entering school, and adults in occupations that expose them to potentially dangerous levels of noise.

Short Answer Questions

1. The purposes of hearing assessment are to determine the _____ and _____ of hearing loss.
2. Information regarding auditory complaints, possible contributing factors to a hearing loss, communication difficulty, and information regarding development may be obtained during the _____ _____.
3. Inspection of the ear canal for evidence of inflammation, foreign objects, excessive cerumen, and other abnormalities is known as _____. This is generally performed using an _____, a device with a light source and magnification that permits visualization of the ear canal.
4. Three types of procedures for removal of _____ from the ear canal are mechanical removal, _____, and suction.
5. The use of _____ audiometry allows for assessment of the flow of energy through the middle ear. Three measures that can be obtained are _____ immittance, tympanometry, and acoustic reflex thresholds.
6. Immittance audiometry may reveal changes in flow of energy through the middle ear with various conditions. A significant _____ pressure may be found with Eustachian tube dysfunction. Increases in _____ in the system may be found with fluid accumulation or growths behind the tympanic membrane. Increases in the _____ of the system may be found with _____ chain fixation, while decreases may be found with _____ of the ossicular chain.
7. Hearing sensitivity is typically defined by determination of the _____ of audibility of sound. This information is typically obtained using _____-_____ stimuli.
8. Hearing thresholds are charted on a graph of intensity as a function of pure-tone frequency, known as an _____.
9. The _____-recognition threshold provides the lowest level at which speech can be perceived. It provides an estimate of thresholds for the "speech frequencies": _____, _____, and _____ Hz.

10. In order to separate conductive and sensorineural components of hearing loss, different presentation of stimuli are utilized. In _____-_____ (AC) presentation, sound is presented through the air to the tympanic membrane. In _____-_____ (BC) presentation, sound is presented via a vibrator, which directly transmits sounds through the bones of the skull to the cochlea, bypassing the outer- and middle-ear systems.
11. A significant difference between bone-conduction and air-conduction thresholds is termed an _____-_____ _____. This represents a conductive component of a hearing loss.
12. Major types of hearing loss can be determined from the thresholds represented on the audiogram. A _____ hearing loss is demonstrated by the presence of an air-bone gap. A _____ hearing loss has elevated thresholds with no air-bone gap. Elevated bone-conduction thresholds and the presence of an air-bone gap characterize a _____ hearing loss.
13. Measurements of _____ function demonstrate how the auditory system performs at intensity levels greater than threshold.
14. Speech-_____ testing is a type of suprathreshold test in which _____ (single-syllable) word lists are presented to listeners.
15. Abnormal or reduced function of hearing is known as _____. The functional limitation imposed by a hearing loss is termed a _____. Obstacles to psychosocial function resulting from a disability are referred to as a _____.
16. Hearing _____ is a method of separating those individuals with normal auditory function from those who need additional testing.
17. The goal of hearing screening in _____ is to determine presence of significant sensorineural hearing loss for the purpose of providing treatment by _____ of age.
18. Two measures commonly used for the purpose of _____ newborn hearing screening include automated _____ _____ _____ (AABR) testing and testing of _____ _____ (OAEs).

19. Screening of _____-_____ children is aimed at identification of children who develop hearing loss later in childhood. This type of screening is typically accomplished using _____ audiometry techniques.
20. Screening of adults who are at-risk for development for hearing loss as a consequence of work-related noise exposure are typically involved in _____ hearing screenings.

Discussion Questions

1. Hearing screening of newborns is not universally applied in all areas. Given the goals of universal newborn hearing screening, discuss why it may not be utilized everywhere.
2. Why is assessment of hearing limitations and restrictions so important in assessment? What factors other than characteristics of the hearing loss itself might contribute to hearing limitations and restrictions?
3. Discuss why the "first question," asking why the patient is being evaluated, is so critical to hearing assessment.
4. Explain the principle of cross-checking, and provide examples in which this principle may be used.
5. Discuss why objective measures of auditory system function, such as auditory-evoked responses and otoacoustic emissions, may be beneficial in some cases. What are the limitations of objective measures?

Resources

Articles and Books

American Speech-Language-Hearing Association. (1997). *Guidelines for audiologic screening*. Rockville, MD: Author.

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Weinstein, B. E. (1990). The quantification of hearing aid benefit in the elderly: The role of self-assessment measure. *Acta Otolaryngological Supplement, 476*, 257–261.

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World Health Organization (WHO). (2001). *International classification of functioning, disability, and health*. Geneva: Author.

Web Sites

American Speech-Language-Hearing Association (ASHA)
Under Legislation and Advocacy, search for State-by-State status of Early Hearing Detection & Intervention Screening Legislation.
www.asha.org/about/Legislation-Advocacy/

Audiology Online
www.audiologyonline.com

Centers for Disease Control and Prevention, Early Hearing Detection & Intervention (EHDI) Program
http://www.cdc.gov/ncbddd/ehdi/

Marion Downs National Center Website
http://www.colorado.edu/slhs/mdnc/

University of Pittsburgh, School of Medicine
Search under Postgraduate Trainee for ePROM otitis media curriculum
www.eprom.pitt.edu/06_browse.asp

Hear-it
Search for US rules on work related hearing protection
http://www.hear-it.org/

National Center for Hearing Assessment and Management, Utah State University
http://www.infanthearing.org/



6

THE AUDIOLOGIST'S ASSESSMENT TOOLS: PURE-TONE AUDIOMETRY

Learning Objectives

Equipment and Test Environment
- The Audiometer
- Transducers
- Test Environment

The Audiogram
- Threshold of Hearing Sensitivity
- The Audiogram
- Modes of Testing
- Audiometric Symbols
- Audiometric Descriptions

Establishing the Pure-Tone Audiogram
- Patient Preparation
- Audiometric Test Technique
- Air Conduction
- Bone Conduction
- Masking
- Audiometry Unplugged: Tuning Fork Tests

Summary

Short Answers Questions

Discussion Questions

Resources

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- Describe the uses, types, and components of audiometers.
- Explain what is meant by a "threshold" of hearing sensitivity.
- Understand the pure-tone audiogram.
- Explain how a description of a hearing loss is derived from the audiogram.
- List the steps taken in establishing a pure-tone audiogram.
- Describe the differences between air- and bone-conduction hearing thresholds.
- Explain the use of masking. Know why and when it is used.

EQUIPMENT AND TEST ENVIRONMENT

The Audiometer

AN audiometer is an electronic instrument used by an audiologist to quantify hearing. An audiometer produces pure tones of various frequencies, attenuates them to various intensity levels, and delivers them to transducers. It also produces **broad-band** and **narrow-band noise**. In addition, the audiometer serves to attenuate and direct signals from other sources, such as a microphone or compact disc player.

Broad-band noise is sound with a wide bandwidth, containing a continuous spectrum of frequencies with equal energy per cycle throughout the band.

Narrow-band noise is bandpass-filtered noise that is centered at one of the audiometric frequencies.

There are several types of audiometers, and they are classified primarily by their functions. For example, a clinical audiometer includes nearly all of the functions that an audiologist might want to use for behavioral audiometric assessment. In contrast, a screening audiometer might generate only pure-tone signals delivered to earphones.

Regardless of audiometer type, there are three main components to any audiometer, as shown schematically in Figure 6-1. The primary components are

- an **oscillator**,
- an **attenuator**, and
- an **interrupter switch**.

There are three main components to any audiometer: an **oscillator**, an **attenuator**, and an **interrupter switch**.

The *oscillator* generates pure tones, usually at discrete frequencies at the octave and mid-octave frequencies of 125, 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, and 8000 Hz.

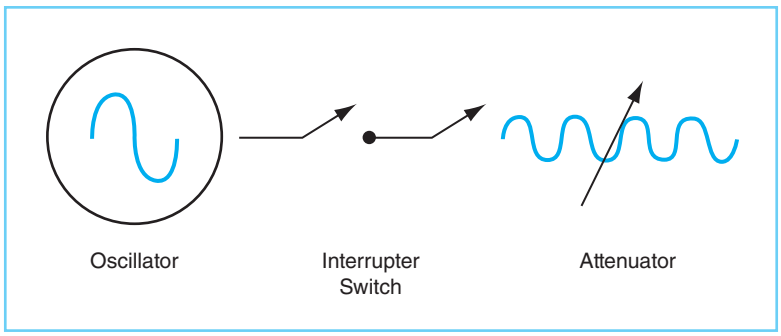


FIGURE 6-1 Components of an audiometer.

Some audiometers do not include all of these frequencies; other audiometers extend to higher frequencies. The oscillator is controlled by some form of frequency-selector switch.

The *attenuator* controls the intensity level of the signal, usually in 5 dB steps from –10 dB HL to a maximum output level that varies by frequency and transducer type. Typical maximum output levels for earphones are: 85 dB at 125 Hz, 105 dB at 250 Hz, 120 dB from 500 through 4000 Hz, and 110 dB at 6000 and 8000 Hz. Typical maximum output levels for bone-conduction vibrators are 65 dB at 500 Hz and 80 dB from 1000 to 4000 Hz. Some audiometers permit dB step sizes smaller than 5 dB. The attenuator is controlled by some form of intensity-selector dial or push button.

The *interrupter switch* controls the duration of the signal that is presented to the patient. The interrupter switch is typically set to the off position for pure-tone signals and is turned on when the presentation button is pressed. The interrupter switch is typically set to the on position for speech signals.

A photograph of an audiometer is shown in Figure 6-2. The appearance of an audiometer and the layout of its dials and buttons vary substantially across manufacturers. Features that are found on clinical audiometers include:

- signal selector to choose the type of signal to be presented;
- signal router to direct the signal to the right ear, left ear, both ears, bone vibrator, loudspeaker, etc.;
- microphone to present speech;



FIGURE 6-2 Photograph of an audiometer. (Photo courtesy of Cardinal Health©.)

- VU meter to monitor the output of the oscillator, microphone, CD player, etc.;
- external input for CD player or other sound sources;
- auxiliary output for loudspeakers or other transducers; and
- patient response indicator to monitor when the patient pushes a patient response button.

The type of audiometer described and shown here is considered a manual audiometer because control over the signal presentation is in the hands of the tester. Automatic audiometers also exist. Signal presentation in automatic audiometers is typically under computer control. These devices are often used for screening purposes. As mentioned in Chapter 2, audiometers must meet calibration specifications set forth by the American National Standards Institute (ANSI S3.6-2004).

A **transducer** is a device that converts one form of energy to another, such as an earphone or bone vibrator.

Transducers

Another important component of the audiometer system is the output **transducer**. Transducers are the devices that convert the

electrical energy from the audiometer into acoustical or vibratory energy. Transducers used for audiometric purposes are earphones, loudspeakers, or bone-conduction vibrators. Earphones are of three varieties, insert, supra-aural, and circumaural. An insert earphone is a small earphone coupled to the ear canal by means of an ear insert, which is made of pliable, soft material used to provide the acoustic coupling between an earphone and the ear canal. A photograph is shown in Figure 6-3. A supra-aural earphone is one mounted in a standard cushion that is placed over the ear. A photograph is shown in Figure 6-4. A circumaural earphone is one in which the transducer is mounted in a larger dome-shaped cushion that sits over and around the ear. The circumaural earphone is used exclusively for extended high-frequency testing and uncommonly for routine threshold testing.

Although supra-aural earphones were the standard transducers for many years, in the 1980s, insert earphones arrived on the scene and, in many clinics, became the earphone of choice. There are several important clinical advantages to using insert earphones over supra-aural earphones. They are:

- **No more collapsing canals**
  Placement of supra-aural earphones can cause the ear canals to collapse or close. This is especially true in older patients whose ear canal cartilage is more pliable. Collapsed canals generally cause high-frequency conductive hearing



FIGURE 6-3 Photograph of insert earphones. (Courtesy of Etymotic Research, Inc.)



FIGURE 6-4 Photograph of supra-aural earphones. (Courtesy of Telephonics Corporation.)

loss on the audiogram, a condition that is not experienced in real life without earphones. The alert audiologist will catch this, but it can cause significant consternation during testing. Insert earphones eliminate this audiometric challenge.

- **Reduced need for masking**

  Earphones deliver sound to the ear canal, but they also deliver vibration to the skull through the earphone cushion. The more contact the cushion has with the head, the more readily the vibration is transferred. This causes crossover to the other ear, a condition that creates the need to mask or keep the nontest ear busy during audiometric testing. Sound that is delivered to one ear is attenuated or reduced by the head as it crosses over to the other ear. This is referred to

as interaural attenuation (IA), or attenuation between the ears. The amount of IA is greater for insert earphones than for supra-aural earphones. This means that crossover is less likely, thereby reducing the need to mask.

- **Enhanced placement stability**
  Earphone placement affects the sound delivered to the ear. The size of this effect is smaller with properly placed insert earphones than with supra-aural earphones.

There are a few conditions in which supra-aural earphones are necessary, such as in those patients with atresia, a stenotic ear canal, or a badly draining ear. For these patients, it is important to have supra-aural earphones available and calibrated for use.

Another transducer used routinely in clinical testing is a bone-conduction vibrator. A bone vibrator is secured to the forehead or mastoid and used to stimulate the cochlea by vibrating the bones of the skull. A photograph is shown in Figure 6-5.



FIGURE 6-5 Photograph of a bone-conduction transducer. (Photo courtesy of Radioear Corp., New Eagle, PA.)

Test Environment

The testing environment must be particularly quiet to obtain valid hearing sensitivity thresholds. The American National Standards Institute (ANSI, 2003) specifies maximum permissible noise levels for audiometric test rooms. In order for these guidelines to be met, special rooms or test booths are used to provide sufficient sound isolation.

THE AUDIOGRAM

Threshold of Hearing Sensitivity

The aim of pure-tone audiometry is to establish hearing threshold sensitivity across the range of audible frequencies important for human communication. Threshold sensitivity is usually measured for a series of discrete sinusoids or pure tones. The object of pure-tone audiometry is to determine the lowest intensity of such a pure-tone signal that the listener can "just barely hear." When thresholds have been measured at a number of different sinusoidal frequencies, the results are illustrated graphically, in a frequency-versus-intensity plot, to show threshold sensitivity across the frequency range. This graph is called an **audiogram.** In clinical pure-tone audiometry, thresholds are usually measured at sinusoidal frequencies over the range from 250 Hz at the low end to 8000 Hz at the high end. Within this range, thresholds are determined at octave intervals in the range below 2000 Hz and at mid-octave intervals in the range above 2000 Hz. Thus, the *audiometric frequencies* for conventional pure-tone audiometry are 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz.

An **audiogram** depicts the hearing sensitivity across a frequency range of 250 to 8000 Hz.

The concept of threshold as the "just-audible" sound intensity is somewhat more complicated than it seems at first glance. The problem is that, when a sound is very faint, the listener may not hear it every time it is presented. When sounds are fairly loud, they can be presented repeatedly, and the listener will almost always respond to them. Similarly, when sounds are very faint, they can be presented repeatedly, and the listener will almost never respond to them. But when the sound intensity is in the vicinity of threshold, the listener may not respond consistently. The same sound intensity might produce a response after some presentations but not after others. Therefore, the search is for the sound intensity that produces a response from the listener about 50% of the time. This is the classical notion of

a sensory threshold. Within the range of sound intensities over which the listener's response falls from 100% to 0%, threshold is designated as the intensity level at which response accuracy is about 50%.

The Audiogram

A **decibel** is a unit of sound intensity.

In clinical audiometry, intensity is expressed on a **decibel** (dB) scale relative to "average normal hearing." The zero point on this scale is the sound intensity corresponding to the average of threshold intensities measured on a large sample of people with normal hearing. This decibel scale of sound intensities is called the *hearing level* scale, and is abbreviated as the HL scale. An audiogram is a plot of the listener's threshold levels at the various test frequencies, where frequency is expressed in Hertz, or Hz, units, and the threshold intensity is expressed on the HL dB scale. Figure 6-6 shows an example of such a plot. The zero line, running horizontally across the top of the graph, is sound intensity corresponding to average

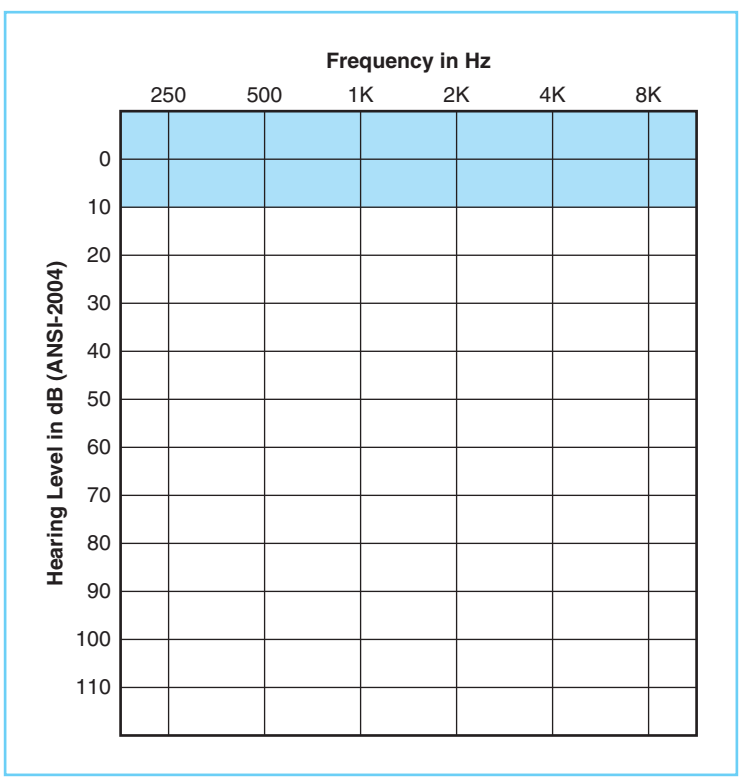


FIGURE 6-6 An audiogram, with frequency expressed in Hz plotted as a function of intensity expressed in dB HL.

normal hearing at each of the test frequencies. Figure 6-7 shows that, for this listener, the threshold at 1000 Hz is 45 dB HL. This means that when 1000 Hz sinusoidal signals were presented to the listener and the intensity was systematically altered, the threshold, or intensity at which the sound was heard about 50% of the time was at an intensity level 45 dB higher than would be required for a person with average normal hearing.

Modes of Testing

There are two modes by which pure-tone test signals are presented to the auditory system: through the air via earphones or directly to the bones of the skull via a bone vibrator. When test signals are presented by earphones, via the air route, the manner of determining the audiogram is referred to as air-conduction pure-tone audiometry. Pure-tone test signals are usually presented either to the right ear or

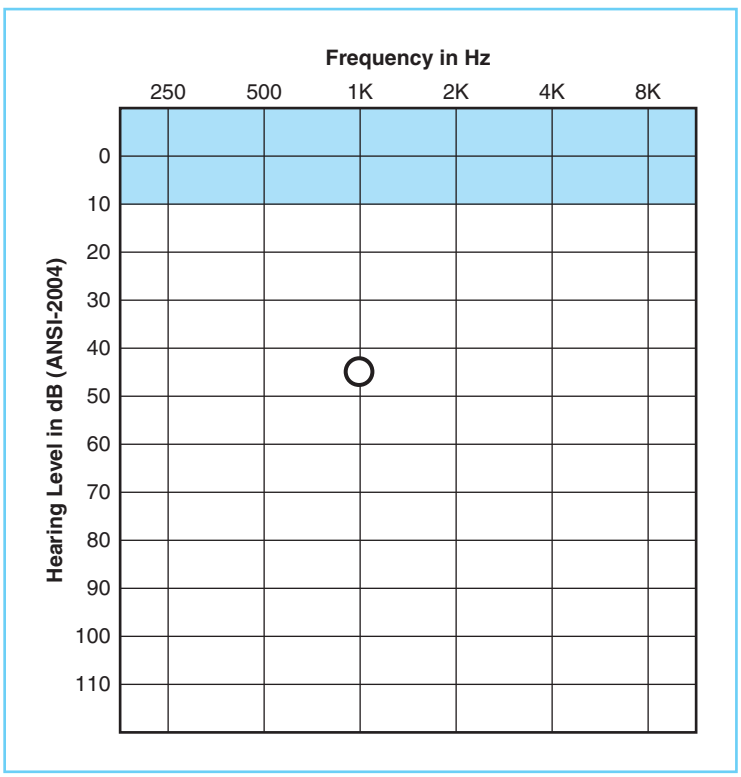


FIGURE 6-7 An audiogram with a single threshold of 45 dB HL plotted at 1000 Hz.

to the left ear independently. An audiogram is generated separately for each ear. When test signals are presented via the bone route through a bone vibrator, the manner of determining the audiogram is referred to as bone-conduction pure-tone audiometry.

The complete pure-tone audiogram, then, consists of four different plots, the air-conduction and bone-conduction curves for the right ear and the air-conduction and bone-conduction curves for the left ear. Figure 6-8 illustrates how air- and bone-conduction thresholds are plotted on the audiogram form.

The two ears are not completely isolated from one another. Signals presented to one ear can be transmitted, via bone conduction, to the other ear. Therefore, special precautions must be taken when testing one ear to be certain that the other ear is not participating in the response. This is particularly the case with unilateral hearing losses in which one ear has a greater hearing loss than the other. In such a case, the better ear may hear loud

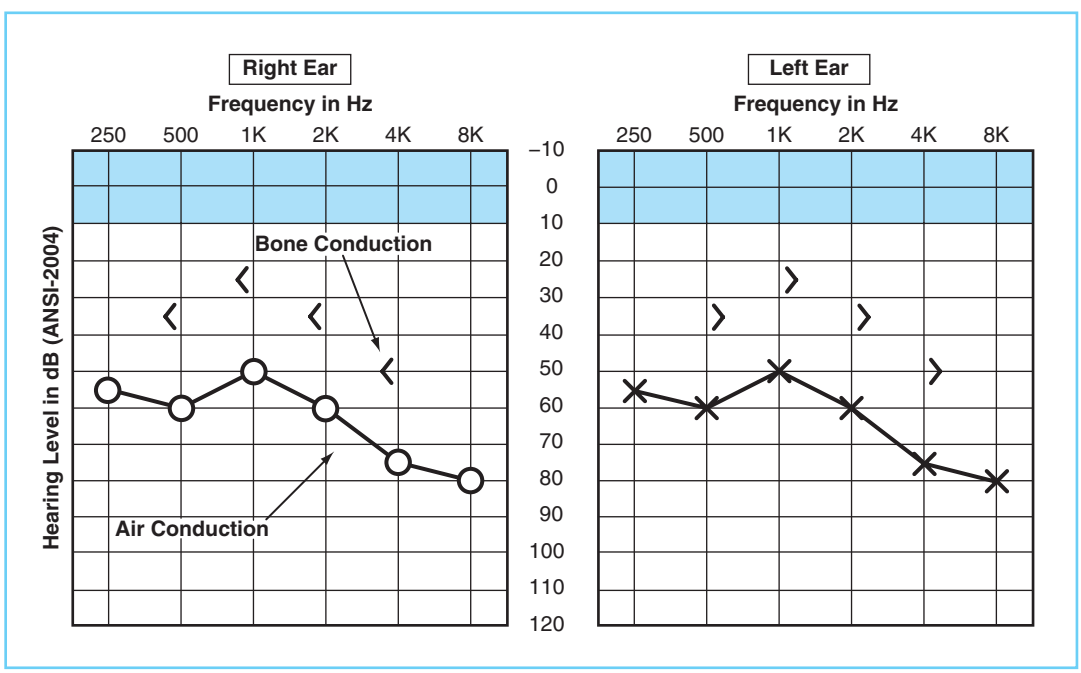


FIGURE 6-8 Right and left ear audiograms with unmasked air-conduction and bone-conduction thresholds.

To **mask** is to introduce sound to one ear while testing the other in an effort to eliminate any influence of crossover of sound from the test ear to the nontest ear.

sounds presented to the poorer ear. The most common method of prevention is to **mask** the nontest ear with an interfering sound so that it cannot hear the test signal being presented to the test ear. In the case of air-conduction testing, this is done whenever large ear asymmetry exists. In the case of bone-conduction testing, however, masking is more often required because of the minimal isolation between ears via bone conduction.

Audiometric Symbols

The most commonly used symbols are based on guidelines from the American Speech-Language-Hearing Association (ASHA, 1990), which are derived primarily from the American National Standards Institute (ANSI S23.21-1978). These symbols are shown in Figure 6-9. A different symbol is used to designate unmasked from masked responses from the right and left ears when signals are presented by air conduction or bone conduction. Different symbols are used for bone conduction, depending on placement

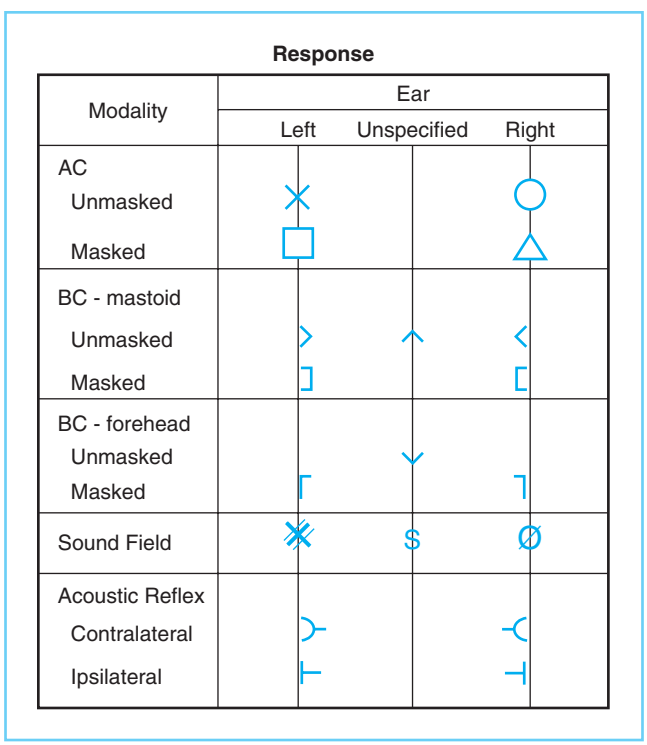


FIGURE 6-9 | Commonly used audiometric symbols. (ASHA, 1990.)

of the bone vibrator. Symbols are also designated when thresholds are obtained to sound presented via loudspeaker in the sound field. There are also recommended symbols for thresholds of the acoustic reflex, which you will learn more about in Chapter 8.

Although these symbols are commonly used, there is a wide range of variation in the symbols and the way they are used across clinics. Fortunately, it is standard for all audiogram forms to have symbol keys to reduce the risk of misinterpretation. Probably the most common variant of the symbol guidelines is the use of separate graphs for results from each ear. This is quite common clinically and is used in this text for the purposes of clarity.

Separate symbols may also be used when a patient does not respond at the intensity limits of the equipment. The convention for a no-response symbol is a downward pointing arrow from the response symbol, directed right for the left ear and left for the right ear, at the intensity level of the maximum output of the transducer at the test frequency. Care must be taken in the use of no-response symbols to ensure that they are not misinterpreted as responses. Many audiologists opt to note no-responses in a manner that more clearly guards against misinterpretation.

Audiometric Descriptions

The pure-tone audiogram tells us a number of important things about a person's hearing loss. First, it provides a metric for degree of loss, whether it is:

- minimal (11–25 dB),
- mild (26–40 dB),
- moderate (41–55 dB),
- moderately severe (56–70 dB),
- severe (71–90 dB), or
- profound (more than 90 dB).

Figure 6-10 shows these ranges.

Second, the audiogram describes the shape of loss or the audiometric contour: a hearing loss may be the same at all frequencies and have a flat configuration; the loss may also increase as the

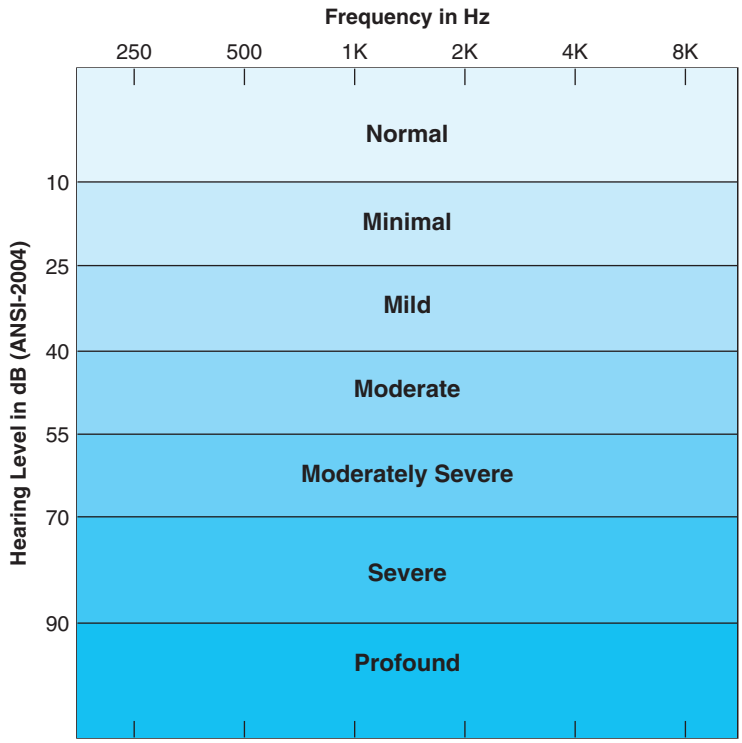


FIGURE 6-10 Degrees of hearing loss plotted on an audiogram.

curve moves from the low-frequency region to the high-frequency region and have a downward sloping contour; or the degree of loss may decrease as the curve moves from the low- to the high-frequency region and have a rising contour (Figure 6-11).

Interaural means between the ears.

Third, the audiogram provides a measure of **interaural** symmetry, or the extent to which hearing sensitivity is the same in both ears or better in one than the other (Figure 6-12).

Fourth, the combination of air- and bone-conduction audiometry allows the differentiation of hearing loss into one of three types (Figure 6-13):

1. conductive,
2. sensorineural, or
3. mixed.

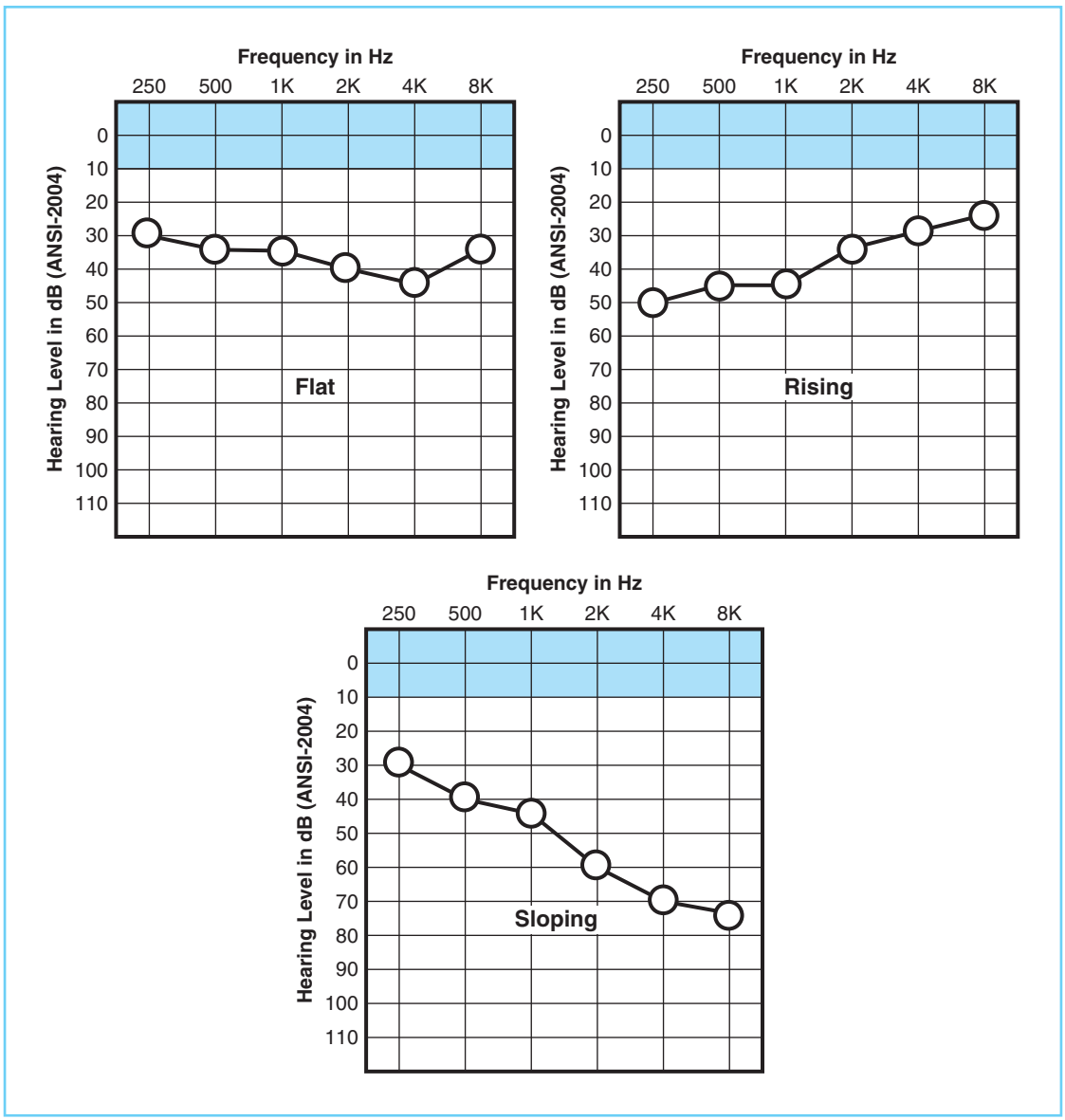


FIGURE 6-11 | Three audiometric configurations: flat, rising, and sloping.

These are the three major categories of **peripheral hearing loss**. *Conductive* losses result from problems in the external ear canal or, more typically, from disorders of the middle-ear vibratory system. *Sensorineural* losses result from disorders in the cochlea or auditory nerve. The audiometric signature of a conductive hearing

A **peripheral hearing loss** can be conductive, sensorineural, or mixed.

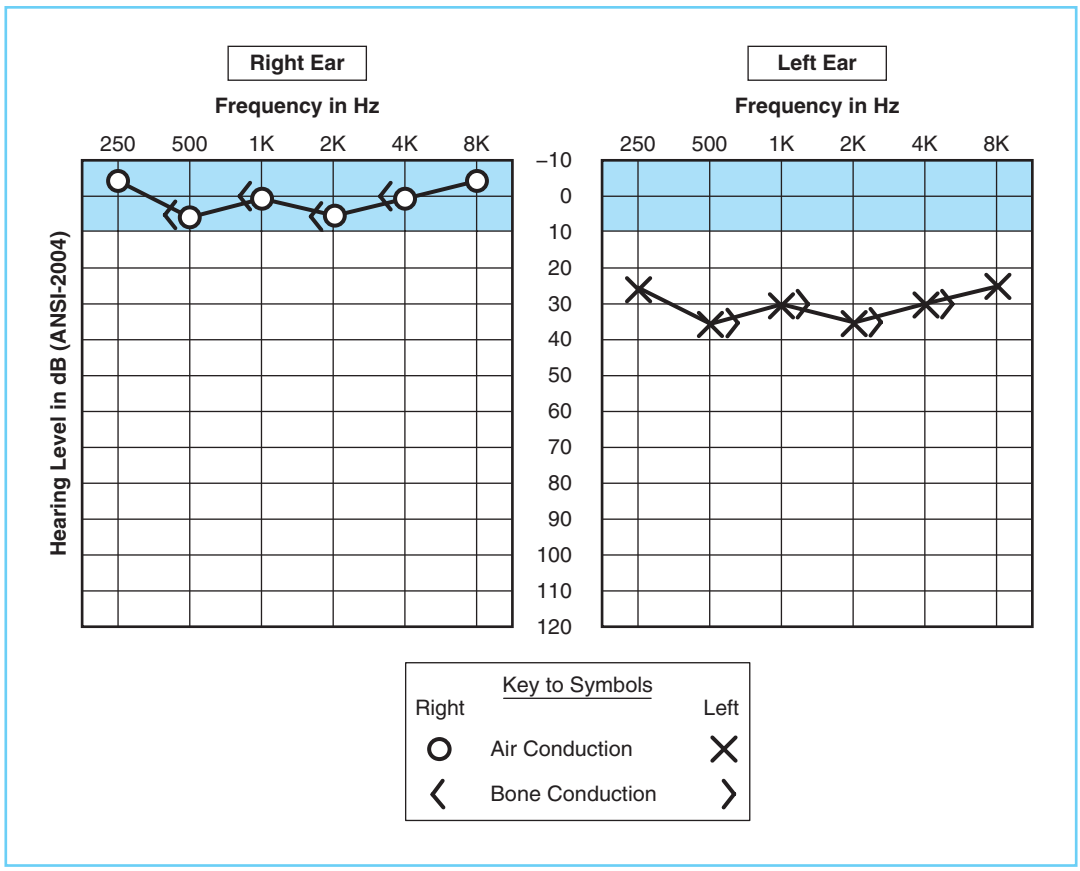


FIGURE 6-12 | Audiogram representing asymmetric hearing loss.

loss is reduced sensitivity via the air-conduction route, but relatively normal sensitivity via the bone-conduction route.

Remember that the air-conduction loss reflects disorders along the entire conductive and sensorineural systems, from middle ear to cochlea to auditory nerve. The bone-conduction loss, however, reflects only a disorder in the cochlea and auditory nerve. The bone-conducted signal goes directly to the cochlea, in effect by-passing the external and middle-ear portions of the auditory system. Strictly speaking, this is not quite true. Changes in middle-ear dynamics do affect bone-conduction sensitivity in predictable ways, but as a first approximation, this is a useful way of thinking about the difference between conductive and sensorineural audiograms. Comparisons

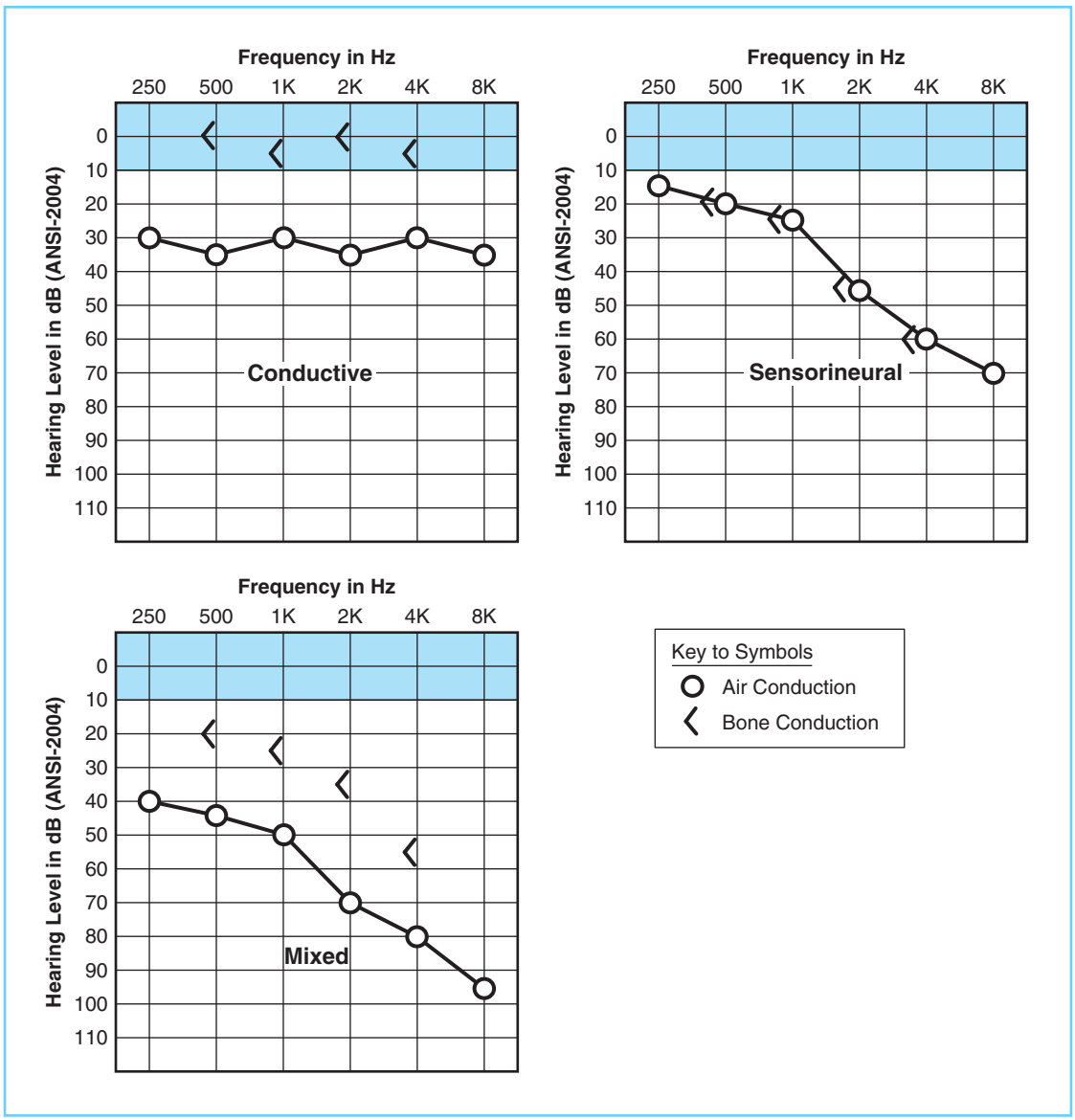


FIGURE 6-13 Audiograms representing three types of hearing loss: conductive, sensorineural, and mixed.

of the air-conduction and bone-conduction threshold curves provide us with the broad category of type of loss. In a pure conductive loss, there is reduced sensitivity by air conduction but relatively normal sensitivity by bone conduction. In a pure sensorineural loss,

AUDIOLOGIST PROFILE

KATE E. BALDOCCHI, AU.D.



WHERE I LIVE: Austin, Texas

WHERE I WORK: Austin Ear, Nose, Nose and Throat (AENT) Clinic. AENT Clinic was established over 30 years ago by two otolaryngologists: Dr. Butler and Dr. Burns. Today the clinic has grown to12 physicians and 10 audiologists. In addition to our five main clinics, AENT Clinic has four satellite offices serving patients in communities surrounding Austin.

WHAT I DO: I am a clinical audiologist. My responsibilities include pediatric and adult audiological assessments, hearing aid evaluations and fittings, and fitting of hearing protection devices.

WHY AUDIOLOGY? Working with patients and their families during the process of fitting hearing aids is very challenging and rewarding. I enjoy knowing patients on a personal level and learning that their quality of life has improved because of my services. It is a luxury to love one's work; and my fellow audiologists and physicians I work with make that possible for me.

however, both air-conduction and bone-conduction sensitivity are reduced equally. If there is a loss by both air and bone conduction, but more loss by air than by bone, then the loss is categorized as *mixed*. In a mixed loss, there is both a conductive and a sensorineural component.

ESTABLISHING THE PURE-TONE AUDIOGRAM

Establishing a pure-tone audiogram is the cornerstone of a hearing evaluation. Simple in concept and strategy, it can also be the most difficult of all measures in the audiologic battery. The paradox is complete. On one hand, pure-tone audiometry is so structured and rule-driven that it can be automated easily for computer-based testing. Such automated testing works well and is quite appropriate for testing large numbers of cooperative adults. On the other hand, in the clinic, the audiologist evaluates

patients of all ages, with varying degrees and types of hearing loss. Establishing a pure-tone audiogram can be quite challenging, and the nuances of testing require substantial experience.

Patient Preparation

It is important to prepare the patient properly for testing, and that begins with correct placement within the test room. In most cases, the patient is seated in a sound-treated room or booth and is observed by the audiologist from an adjoining room through a window. The experienced audiologist gains considerable insight from observing patients as they respond to sounds. It is most common to face the patient at an angle looking slightly away from the window. This is important to avoid the possibility of any inadvertent facial or other physical cuing that a sound is being presented. An alternative is to arrange the lighting so that the audiologist is not altogether visible through the window. Regardless, the audiologist should be in a position to observe the response of the patient, whether it be the raising of a hand or finger, or the pressing of a response button.

The next step in the preparation process is inspection of the ear canals. As discussed in Chapter 5, otoscopic inspection of the ear canal is an important prerequisite to earphone placement and testing. If the ear canal is free of occluding cerumen, testing may proceed. If the ear canal is occluded with wax, it is far better to proceed only after it has been removed.

Once the ear canal has been inspected and prior to earphone placement, the patient should be instructed about the nature of the test and the audiologist's expectation of the patient. Every audiologist has a slightly different way of saying it, but the instructions are essentially these: *Following earphone placement, you will be hearing some tones or beeps. Please respond each time you hear the sound by raising a finger or pressing a button for as long as you hear the sound. Stop responding when you no longer hear the sound. We are interested in knowing the softest sound that you can hear, so please respond even if you just barely hear it*. You should also instruct the patient that you will be testing different tones and in both ears. It is important that the patient understands the overt response that you are expecting. Appropriate responses include raising a finger

or hand, pressing a response switch, or saying yes when a tone has been perceived.

Proper earphone placement is an important next step in the process. A misplaced earphone will result in elevation of hearing thresholds in the lower frequencies. Insert earphones are placed by compressing the pliable cuff, pulling up and back on the external ear, and placing the cuff firmly into the ear canal. It is helpful to hold the cuff in place momentarily while it expands to fill the ear canal. If you are using supra-aural earphones, care must be taken to ensure that the earphone speaker is directed over the ear canal opening.

Audiometric Test Technique

The establishment of pure-tone thresholds is based on a psychophysical paradigm that is a modified method of limits. Modern audiometric techniques are based on a consensus of recommendations that trace back to pioneering efforts of Reger (1950) and especially Carhart and Jerger (1959). Although the precise strategy may vary among audiologists, the following strategies and conventions generally apply:

1. Test the better ear first. Based on the patient's report, the better ear should be chosen to begin testing. Knowledge of the better-ear thresholds becomes important later for masking purposes. If hearing is reported to be the same in both ears, begin with the right ear.
2. Begin threshold search at 1000 Hz. This is a relatively easy signal to perceive, and it is often a frequency at which better hearing occurs. You must begin somewhere, and clinical experience suggests that this is a good place to start.
3. Continuous or pulsed tones should be presented for about 1 second. Pulsed tones are often easier for the listener to perceive and can be achieved manually or, on most audiometers, automatically.
4. Begin presenting signals at an intensity level at which the patient can clearly hear. This gives the patient experience listening to the signal of interest. If you anticipate from the case history and from conversing with the patient that hearing is going to be normal or near normal, then begin

testing at 40 dB HL. If you anticipate that the patient has a mild hearing impairment, then begin at a higher intensity level, say 60 dB, and so on.

5. If the patient does not respond, increase the intensity level by 20 dB until a response occurs. Once the patient responds to the signal, threshold search begins.
6. Threshold search follows the "down 10, up 5" rule. This rule states that if the patient hears the tone, intensity is decreased by 10 dB, and if the patient does not hear the tone, intensity is increased by 5 dB. This threshold search is illustrated in Figure 6-14.
7. Threshold is considered to be the lowest level at which the patient perceives the tone about 50% of the time (either 2 out of 4 or 3 out of 6 presentations).
8. Once threshold has been established at 1000 Hz, proceed to test 2000, 3000, 4000, 6000, 8000, 1000 (again), 500, and 250 Hz. Repeat testing at 1000 Hz in the first ear tested to ensure that the response is not slightly better now that the patient has learned the task.
9. Test the other ear in the same manner.

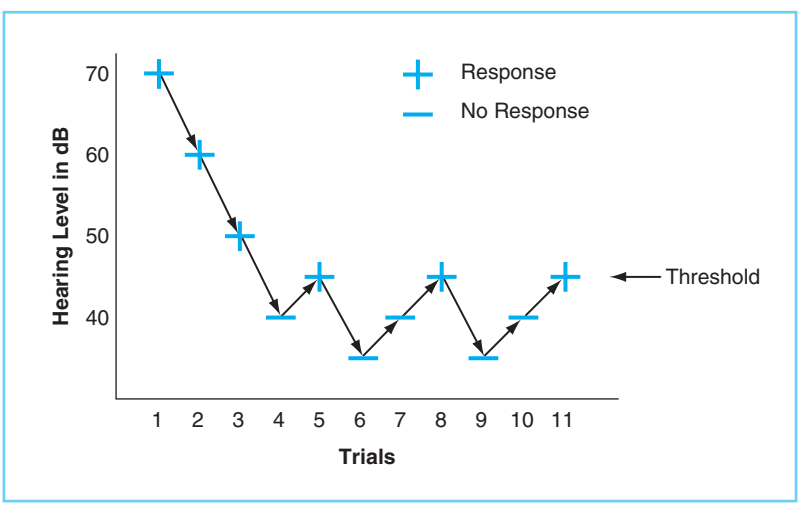


FIGURE 6-14 Schematic representation of a threshold search, showing the "down -10, up -5" strategy for bracketing hearing threshold level.

Air Conduction

Hearing thresholds by air conduction are established to describe hearing sensitivity for the entire auditory system. Air-conduction testing provides an assessment of the functional integrity of the outer, middle, and inner ears. The term *air conduction* is used because signals are presented through the air via earphones.

As you learned earlier, there are two major types of air-conduction transducers, supra-aural earphones and insert earphones. Examples are shown previously in Figures 6-3 and 6-4. Supra-aural earphones are mounted in cushions that are placed over the outer ear. This type of earphone was the standard for many years. It had as its advantages ease of placement over the ears and ease of **calibration**.

Calibration is the process of adjusting the output of an instrument to a known standard.

The newer type of earphone is called an insert earphone. An insert earphone consists of a loudspeaker mounted in a small box that sends the acoustic signal through a tube to a cuff that is inserted into the ear canal. Insert earphones are now the standard for clinical use. As you learned earlier, insert earphones have several advantages related to sound isolation and interaural attenuation.

If a patient has normal outer- and middle-ear function, then air-conduction thresholds will tell the entire story about hearing sensitivity of the cochlea. If a patient has a disorder of outer- or middle-ear function, then air-conduction thresholds reflect the additive effects of (1) any sensorineural loss due to inner-ear disorder and (2) any conductive loss imposed by outer- or middle-ear disorder. Bone-conduction testing must be completed to separate the contribution of the two disorders to the overall extent of the loss.

Bone Conduction

Bone-conduction thresholds are established in a manner similar to air-conduction thresholds, but with a different transducer. In this case, a bone vibrator (shown previously in Figure 6-5) is used to generate vibrations of the skull and stimulate the cochlea directly. Theoretically, thresholds by bone conduction reflect function of the cochlea, regardless of the status of the outer

or middle ears. Therefore, if a person has normal middle-ear function on one day and middle-ear disorder on the next, hearing by bone conduction will be unchanged, while hearing by air conduction will be adversely affected.

The bone-conduction transducer has changed little over the years, and the only real decisions that have to be made are related to vibrator placement and masking issues. Some clinicians choose to place the vibrator on the mastoid-bone prominence behind the pinna, so called mastoid placement. Others choose to place it on the forehead.

Regardless of where the bone vibrator is placed on the skull, both cochleas are likely to be stimulated to the same extent. Actually, there is a little interaural attenuation of high-frequency signals when the bone is placed on the mastoid, but it is negligible for lower frequencies.

One advantage of mastoid placement is that, because there is a little interaural attenuation of the high frequencies, the cochlea on the side with the bone vibrator is at least partially isolated. This may reduce the need to mask or make it easier in some situations. Another advantage is that thresholds are slightly better with mastoid placement, an important factor when a hearing loss is near the level of maximum output of the bone vibrator. In such a case, you may be able to measure threshold with mastoid placement and not be able to do so with forehead placement.

Forehead placement also has its advantages. Some are simply practical. The forehead is an easier location to achieve stable vibrator placement, enhancing test-retest reliability. It is also easier to prepare the patient by putting on the bone vibrator and earphones at the start of testing and not having to move back and forth from room to room to switch ears. The assumption of forehead bone-conduction placement is that bone-conduction thresholds are always masked, which is probably good practice in all cases.

Most seasoned audiologists are prepared to use either mastoid or forehead placement, depending on the nature of the clinical question.

Contributors to Bone-Conduction Hearing

When a sound is delivered to the skull through a bone vibrator, the cochlea is stimulated in several ways. The primary stimulation of the cochlea occurs when the temporal bone vibrates, causing displacement of the cochlear partition. A secondary stimulation occurs as a result of the middle-ear component, due to a lag between the vibrating mastoid process and the vibrating ossicular chain. This is referred to as inertial bone conduction. That is, the ossicles are moving relative to the head, thereby stimulating the cochlea. A third, and minor, component of bone-conducted hearing is sometimes referred to as osseotympanic bone conduction. Here, the vibration of the external ear canal wall is radiated into the ear canal and tranduced by the tympanic membrane.

The result of all of this is that most of the hearing measured by bone conduction is due to direct stimulation of the cochlea—most, but not all. Therefore, in certain circumstances, a disorder of the middle ear can reduce the inertial and osseotympanic components of bone conduction, resulting in an apparent sensorineural component to the hearing loss. We often see this in patients with otosclerosis. They show a hearing loss by bone conduction around 2000 Hz, the so-called Carhart's notch. Once surgery is performed to free the ossicular chain, the "sensorineural" component to the loss disappears. Actually, what appears to occur is that the inertial component to bone-conducted hearing that was reduced by stapes fixation is restored.

Masking

Crossover results when sound presented to one ear through an earphone crosses the head via bone conduction and is perceived by the other ear.

Air-conduction and bone-conduction pure-tone audiometry are often confounded by **crossover** or *contralateralization* of the signal. A signal that is presented to one ear, if it is of sufficient magnitude, can be perceived by the other ear. This is known as crossover of the signal. Suppose, for example, that a patient has normal hearing in the right ear and a profound hearing loss in the left ear. When tones presented to the left ear reach a certain level, they

will cross over the head and be heard by the right ear. As a result, although you may be trying to test the left ear, you will actually be testing the right ear because the signal is crossing the head.

When crossover has occurred, you need to isolate the ear that you are trying to test by *masking* the other (nontest) ear. Masking is a procedure wherein noise is placed in one ear to keep it occupied while the other ear is being tested. In the current example, the right, or normal hearing, ear would need to be masked by introducing sufficient noise to keep it occupied while the left ear is being tested. With appropriate masking noise in the right ear, the left ear can be isolated for determination of thresholds.

One of the most important concepts related to masking is that of **interaural attenuation**. The term interaural attenuation was coined to describe the amount of reduction in intensity (attenuation) that occurs as a signal crosses over the head from one ear to the other (interaural or between ears). Using our example, let us say that the right ear threshold is 10 dB and the left ear threshold is 100 dB at 1000 Hz. As you try to establish threshold in the left ear, the patient responds at a level of, say, 70 dB, because the tone crosses the head and is heard by the right ear. The amount of interaural attenuation in this case is 60 dB (70 dB threshold in the unmasked left ear minus 10 dB threshold in the right ear). That is, the signal level being presented to the left ear was reduced or attenuated by 60 dB as it crossed the head.

Interaural attenuation (IA) is the reduction in sound energy of a signal as it is transmitted by bone conduction from one side of the head to the opposite ear.

The amount of interaural attenuation depends on the type of transducer used. Table 6-1 shows the amount of interaural attenuation for two different types of transducers: supra-aural earphones and insert earphones. Insert earphones have the highest amount of interaural attenuation and, thus, the lowest risk of crossover. This is related to the amount of vibration that is delivered by the transducer to the skin surface. An insert earphone produces sound vibration in a loudspeaker that is separated from the insert portion by a relatively long tube. Very little of the insert is in contact with the skin, and the amount of vibration transferred from it to the skull is minimal. Supra-aural earphones are in contact with more of the surface of the skin, thereby reducing the amount of interaural attenuation and increasing the risk of crossover.

TABLE 6-1 Average values of interaural attenuation for supra-aural earphones (Sklare & Denenberg, 1987) and insert earphones (Killion et al., 1985)

Frequency (Hz)	Supra-aural (TDH-49)	Insert (ER-3A)
250	54	95
500	59	85
1000	62	70
2000	58	75
4000	65	80

A bone-conduction transducer vibrates the skin and skull directly, resulting in the lowest amount of interaural attenuation and the highest risk of crossover. Interaural attenuation by bone conduction is negligible in the low frequencies and ranges from 0 to 15 dB at 4000 Hz.

The need to mask the nontest ear is related to the amount of interaural attenuation. If the difference in thresholds between ears exceeds the amount of interaural attenuation, then there is a possibility that the nontest rather than the test ear is responding. Minimum levels of interaural attenuation are usually set to provide guidance as to when crossover may be occurring. These levels are set as a function of transducer type as follows:

Supra-aural earphones: 40 dB

Insert earphones: 50 dB

Bone-conduction vibrator: 0 dB

Thus, if you are using supra-aural earphones, crossover may occur when the threshold from one ear exceeds the threshold from the other ear by 40 dB or more. If you are using insert earphones, crossover may occur if inter-ear asymmetry exceeds 50 dB. If you are using a bone-conduction vibrator, crossover may occur at any time, since the signal is not necessarily attenuated as it crosses the head. These minimum interaural attenuation levels dictate when masking should be used.

Air-Conduction Masking

Masking should be used during air-conduction audiometry whenever the air-conducted threshold of the ear under test exceeds the bone-conduction threshold of the nontest ear by more than the minimum interaural attenuation levels. For example, say you have established air-conduction thresholds in the right ear to be 0 dB throughout the frequency range. Because bone-conduction thresholds cannot be poorer than air-conduction thresholds, then bone-conduction threshold for that ear is considered 0 dB. If you are using insert earphones and are testing the left ear, you know that thresholds are valid for the left ear if they are within 50 dB of the right-ear bone-conduction thresholds. You know this because 50 dB is the minimum interaural attenuation for insert earphones. Therefore, if a threshold in the left ear is 50 dB or better, you can safely assume that no masking is needed and that the response is truly a threshold from the left ear. If, however, the threshold exceeds 50 dB, then it could be a response from the right ear due to crossover, and masking is necessary.

The rule for air-conduction masking is relatively simple: *if the thresholds from the test ear exceed the bone-conduction thresholds of the nontest ear by the amount of minimum interaural attenuation, then masking must be used.* An important caveat is that, even though you are testing by air conduction, the critical difference is between the air-conduction thresholds of the test ear and the bone-conduction thresholds of the nontest ear. Remember that the signal crossing over is from vibrations transferred from the transducer to the skull. These vibrations are perceived by the opposite cochlea directly, not by the opposite outer ear. Therefore, if the nontest ear has an air-conduction threshold of 30 dB and a bone-conduction threshold of 0 dB, then masking should be used if the test ear has a threshold of 50 dB, not 80 dB.

It is typical in pure-tone audiometry to establish air-conduction thresholds in the better ear first, followed by air-conducted thresholds in the poorer ear. In many instances this procedure works well. Problems arise when the better ear has a conductive hearing loss, and the air-conduction thresholds are not reflective of the bone-conduction thresholds for that ear. Once bone-conduction thresholds are ultimately established, air-conduction thresholds

may need to be re-established if the thresholds from one ear turn out to have exceeded the bone-conduction thresholds from the other ear by more than minimum interaural attenuation.

Bone-Conduction Masking

Masking should be used during bone-conduction audiometry under most circumstances, because the amount of interaural attenuation is negligible. For example, if you place the bone vibrator on the right mastoid, it may stimulate both cochleas identically because there is no attenuation of the signal as it crosses the head. In reality, there is some amount of interaural attenuation of the bone-conducted signal. However, the amount is small enough that it is safest to assume that there is no attenuation and simply always mask during bone-conduction testing. Some clinicians choose to surrender to this notion and test with the bone vibrator placed on the forehead, always masking the nontest ear.

The rule for bone-conduction masking is very simple: *always use masking in the nontest ear during bone conduction testing*. It is safest to assume that no interaural attenuation occurs and that the risk of testing the nontest ear is omnipresent.

Masking Strategies

Students who become audiologists will eventually learn how to mask. This will be no easy task at first. The idea seems simple—keep one ear busy while you test the other. But there is a significant challenge in doing that. You must ensure that you have enough masking to keep the nontest ear busy, but you must also ensure that you do not have too much masking in the nontest ear or you will begin to mask the ear you are trying to test.

There are a number of different approaches to determine what is effective masking. One that has stood the test of time is called the **plateau method**. A graphic representation of the plateau method is shown in Figure 6-15.

The **plateau method** is a method of masking the nontest ear in which masking is introduced progressively over a range of intensity levels until a plateau is reached, indicating the level of masked threshold of the test ear.

Briefly, threshold for a given pure tone is established in the test ear, narrow-band noise is presented to the nontest ear, and threshold is reestablished in the test ear. If the nontest ear is responding, under masking is occurring. The presence of masking noise in

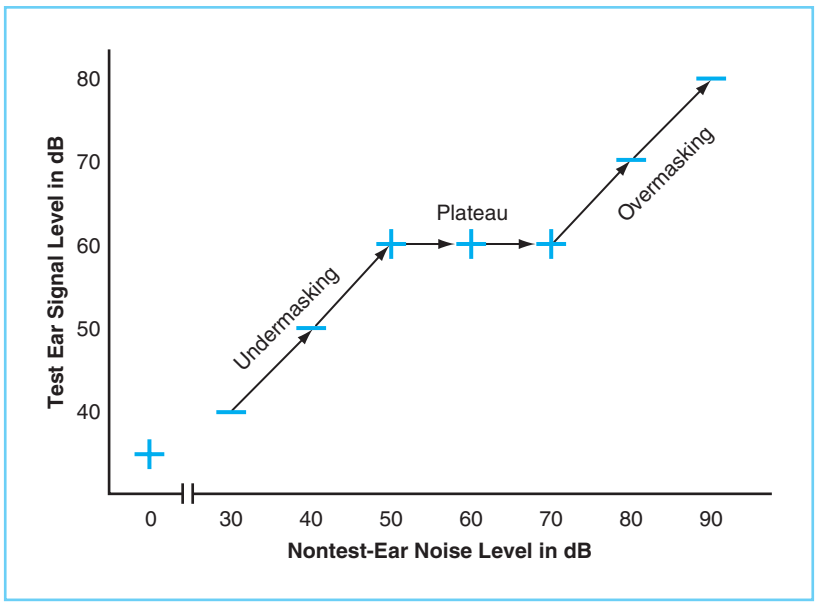


FIGURE 6-15 Schematic representation of the plateau method of masking. The patient responds to a pure-tone signal presented at 30 dB with no masking in the nontest ear. When 30 dB of masking is introduced, the patient no longer responds, indicating that the initial response was heard in the nontest ear. During the undermasking phase, the patient responds as the pure-tone level is increased but discontinues responding when masking is increased by the same amount. Threshold for the test ear is at the level of the plateau, or 60 dB. At the plateau, the patient continues to respond as masking level is increased in the nontest ear. During overmasking, the patient discontinues responding as masking level is increased.

that ear will shift the threshold in the test ear, and the patient will stop responding. The level of the pure tone is then increased and presented. If the patient responds, the masking level is increased and so on. Eventually a level of *effective masking* will be reached where increasing the masking noise will no longer result in a shift of threshold in the test ear. This is referred to as the *plateau* of the masking function and signifies that the nontest ear has been effectively masked and that responses are truly from the test ear. When masking is raised above this level, the masking noise itself may exceed the interaural attenuation value and actually cross over to interfere with the test ear. This is referred to as **overmasking**.

Overmasking results when the Intensity level of masking in the nontest ear is sufficient to cross over to the test ear, thereby elevating the threshold in the test ear.

There are a number of other techniques used in masking the nontest ear. One popular method is referred to as *step masking* (Katz & Lezynski, 2002). In this procedure, an initial masking

level of 30 dB SL (i.e., 30 dB above the patient's air-conduction threshold in the ear being masked) is used. If the patient's threshold in the test ear does not change with this masking noise in the nontest ear, the threshold is considered to be accurate with no evidence of crossover. If the threshold in the test ear changes significantly, then a subsequent masking level, usually of an additional 20 dB, is used. This process is continued until an accurate threshold is determined.

One other masking technique that is used for establishing bone-conduction thresholds is the sensorineural acuity level (SAL) test. For conventional bone-conduction testing, pure tones are presented through the bone vibrator and masking noise through an earphone. The bone vibrator is often placed on the forehead, and noise is presented to the nontest ear to mask it. The SAL test is done in the opposite manner. Threshold is established in the test ear by air conduction. Bone-conducted noise is then introduced to the bone vibrator on the forehead at a maximum level, and air-conduction thresholds are reestablished. The amount of threshold shift that occurs is then compared to a normative level, and the conductive component is calculated. The SAL test is a very useful clinical technique for at least three reasons:

1. it is often a much easier task for young children than conventional masked bone conduction,
2. it may be more accurate for small air-bone gaps, and
3. it serves as a valuable cross-check for conventional masked bone-conduction audiometry.

The Masking Dilemma

A **masking dilemma** occurs when both ears have large air-bone gaps, and masking can only be introduced at a level that results in overmasking.

A point can be reached where masked testing cannot be completed due to the size of the air-bone gap. This is often referred to as a *masking dilemma*. A **masking dilemma** occurs when the difference between the bone-conduction threshold in the test ear and the air-conduction threshold in the nontest ear approaches the amount of interaural attenuation. An example of such an audiogram is shown in Figure 6-16. Unmasked bone-conduction thresholds for the right ear are around 0 dB. Unmasked air-conduction thresholds for the left ear are around 60 dB. If we wish to mask the left ear and establish either air-conduction or bone-conduction thresholds

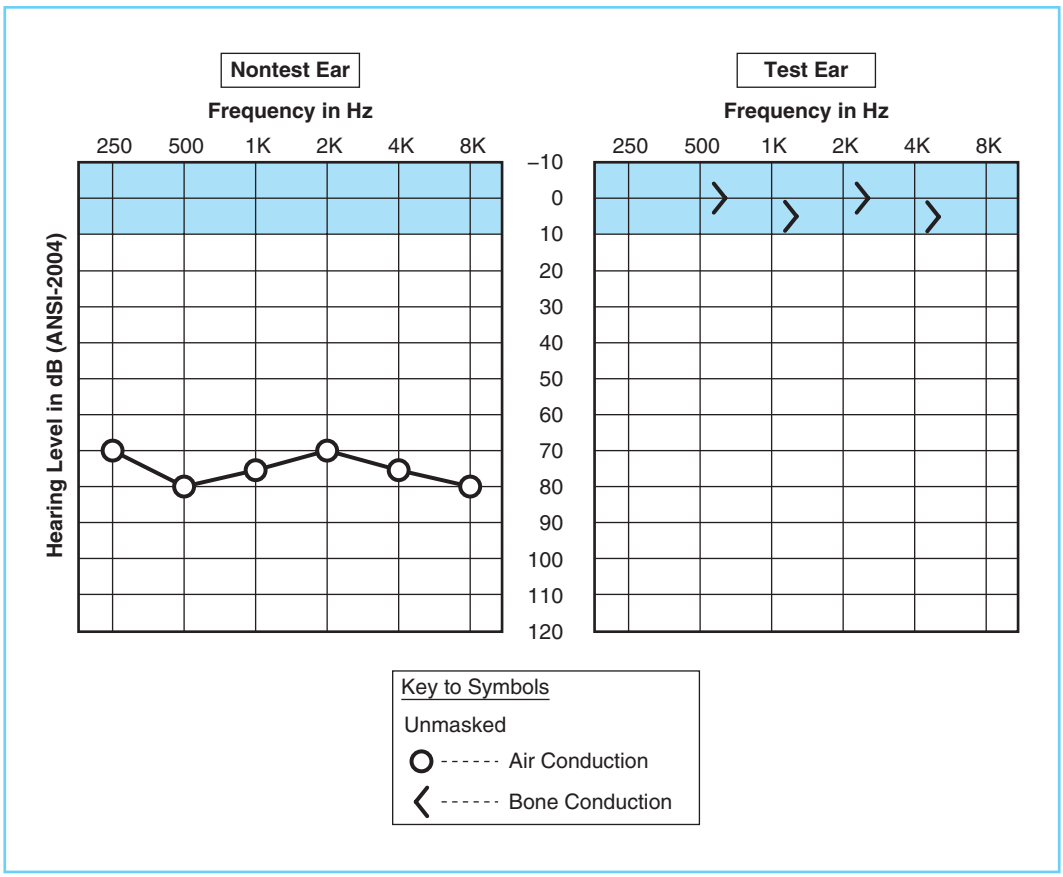


FIGURE 6-16 An audiogram representing the masking dilemma, in which overmasking occurs as soon as masking noise is introduced into the nontest ear.

in the right ear, we are in trouble from the start, because we need to introduce masking to the left ear at 70 dB, a level that could cross over the head and mask the ear that we are trying to test. When a masking dilemma occurs, threshold may not be determinable by conventional audiometric means.

Audiometry Unplugged: Tuning Fork Tests

Prior to the advent of the electronic audiometer, tuning forks were used to screen for hearing loss and to predict the presence of middle-ear disorder. Most otologists still use tuning forks today to assess the probability of conductive disorder. Most audiologists

still use the audiometric equivalent of at least one or two of the old tuning-fork tests as a cross-check for the validity of their bone-conduction audiometric results.

A tuning fork is a metal instrument with two prongs and a shank that is designed to vibrate at a fixed frequency when struck. Tuning forks of 256 and 512 Hz are commonly used. Because the intensity can vary considerably depending on the force with which the fork is struck, estimating threshold levels can be difficult. But in the hands of a skilled observer, tuning fork tests can be quite accurate at assessing the presence of conductive disorder. There are four primary tuning fork tests: the Schwabach, Rinne, Bing, and Weber.

The *Schwabach* test is done by placing the shank of the tuning fork on the mastoid. The patient is instructed to indicate the presence of sound for the duration that it is perceived, while the examiner does the same. If the patient perceives the sound longer than the examiner, the result is consistent with conductive disorder. If the examiner perceives the sound longer than the patient, the result is consistent with sensorineural disorder.

The *Rinne* test is carried out by comparing the length of time that a tone is perceived by air conduction in comparison to bone conduction. If the tone is heard for the same duration by air and bone conduction, it is considered a positive Rinne, consistent with sensorineural disorder. If the tone is heard for a longer duration by bone conduction than by air, it is considered a negative Rinne, consistent with conductive disorder.

The *Bing* test is done by comparing the perceived loudness of a bone-conducted tone with the ear canal unoccluded and occluded. In an ear with a conductive hearing loss, occluding the ear canal should not have much of an effect on loudness perception of the tone, due to the already-present occlusion effect of the middle-ear disorder. If the tone is perceived to be louder with the ear canal occluded, results are consistent with normal hearing or a sensorineural hearing loss. If the tone is not perceived to be louder, results are consistent with a conductive hearing loss. An audiometric variation of the Bing test is often referred to as the *occlusion index*. The occlusion index is calculated by measuring

bone-conduction thresholds at 250 or 500 Hz with and without the ear canal occluded. A significant improvement in threshold with the ear canal occluded rules out conductive hearing loss.

The *Weber* test is carried out by placing the tuning fork in the center of the forehead and asking the patient to indicate in which ear the sound is perceived. If one ear has a conductive hearing loss, the sound will lateralize to that side. If both ears have a conductive hearing loss, the sound will lateralize to the side with the largest conductive component. Perception of the sound at midline suggests normal hearing, sensorineural hearing loss, or symmetric conductive loss. Said another way, if the Weber lateralizes to the better ear, the loss in the poorer ear is sensorineural. If the Weber lateralizes to the poorer ear, the loss in the poorer ear is conductive. The Weber is most effective with low-frequency stimulation. The *audiometric Weber* is carried out in the same manner, except the stimulation is done with a bone vibrator rather than a tuning fork.

Most seasoned audiologists are well versed at carrying out audiometric Weber testing and measurement of the occlusion index. Both measures can be very useful in verifying the presence of an air-bone gap.

Summary

- An audiometer is an electronic instrument used by an audiologist to quantify hearing.
- An audiometer produces pure tones of various frequencies and other signals, attenuates them to various intensity levels, and delivers them to transducers.
- An important component of the audiometer system is the output transducer, which converts electrical energy from the audiometer into acoustical or vibratory energy. Transducers used for audiometric purposes are earphones, loudspeakers, and bone-conduction vibrators.
- The aim of pure-tone audiometry is to establish hearing threshold sensitivity across the range of audible frequencies important for human communication.
- Establishing a pure-tone audiogram is the cornerstone of a hearing evaluation.

- The establishment of pure-tone thresholds is based on a psychophysical paradigm that is a modified method of limits.
- Hearing thresholds by air conduction are established to describe hearing sensitivity for the entire auditory system.
- Hearing thresholds by bone conduction reflect function of the cochlea, regardless of the status of the outer or middle ears.
- Air-conduction and bone-conduction pure-tone audiometry are often confounded by *crossover* or *contralateralization* of the signal.
- When crossover has occurred, the test ear needs to be isolated by *masking* the other (nontest) ear.
- Tuning fork tests and their audiometric equivalents can be helpful in elucidating the presence of conductive disorder.

Short Answers Questions

1. An _____ is an electronic instrument used to quantify hearing sensitivity.
2. A _____ is a device that converts energy from one form to another.
3. Output transducers on an audiometer convert _____ energy to _____ energy.
4. Signals presented via _____ conduction are transduced by earphones or loudspeakers. Signal presented via _____ conduction are transduced by a bone vibrator.
5. Advantages of using insert earphones include: reduction in occurrence of _____ ear canals, reduction in need for _____, and enhanced placement _____.
6. The guidelines for maximum permissible noise levels for audiometric test rooms are provided by the _____ _____ _____ _____ (ANSI).
7. An _____ is a graph depicting hearing sensitivity. This graph demonstrates the _____ level of a sound as a function of _____.
8. Hearing sensitivity is measured by determining a person's _____ for a sound. This refers to the very softest sound that can be heard approximately _____ % of the time.

9. Audiometric _____ are used to denote specific features of a hearing threshold, such as location, mode of testing, presence of masking, and no response to sound.
10. The interaural _____ of a hearing loss describes the extent to which hearing sensitivity in one ear is the same as or different from the other ear.
11. By comparing air-conduction and bone-conduction thresholds, the _____ of peripheral hearing loss can be determined. The three types of peripheral hearing loss include: _____, _____ , and _____ hearing loss.
12. A _____ hearing loss is characterized by elevated air-conduction thresholds and normal bone-conduction thresholds. With this type of hearing loss, the problem is in the _____ ear canal or _____ _____ vibratory system.
13. A _____ hearing loss is characterized by similarly elevated air- and bone-conduction thresholds. With this type of hearing loss, the problem is in the _____ or _____ _____.
14. A _____ hearing loss is characterized by elevated bone-conduction thresholds and air-conduction thresholds that are significantly worse than bone-conduction thresholds. With this type of hearing loss, the problem lies in _____ the external ear canal or middle-ear vibratory system and in the cochlea or auditory nerve.
15. When preparing to test the hearing sensitivity of a patient, the patient should be seated in a _____ - _____ test booth or room, in a manner that allows the audiologist to view the patient's _____.
16. Prior to beginning a hearing test, an _____ examination should be performed to ensure that the external ear canal is not occluded with _____.
17. The test technique for determining audiometric threshold is based on the psychophysical modified "method of _____."
18. Bone-conduction thresholds are obtained using a bone _____ placed on either the _____ or _____.

19. The phenomenon of _____ occurs when sound presented to one ear crosses the head via bone conduction and is perceived by the other ear.
20. To eliminate the effects of crossover when testing hearing, the use of _____ noise is applied to the nontest ear.
21. The reduction in sound energy of a signal as it is transmitted by bone conduction from one side of the head to the opposite ear is known as _____ _____. The amount of interaural attenuation found during hearing testing depends on the type of _____ used.
22. Masking for _____ conduction is used in most cases because interaural attenuation is negligible.
23. In the _____ method of masking, a masking noise is introduced progressively over range of intensity levels until a plateau is reached.
24. In the case of _____, a masking noise is present, but the nontest ear is still responding. With an effective level of _____, the intensity of the masking noise is sufficient to prevent the nontest ear from responding. In _____, the intensity of the masking noise crosses over to the test ear, elevating the threshold in the test ear.
25. A _____ _____ occurs when the only effective masking level would be overmasking. This is found in cases where both ears have significant _____ - _____ _____.
26. The presence of an air-bone gap can often be detected using _____ _____ measures.
27. With the _____ test, the shank of a tuning fork is placed on the mastoid after being struck, and the patient is instructed to indicate the presence of sound for the duration it is perceived. A _____ hearing loss is suspected when the patient perceives sound longer than the examiner.
28. The _____ test is performed by comparing the length of time a tone is perceived by air conduction to bone conduction. A _____ result occurs when the tone is heard longer by bone conduction than air conduction, and is consistent with a _____ disorder.
29. In the _____ test, the loudness of a bone-conducted tone is compared between unoccluded and occluded ear

canal conditions. In the case of a _____ hearing loss, occluding the ear canal does not have an effect on loudness perception of the tone, due to an already-present occlusion effect caused by middle-ear disorder.

30. The _____ test is performed by placing the tuning fork in the center of the forehead and asking the patient to indicate in which ear sound is perceived. If the tone lateralizes to the better ear, the loss in the poorer ear is _____ _____. If the tone lateralizes to the poorer ear, the loss in the _____ ear is conductive.

Discussion Questions

1. What are the advantages and disadvantages of using insert versus supra-aural earphones?
2. Explain the importance of proper instruction and preparation of a patient prior to testing of hearing.
3. Discuss the advantages and disadvantages of the different bone oscillator placements.
4. Describe the plateau method for masking.
5. Describe the making dilemma. Explain why it is difficult to obtain accurate behavioral thresholds in the case of a masking dilemma.
6. How are tuning fork tests useful in the practice of modern clinical audiology?

Resources

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7

THE AUDIOLOGIST'S ASSESSMENT TOOLS: SPEECH AUDIOMETRY AND OTHER BEHAVIORAL MEASURES

Learning Objectives

Speech Audiometry
- Uses of Speech Audiometry
- Speech Audiometry Materials
- Clinical Applications of Speech Audiometery
- Predicting Speech Recognition

Other Behavioral Measures
- Traditional Site-of-Lesion Measures
- Masking Level Difference

Summary

Short Answer Questions

Discussion Questions

Resources

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- Know and describe the various speech audiometry measures used clinically.
- Understand the uses of the various types of speech audiometry tests.
- Explain how word-recognition thresholds function as a cross-check for pure-tone results.
- Describe how speech audiometry can be useful for site-of-lesion testing.
- Understand how speech audiometry measures are impacted by the redundancy of the auditory system and the speech signal.
- Describe how the speech audiometry materials may be sensitized to reduce redundancy.
- Know and describe other behavioral diagnostic measures, such as tests of auditory adaptation and recruitment and the test for binaural release from masking.

SPEECH AUDIOMETRY

The goal of **speech audiometry** is to quantify a patient's ability to understand everyday communication.

SPEECH AUDIOMETRY is a key component of audiologic assessment. Because it uses the kinds of auditory signals present in everyday communication, speech audiometry can tell us, in a more realistic manner than with pure tones, how an auditory disorder might impact communication in daily living. Also, the influence of disorder on speech processing can be detected at virtually every level of the auditory system. Speech measures can thus be used diagnostically to examine processing ability and the manner in which it is affected by disorders of the middle ear, cochlea, auditory nerve, brainstem pathways, and auditory centers in the cortex. In addition, there is a predictable relation between a person's hearing for pure tones and hearing for speech. Thus, speech audiometric testing can serve as a cross-check of the validity of the pure-tone audiogram.

Suprathreshold = at levels above threshold.

In many ways, speech audiometry can be thought of as our best friend in the clinic. Young children usually respond more easily to the presentation of speech materials than to pure tones. As a result, estimates of thresholds for speech recognition are often sought first in children to provide the audiologist guidance in establishing pure-tone thresholds. In adults, **suprathreshold** speech understanding may be a sensitive indicator of retrocochlear disorder, even in the presence of normal hearing sensitivity. A thorough assessment of speech understanding in such patients may assist in the diagnosis of neurologic disease. In elderly individuals, speech audiometry

is a vital component in our understanding of the patient's communication function. The degree of hearing impairment described by pure-tone thresholds often underestimates the amount of communication disorder that a patient has, and suprathreshold speech audiometry can provide a better metric for understanding the degree of hearing impairment resulting from the disorder.

Uses of Speech Audiometry

Speech audiometric measures are used routinely in an audiologic evaluation and contribute in a number of important ways, including:

- measurement of threshold for speech,
- cross-check of pure-tone sensitivity,
- quantification of suprathreshold speech-recognition ability,
- assistance in differential diagnosis,
- assessment of auditory processing ability, and
- estimation of communicative function.

Speech Thresholds

The term *speech threshold* (ST) refers to the lowest level at which speech can be either detected or recognized. The threshold of detection is referred to as the *speech detection threshold* (SDT) or the *speech awareness threshold* (SAT). Although synonymous, the term SDT is probably more accurate and will be used here to designate the lowest level at which speech is perceived. The threshold of recognition is referred to as the *speech-recognition threshold, speech reception threshold*, or *spondee threshold*. Historically, speech reception threshold was the more common term; spondee threshold the more accurate one. Here the term *speech-recognition threshold* **(SRT)** will be used to designate the lowest level at which spondee words can be identified.

SRT is the threshold level for speech recognition, expressed as the lowest intensity level at which 50% of spondaic words can be identified.

The speech threshold is a measure of the threshold of sensitivity for hearing or identifying speech signals. Even in isolation, a speech threshold provides significant information. It estimates hearing sensitivity in the frequency region of the audiogram where the major components of speech fall, thereby providing a useful estimate of degree of hearing loss for speech.

Pure-tone Cross-check

The **pure-tone average** is the average of thresholds obtained at 500, 1000, and 2000 Hz, and should closely agree with the ST or SRT.

Often the audiologist will establish an SRT first to provide guidance as to the level at which pure-tone thresholds are likely to fall. The SRT should agree closely with the pure-tone thresholds averaged across 500, 1000, and 2000 Hz (**pure-tone average** or PTA). That is, if both the pure-tone intensity levels and the speech intensity levels are expressed on the dB HL scale, the degree of hearing loss for speech should agree with the degree of hearing loss for pure tones in the 500 through 2000 Hz region. In practice, speech signals seem to be easier to process and sometimes result in lower initial estimates of threshold than testing with pure tones. In such a case, the audiologist will be alerted to the fact that the pure-tone thresholds may actually be suprathreshold and that the patient will need to be reinstructed. The extreme case of this is the patient who is feigning a hearing loss, often called malingering. In the case of malingering, the SRT may be substantially better than the PTA.

Speech Recognition

Pure-tone thresholds and speech detection thresholds characterize the lowest level at which a person can detect sound, but they provide little insight into how a patient hears above threshold, at suprathreshold levels. Speech recognition testing is designed to provide an estimate of suprathreshold ability to recognize speech. In its most fundamental form, speech recognition testing involves the presentation of single-syllable words at a fixed intensity level above threshold. This is referred to as word-recognition testing or, more colloquially, as speech discrimination testing. The patient is asked to repeat the words that are presented, and a percentage-correct score is calculated.

Results of word-recognition testing are generally predictable from the degree and configuration of the pure-tone audiogram. It is in this predictability that the value of the test lies. If word-recognition scores equal or exceed those that might be expected from the audiogram, then suprathreshold speech recognition ability is thought to be normal for the degree of hearing loss. If word recognition scores are poorer than would be expected, then suprathreshold ability is abnormal for the degree of hearing loss. Abnormal speech recognition is often the result of cochlear distortion or retrocochlear disorder.

Thus, word-recognition testing can be useful in providing estimates of communication function and in identifying patients with speech perception that is poorer than might be predicted from the audiogram.

Differential Diagnosis

Speech audiometric measures can be useful in differentiating whether a hearing disorder is due to changes in the outer or middle ear, cochlea, or auditory peripheral or central nervous systems. Again, in the cases of cochlear disorder, word-recognition ability is usually predictable from the degree and slope of the audiogram. Although there are some exceptions, such as hearing loss due to **endolymphatic hydrops**, word-recognition ability and performance on other forms of speech audiometric measures are highly correlated with degree of hearing impairment in certain frequency regions. When performance is poorer than expected, the likely culprit is a disorder of the VIIIth nerve or central auditory nervous system structures. Thus, unusually poor performance on speech audiometric tests lends a measure of suspicion about the site of the disorder causing the hearing impairment.

Endolymphatic hydrops is the cause of Ménière's disease.

Auditory Processing

Speech audiometric measures also permit us to evaluate the ability of the central auditory nervous system to process acoustic signals. As neural impulses travel from the cochlea through the VIIIth nerve to the auditory brainstem and cortex, the number and complexity of neural pathways expands progressively. The system, in its vastness of pathways, includes a certain level of redundancy or excess capacity of processing ability. Such redundancy serves many useful purposes, but it also makes the function of the central auditory nervous system somewhat impervious to our efforts to examine it. For example, a patient can have a rather substantial lesion of the auditory brainstem or auditory cortex and still have normal hearing and normal word-recognition ability. As a result, we have to sensitize the speech audiometric measures in some way before we can peer into the brain and understand its function and disorder.

With the use of advanced speech audiometric measures, we are able to measure central auditory nervous system function, often

referred to as auditory processing ability. Such measures are often useful diagnostically in helping to identify the presence of neurologic disorder. They are also helpful in that they provide insight into a patient's auditory abilities beyond the level of cochlear processing. We are often faced with the question of how a patient will hear after a peripheral sensitivity loss has been corrected with hearing aids. Estimates of auditory processing ability are useful in predicting suprathreshold hearing ability.

Estimating Communicative Function

Speech thresholds tell us about a patient's hearing sensitivity and, thus, what intensity level speech will need to reach to be made audible. Word-recognition scores tell us how well speech can be recognized once it is made audible. Advanced speech audiometric measures tell us how well the auditory nervous system processes auditory information at suprathreshold levels. Taken together, these speech audiometric measures provide us with a profile of a patient's communication function. If we know only the pure-tone thresholds, we can only guess as to the patient's functional impairment. If, on the other hand, we have estimates of the ability to understand speech, then we have substantive insight into the true ability to hear.

Speech Audiometry Materials

The goal of speech audiometry is to permit the measurement of patients' ability to understand everyday communication. The question of whether patients can understand speech seems like an easy one, but several factors intervene to complicate the issue.

Continuous discourse is running speech, such as a talker reading a story, used primarily as background competition.

A **phoneme** is the smallest distinctive class of sounds in a language.

You might think that the easiest way to assess a person's speech understanding ability would be to determine whether the person can understand running speech or **continuous discourse**. The problem with such an assessment lies in the redundancy of information contained in continuous speech. There is simply so much information in running speech that an adult patient with nearly any degree of disorder of the auditory system can extract enough of it to understand what is being spoken. On the other hand, you might think that the easiest way to assess speech understanding is by determining whether a patient can hear the difference between two **phonemes** such as /p/ and /g/. The problem with this type of

assessment is that there is so little redundancy in the speech target, that a patient with even a mild disorder of the auditory system may be unable to discriminate between the sounds.

In reality, different types of speech materials are useful for different types of speech audiometric measures. The materials of speech audiometry include nonsense syllables, single-syllable or monosyllabic words, two-syllable words, **sentential approximations**, sentences, and sentences with key words at the end.

Sentential approximations are contrived nonsense sentences, designed to be syntactically appropriate but meaningless.

Types of Materials

The materials used in speech audiometry vary from nonsense syllables to complete sentences. Each type of material has unique attributes, and most are used in unique ways in the speech audiometric assessment.

Nonsense syllables, such as *pa, ta, ka, ga*, have been used as a means of assessing a patient's ability to discriminate between phonemes of spoken language. Ability to discriminate small differences relies on an intact peripheral auditory system, somewhat limiting the applicability of such measures clinically, where many individuals have disordered peripheral systems.

Single-syllable or monosyllabic words, such as *cat, tie, lick*, have been used extensively in the assessment of word recognition ability. In fact, the most popular materials for the measurement of suprathreshold speech understanding have been monosyllabic words, grouped in lists that were designed to be **phonetically balanced** across the speech sounds of the English language. These 50-word lists were compiled during World War II as test materials for comparing the speech transmission characteristics of aircraft radio receivers and transmitters. The words were selected from various sources and arranged into 50-word lists so that all of the sounds of English were represented in their relative frequency of occurrence in the language within each list. Hence the lists were considered to be phonetically balanced and became known as PB lists.

Phonetically balanced word lists contain speech sounds that occur with the same frequency as those of conversational speech.

Spondaic words, or spondees, are two-syllable words, such as *northwest, cowboy*, and *hotdog*, that are used routinely in speech

Spondaic words are two-syllable words spoken with equal emphasis on each syllable.

audiometric assessment. Spondees can be spoken with equal emphasis on both syllables and have the advantage that, with only small individual adjustments, can be made *homogeneous with respect to audibility*. That is, they are all just recognizable at about the same speech intensity level.

Sentences and variations of sentence materials are also used as speech audiometric measures. For example, the Central Institute for the Deaf (CID) Everyday Sentences (Silverman & Hirsh, 1955) is a test that contains 10 sentences per list, with common sentences varying from 2 to 12 words per sentence. The test is scored by calculating the percentage of key words that are recognized correctly. A more modern variation of the sentence test is the Connected Speech Test (Cox et al., 1987).

A novel procedure employing sentences with variable context is the Speech-Perception-in-Noise (SPIN) test (Kalikow et al., 1977; Bilger et al., 1984). In this case, the test item is a single word that is the last of a sentence. There are two types of sentences, those having high predictability in which word identification is aided by context (e.g. "They played a game of cat and *mouse*") and those having low predictability in which context is not as helpful (e.g. "I'm glad you heard about the *bend*"). Sentences are presented to the listener against a background of competing **multitalker babble**. Another sentence-based procedure is the Synthetic Sentence Identification (SSI) test (Jerger et al., 1968). Artificially created, seven-word sentential approximations (e.g., "Agree with him only to find out") are presented to the listener against a competing background of single-talker continuous discourse.

Multitalker babble is a recording of numerous people talking at once and is used as background competition.

Redundancy in Hearing

There is a great deal of redundancy associated with our ability to hear and process speech communication. Intrinsically, the central auditory nervous system has a rich system of anatomic, physiologic, and biochemical overlap. Among other functions, such **intrinsic redundancy** permits multisensory processing and simultaneous processing of different auditory signals. Another aspect of intrinsic redundancy is that the nervous system can be altered substantially by neurologic disorder and still maintain its ability to process information.

Intrinsic redundancy is the abundance of information present in the central auditory system due to the excess capacity inherent in its richly innervated pathways.

Extrinsically, speech signals contain a wealth of information due to **phonetic, phonemic, syntactic**, and **semantic** content and rules. Such **extrinsic redundancy** allows us to hear only part of a speech segment and still understand what is being said. We are capable of perceiving consonants from the coarticulatory effects of vowels even when we do not hear the acoustic segments of the consonants. We are also capable of perceiving an entire sentence from hearing only a few words that are imbedded into a semantic context. Extrinsic redundancy increases as the content of the speech signal increases. Thus, a nonsense syllable is least redundant; continuous speech is most redundant. The immunity of speech perception to the effects of hearing sensitivity loss varies directly with the amount of redundancy of the signal. The relationship is shown in Figure 7-1. The more redundancy inherent in the signal, the more immune that signal is to the effects of hearing loss. Stated another way, perception of speech that has less redundancy is more likely to be affected by the presence of hearing loss than is perception of speech with greater redundancy.

Phonetic pertains to an individual speech sound.

Phonemic pertains to the smallest distinctive class of sounds in a language, representing the set of variations of a speech sound that are considered the same sound and represented by the same symbol.

Syntactic refers to the arrangement of words in a sentence.

Semantic refers to the meaning of words.

Extrinsic redundancy is the abundance of information present in the speech signal.

The issue of redundancy plays a role in the selection of speech materials. If you are trying to assess the effects of a cochlear hearing impairment on speech perception, then signals that have reduced redundancy should be used. Nonsense syllables or monosyllable words are sensitive to peripheral hearing impairment and are useful in quantifying its effect. Sentential approximations and sentences, on the other hand, are not. Redundancy in these materials is simply too great to be affected by most degrees of hearing impairment.

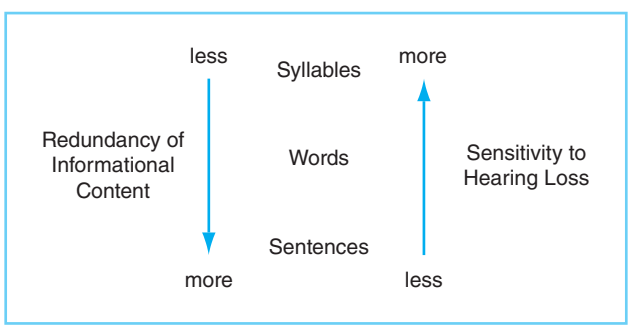


FIGURE 7-1 Relationship of redundancy of informational content and sensitivity to the effects of hearing loss on three types of speech-recognition materials.

If you are trying to assess the effects of a disorder of the central auditory nervous system on speech perception, the situation becomes more difficult. Speech signals of all levels of redundancy provide too much information to a central auditory nervous system that, itself, has a great deal of redundancy. Even if the intrinsic redundancy is reduced by neurologic disorder, the extrinsic redundancy of speech may be sufficient to permit normal processing. The solution to assessing central auditory nervous system disorders is to reduce the extrinsic redundancy of the speech information enough to reveal the reduced intrinsic redundancy caused by neurologic disorder. This concept is shown in Table 7-1. Normal intrinsic redundancy and normal extrinsic redundancy result in normal processing. Reducing the extrinsic redundancy, within limits, will have little effect on a system with normal intrinsic redundancy. Similarly, a neurologic disorder that reduces intrinsic redundancy will have little impact on perception of speech with normal extrinsic redundancy. However, if a system with reduced intrinsic redundancy is presented with speech materials that have reduced extrinsic redundancy, then the abnormal processing caused by the neurologic disorder will be revealed.

To reduce extrinsic redundancy, speech signals must be sensitized in some way. Table 7-2 shows some methods for reducing redundancy of test signals. In the frequency domain, speech can be sensitized by removing high frequencies (passing the lows and cutting out the highs or low-pass filtering), thus limiting the phonetic content of the speech targets. Speech can also be sensitized in the time domain by time compression, a technique that removes segments of speech and compresses the remaining segments to increase

TABLE 7-1 The relationship of intrinsic and extrinsic redundancy to speech recognition ability

Intrinsic		Extrinsic		Speech Recognition
normal	+	normal	=	normal
normal	+	reduced	=	normal
reduced	+	normal	=	normal
reduced	+	reduced	=	abnormal

TABLE 7-2 Methods for reducing extrinsic redundancy

Domain	Technique
frequency	low-pass filtering
time	time compression
intensity	high-level testing
competition	speech in noise
binaural	dichotic measures

speech rate. In the intensity domain, speech can be presented at sufficiently high levels at which disordered systems cannot seem to process effectively. Another very effective way to reduce redundancy of a signal is to present it in a background of competition. Yet another way to challenge the central auditory system is to present different but similar signals to both ears simultaneously in what is referred to as a *dichotic* measure.

One confounding variable in the measurement of auditory nervous system processing is the presence of cochlear hearing impairment. In such cases, signals that have enhanced redundancy need to be used so that hearing sensitivity loss does not interfere with interpretation of the measures. That is, you want to use materials that are not affected by peripheral hearing loss so that you can assess processing at higher levels of the system. Nonsense-syllable perception would be altered by the peripheral hearing impairment, and any effects of central nervous system disorder would not be revealed. Use of sentences would likely overcome the peripheral hearing impairment, but their redundancy would be too great to challenge nervous-system processing, even if it is disordered. The solution is to use highly redundant speech signals to overcome the hearing sensitivity loss and then to sensitize those materials enough to challenge auditory processing ability.

Other Considerations

Another factor in deciding which speech materials to use is whether the measure is open set or closed set in nature. **Open-set** speech materials are those in which the choice of a response is limited only to the constraints of a language. For example, PB-word

Open set means the choice can be from among all available targets in the language.

Audiologist Profile

Teri Wilson-Bridges, M.A., CCC-A



Where I Live: Laurel, Maryland

Where I Work: The Hearing and Speech Center at Washington Hospital Center in Washington, D.C. Washington Hospital Center is the largest private hospital in the nation's capital. The Hospital Center, a member of MedStar Health, is a 900-bed acute care not-for-profit hospital. The Hearing and Speech Center is a freestanding department within the hospital that has a large staff: five audiologists, two audiology interns, one PRN audiologist, five speech-language pathologists, six PRN speech-language pathologists, and three administrative staff members.

What I Do: I am the director of the Hearing and Speech Center. I am responsible for the professional, administrative, and financial functions of the department. My time is mostly administrative; however, I do see patients two days a week. My clinical work includes performing hearing evaluations and various auditory evoked potential measures. I am active in local and national professional organizations.

Why Audiology? Audiology is an exciting and fascinating field. I enjoy the interaction with patients and family members, as well as working with other health-care professionals in order to make a difference in the quality of life for my patients. What could be better and more rewarding?

Closed set means the choice is from a limited set; multiple choice.

lists are considered open set because the correct answer can be any single-syllable word from the English language. **Closed-set** speech materials are those that limit the possible choices. For example, picture-pointing tasks have been developed, mostly for pediatric testing, wherein the patient has a limited number of foils from which to choose the correct answer.

Some speech materials have been designed specifically to evaluate children's speech perception. Children's materials must be carefully designed to account for language abilities of children and to make the task interesting. Specific target words or sentences must be of a vocabulary level that is appropriate, defined, and

confined so that any reduction in performance can be attributable to hearing disorder and not to some form of language disorder. The task must also hold a child's interest for a time sufficient to complete testing. Closed-set picture-pointing tasks have been developed that effectively address both of these issues.

Clinical Applications of Speech Audiometry

For clinical purposes, speech audiometric measures fall into one of four categories:

1. speech-recognition threshold,
2. speech-awareness threshold,
3. word-recognition score, or
4. sensitized-speech measures.

In a typical clinical situation, a speech threshold (awareness or recognition) will be determined early as a cross-check for the validity of pure-tone thresholds. Following completion of pure-tone audiometry, word-recognition scores will be obtained as estimates of suprathreshold speech understanding in quiet. Finally, either as part of a comprehensive audiological evaluation or as part of an advanced speech audiometric battery, sensitized speech measures will be used to assess processing at the level of the auditory nervous system.

Speech-Recognition Threshold

The first threshold measure obtained during an audiological evaluation is usually the spondee or speech-recognition threshold, also known as the speech reception threshold. The SRT is the lowest level at which speech can be identified. The main purpose of obtaining an SRT is to provide an anchor against which to compare pure-tone thresholds.

The preferred materials for the measurement of a speech-recognition threshold are spondaic words. In theory, almost any materials could be used, but the spondees have the advantage of being homogeneous with respect to audibility, or just audible at about the same speech intensity level. This helps greatly in establishing a threshold for speech.

The original spondee words were developed at the Harvard Psychoacoustic Laboratory and included 42 words (Hudgins et al., 1947). The list was later streamlined into 36 words at CID (Hirsh et al., 1952) and recorded into the CID W-1 and CID W-2 tests that were used for many years. In current clinical practice, a list of 15 words is commonly used. Table 7-3 lists the 15 spondees that have been found to be reasonably homogenous for routine clinical use.

Early recordings of spondee words used a carrier phrase "Say the word ..." to introduce to the patient that a word was about to be presented. Although the use of a carrier phrase remains quite common and is recommended for word-recognition testing, it is now seldom used in establishing an SRT because it was found to have little influence on test outcome.

Another clinical practice that has changed over the years is the use of monitored live voice for spondee presentation rather than the use of recorded materials. Again, although the use of recorded materials is important for word-recognition testing, it has been found to have little influence on SRT outcome. Because monitored live-voice testing is more efficient than the use of recorded materials, clinicians have adopted it as standard practice for determining an SRT.

One other aspect of speech threshold testing that varies from word-recognition testing is that of familiarization with the test materials. The goal of SRT testing is to determine a threshold for speech recognition. The use of words that are equated for audibility is one important component of the process. But if one word is familiar to a listener and another is less so, audibility is

TABLE 7-3 Spondaic words that are considered homogenous with regard to audibility (Young et al., 1982)

Spondaic Words		
baseball	inkwell	railroad
doormat	mousetrap	sidewalk
drawbridge	northwest	toothbrush
eardrum	padlock	woodwork
grandson	playground	workshop

likely to be influenced. One easy way around this issue is simply to familiarize the patient with the spondee words before testing begins. Familiarization is a common and recommended practice in establishing an SRT.

Although every audiologist has a slightly different way of saying it, the instructions are essentially these: *"The next test is to determine the lowest level at which you can understand speech. You will be hearing some two-syllable words, such as baseball and hotdog. Your job is simply to repeat each word. At first these will be at a comfortable level so that you become familiar with the words. Then they will start getting softer. Keep repeating what you hear no matter how soft they become, even if you have to guess at the words."*

The procedure for determining the SRT is essentially one of presenting a series of spondaic words and systematically varying the intensity to determine the lowest level at which the patient can identify about 50% of the test items. A number of different procedures have been developed and recommended over the years, and most of them can be used to establish a valid SRT. Two procedures are presented in the accompanying box as examples for you to consider for clinical use.

Techniques for Establishing an SRT

Clinical Note

Technique A (after Downs & Dickinson Minard, 1996):

- Familiarize the patient with the spondees.
- Present one spondee at the lowest attenuator setting (or 30 dB below an SRT established during a previous evaluation). Ascend in 10 dB steps, presenting one word at each level, until the patient responds correctly.
- Descend 15 dB.
- Present up to five spondees until: (a) the patient misses three spondees, after which you should ascend 5 dB and try again; or (b) the patient first repeats two spondees correctly. This level is the SRT.

continues

Clinical Note

continued

Technique B (after Huff & Nerbonne, 1982).

- Familiarize the patient with the spondees.
- Present one spondee at a level approximately 30 dB above estimated threshold. If the patient does not respond correctly, increase the intensity by 20 dB. If the patient responds correctly, decrease the level by 10 dB.
- Continue to present one word until the patient does not respond correctly. At this level, present up to five words. If the patient identifies fewer than three words, increase the level by 5 dB. If the patient identifies three words, decrease the level by 5 dB.
- Threshold is the lowest intensity level at which three out of five words are identified correctly.

An important clinical value of this SRT is that it should agree closely with the pure-tone thresholds averaged across 500, 1000, and 2000 Hz. If both the pure-tone intensity levels and the speech intensity levels are expressed on a hearing level (HL) decibel scale, then the degree of hearing loss for speech should agree with the degree of hearing loss for pure tones in the 500 through 2000 Hz region. In clinical practice, the SRT and the PTA should be in fairly close agreement, differing by no more than ± 6 dB. If, for example, the SRT is 45 dB, the PTA should be at some level between 39 and 51 dB. If there is a larger discrepancy between the two numbers, then one or the other is probably an invalid measure.

Speech Detection Threshold

Speech detection threshold (SDT) is the lowest level at which the presence of a speech signal can just be detected.

A **speech detection threshold** (SDT), sometimes referred to as speech awareness threshold, is the lowest level at which a patient can just detect the presence of a speech signal. Determination of SDT is usually not a routine part of the audiometric evaluation and is used only when an SRT cannot be established.

An SDT is determined in place of an SRT in patients who do not have the language competency to identify spondaic words, especially in young children who have not yet developed the

vocabulary to identify words or pictures representing words. It may also be necessary to establish SDTs rather than SRTs in patients who do not speak a language for which spondees have been recorded or in patients who have lost language function due to a cerebrovascular accident or other neurologic insult.

Speech detection threshold testing is carried out in a manner similar to pure-tone threshold testing. When testing younger patients, procedural adaptations need to be made and are discussed in greater detail in Chapter 10.

The SDT is established by presenting some form of speech. Commonly used speech signals include familiar words, connected speech, spondaic words, or even repeated nonsense syllables, such as "*ba ba ba ba ba*." As with SRT measure, the use of monitored live voice for speech presentation rather than the use of recorded materials has been found to have little influence on SDT outcome. Because monitored live-voice testing is more efficient than the use of recorded materials, clinicians have adopted it as standard practice for determining an SDT.

The procedure for determining the SDT is one of presenting the speech target and systematically varying the intensity to determine the lowest level at which the patient can just detect the speech. The most common clinical procedure is a descending technique similar to that used in pure-tone threshold testing:

- Present a speech signal at a level at which the patient can clearly hear. If normal hearing is anticipated, begin testing at 40 dB HL.
- If the patient does not respond, increase the intensity level by 20 dB until a response occurs. Once the patient responds, threshold search begins.
- Follow the "down 10, up 5" rule by decreasing the intensity by 10 dB after each response and increasing the intensity by 5 dB after each no-response.
- Threshold is considered to be the lowest level at which the patient responds to speech about 50% of the time.

The important clinical value of the SDT is that it should agree closely with the best pure-tone threshold within the audiometric frequency range. For example, if the best pure-tone threshold is

at 0 dB at 250 Hz, then the SDT should be around 0 dB. Or, if the best pure-tone threshold is 25 dB at 1000 Hz, then the SDT should be approximately 25 dB. Because speech is composed of a broad spectrum of frequencies, speech detection thresholds will reflect hearing at the frequencies with the best sensitivity.

The SDT will occur at a lower intensity level than the SRT, because the SDT depends on audibility alone, whereas the SRT requires that a patient both hear and identify the speech signal. Threshold of detection can be expected to be approximately 5 to 10 dB better than threshold of recognition.

Word Recognition

The most common way that we describe suprathreshold hearing ability is with word-recognition measures. Word-recognition testing, also referred to as speech discrimination, word discrimination, and PB-word testing, is an assessment of a patient's ability to identify and repeat single-syllable words presented at some suprathreshold level.

The words used for word-recognition testing are contained in lists of 50 items that are phonetically balanced with respect to the relative frequency of occurrence of phonemes in the language. Raymond Carhart, one of the early pioneers of audiologic evaluation, adapted these so-called PB lists to audiologic testing. He reasoned that if you first established the threshold for speech, the SRT, then presented a PB list at a level 25 dB above the SRT, the percent correct word repetition for a PB list would tell you something about how well the individual could understand speech in that ear. This measure, the PB score at a constant suprathreshold level, came to be called the *discrimination score*, on the assumption that it was proportional to the individual's ability to "discriminate" among the individual sounds of speech. This basic speech audiometric paradigm, a percent-correct score at a defined **sensational level** above the SRT, formed the framework for audiologic and aural rehabilitation procedures that remain in use today.

Sensation level (SL) is the intensity level of a sound in dB above an individual's threshold.

Materials

The first monosyllabic word lists used clinically were those developed at the Harvard Psychoacoustics Laboratory (PAL). They were

called the PAL PB-50 test (Egan, 1948). These 20 lists of 50 words each were designed to be phonetically balanced within each list. The PAL PB-50 test served as the precursor for materials used today. Subsequent modifications of the original PB lists include the CID W-22 test (Hirsh et al., 1952) and the NU-6 test (Tillman & Carhart, 1966).

The CID W-22 word lists were designed to try to improve the materials by using words that were more familiar and more representative of the phonetic content of spoken English. The W-22 test contains four 50-word lists that are arranged in six different randomizations. The Northwestern University Auditory Test Number 6, or NU-6 test, was developed using consonant-nucleus-consonant (CNC) words. Four lists of 50 words each were used based on the notion of *phonemic* balance rather than *phonetic* balance. The idea here was that the lists should represent the spoken phonemes or groups of speech sounds in the language, rather than all of the individual phonetic variations.

A number of other word-list materials have been developed over the years in an effort to refine word-recognition testing. Despite these efforts, however, the W-22 and especially the NU-6 lists enjoy the most widespread clinical use.

Procedural Considerations

Most recordings for word-recognition testing use a carrier phrase "Say the word ..." to introduce to the patient that a word is about to be presented. The use of a carrier phrase remains quite common and is recommended for word-recognition testing as it has been found to have an influence on test outcome.

One of the most important considerations in word-recognition testing is the use of recorded materials. Although monitored live-voice testing is more efficient than the use of recorded materials and enjoys widespread clinical acceptance as a result, the advantages of using recorded speech are numerous and important. Perhaps most importantly, interpretation of word-recognition testing outcome is based on results from data collected with recorded materials. Diagnostically, word-recognition testing is carried out as a matter of routine for the

times when results are not predictable or significant changes in functioning have occurred. In both cases, the underlying cause of the result may signal health concerns that alert the audiologist to make appropriate medical referrals. The first question, then, is whether results are predictable from the degree of hearing loss. For example, is a score of 68% normal for a patient with a moderate hearing loss? This can be assessed by comparing the score to published data for patients with known cochlear hearing loss. If the score falls within the expected range, then it is consistent with degree of hearing loss. If not, then there is reason for concern that the underlying cause of the disorder is retrocochlear in nature. These published data are based on standard recordings of word-recognition tests, and comparisons to scores obtained with live-voice testing are not valid. A similar problem occurs when observing changes in performance. On many occasions as an audiologist, you will encounter patients who are being monitored for one reason or another. The question is often whether the patient is getting worse. If you encounter a significant decline on recorded speech measures, you can be fairly confident that a real change has occurred. If the same decline is noted on live-voice testing, you will have no basis for making a decision. There are other advantages to the use of recorded materials that relate to inter-patient and inter-clinic comparisons. As a result, recorded word-recognition testing has become an important audiologic standard of care.

Another important procedural consideration is presentation level. Early in the development of word-recognition testing as a clinical tool, the choice of an intensity level to carry out testing was based on the performance of normal-hearing listeners. Data from groups of subjects with normal hearing showed that, by 25–40 dB above the SRT, most subjects achieved 100% word recognition. As a result, the early clinical standard was to test patients at 40 dB sensation level or 40 dB above the pure-tone average or SRT. Over the years, this notion of testing at 40 dB SL began to be questioned as clinicians realized that the audibility of speech signals varied with both degree and configuration of hearing loss. If a patient has a flat hearing loss in both ears, then the parts of speech that are audible to the listener are equal for both ears at 40 dB SL. If, however, one ear has a flat loss and the

other a sloping hearing loss, the one with the sloping loss is at a disadvantage in terms of the speech signals that are audible to that ear, and the word-recognition score would be poorer for that ear. In this case, the differences between scores from one ear to the other could be accounted for on the basis of the audiometric configuration, and little is learned diagnostically.

Modern clinical practice has largely abandoned the notion of equating the ears by using equal SL, or even equating the ears using comfort level. Instead these strategies have been replaced with the practice of testing and comparing ears at equal SPL and in searching for the maximum word-recognition scores at high-intensity levels. The notion is a simple one. If the best or maximum score is obtained from both ears, then intensity level is removed from the interpretation equation. Maximum scores can then be compared between ears and to normative data to see if they are acceptable for the degree of hearing loss.

This thinking has led to an exploration of speech recognition across the patient's dynamic range of hearing rather than at just a single suprathreshold intensity level (Jerger & Jerger, 1971). The goal in doing so is to determine a maximum score, regardless of test level. To obtain a maximum score, lists of words or sentences are presented at three to five different intensity levels, extending from just above the speech threshold to the upper level of comfortable listening. In this way, a **performance-intensity function** is generated for each ear. The shape of this function often has diagnostic significance. Figure 7-2 shows examples of PI functions. In most cases, the PI function rises systematically as speech intensity is increased, to an asymptotic level representing the best speech recognition that can be achieved in that ear. In some cases, however, there is a paradoxical **rollover** effect, in which the function declines substantially as speech intensity increases beyond the level producing the maximum performance score. In other words, as speech intensity level increases, performance rises to a maximum level then declines or "rolls over" sharply as intensity increases. This rollover effect is commonly observed when the site of hearing loss is retrocochlear, in the auditory nerve or the auditory pathways in the brainstem.

Performance-intensity function (PI function) is a graph of percentage-correct speech recognition scores plotted as a function of presentation level of the target signals.

Rollover is a decrease in speech recognition ability with increasing intensity level.

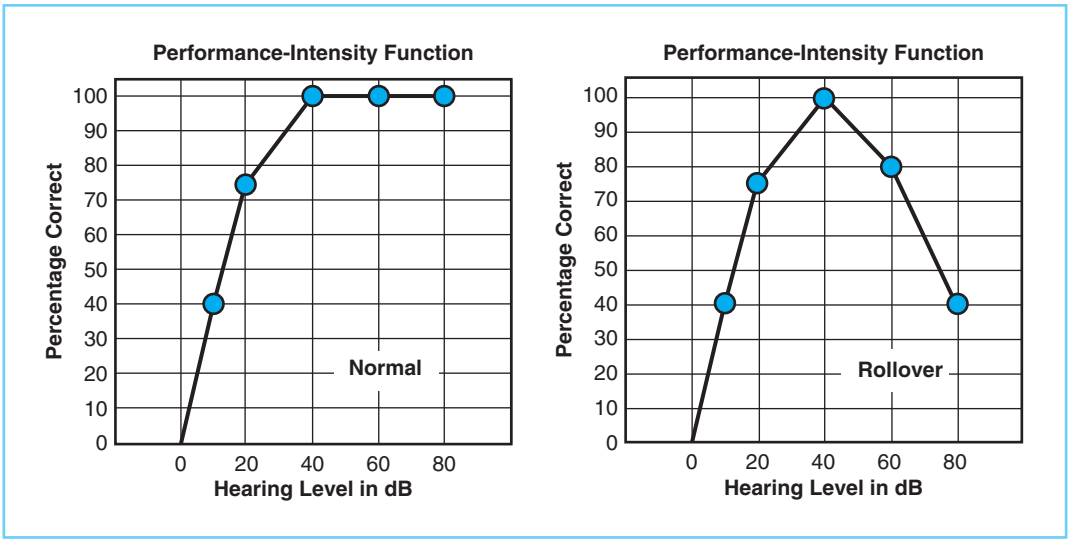


FIGURE 7-2 Examples of two performance-intensity functions, one normal and one with rollover.

The use of PI functions is a way of sensitizing speech by challenging the auditory system at high-intensity levels. Because of its ease of administration, many audiologists use it routinely as a screening measure for retrocochlear disorders. The most efficacious clinical strategy is to present a word list at the highest intensity level (usually 80 dB HL). If the patient scores 80%, then potential rollover of the function is minimal, and testing can be terminated. If the patient scores below 80%, then rollover could occur, and the function is completed by testing at lower intensity levels.

Other modifications of word-recognition testing involve the use of half lists of 25 words each or the use of lists that are rank-ordered in terms of difficulty. Both of these modifications are designed to enhance the efficiency of word-recognition testing. They are probably best reserved for rapid assessment of those patients with normal performance.

Procedure

Although every audiologist has a slightly different way of saying it, the instructions are essentially these: *"You will now be hearing some single-syllable words following the phrase, 'Say the word.' For example,*

you will hear, 'Say the word book.' Your job is simply to repeat the final word 'book.' If you are not sure of the word, please make a guess at what you heard."

The procedure for determining the word-recognition score is quite simple. Once a level has been chosen, the list of words is presented. The audiologist then scores each response as correct or incorrect. The word-recognition score is then calculated as the percentage correct score. For example, if a 50-word list is presented and the patient misses 10 words, then the score is 40 out of 50 or 80% correct. Testing is then completed in the other ear.

Interpretation

Interpretation of word-recognition measures is based on the predictable relation of maximum word-recognition scores to degree of hearing loss (Yellin et al., 1989; Dubno et al., 1995). If the maximum score falls within a given range for a given degree of hearing loss, then the results are considered to be within expectation for a cochlea hearing loss. If the score is poorer than expected, then word-recognition ability is considered to be abnormal for the degree of hearing loss and consistent with retrocochlear disorder. Table 7-4 can be used to determine whether a score exceeds expectations based on degree of hearing loss, in this case the PTA or pure-tone average of thresholds at 500,1000, and 2000 Hz. The number represents the lowest maximum score that 95% of individuals with hearing loss will obtain on this particular measure, the 25-item NU-6 word lists. Any score below this number for a given hearing loss is considered to be abnormal.

Sensitized Speech Measures

Some problems in speech understanding appear to be based not on the distortions introduced by peripheral hearing loss, but on deficits resulting from disorders in the auditory pathways within the central nervous system. Revealing these disorders relies on the use of sensitized speech materials that reduce the extrinsic redundancy of the signal. Although redundancy can be reduced by low-pass filtering or time compression, these methods have not proven to be clinically useful because of their susceptibility to the effects of cochlear hearing loss. Perhaps the most successfully used sensitized speech measures are those in which competition is presented

TABLE 7-4 Values used to determine whether a maximum word-recognition score on the 25-item NU-6 word lists meets expectations based on degree of hearing loss, expressed as the pure-tone average (PTA) of 500,1000, and 2000 Hz

PTA (in dB HL)	Maximum Word-Recognition Scores
0	100
5	96
10	96
15	92
20	88
25	80
30	76
35	68
40	64
45	56
50	48
55	44
60	36
65	32
70	28

Source: Adapted from Confidence Limits for Maximum Word-recognition Scores, by J. R. Dubno, F. Lee, A. J. Klein, L. J. Matthews, and C. F. Lam, 1995, *Journal of Speech and Hearing Research, 38,* 490–502.

either in the same ear or the opposite ear as a means of stressing the auditory system.

There are any number of measures of speech-in-noise that have been developed over the years, among them, for example, the SPIN and HINT. The SPIN, or Speech-Perception-in-Noise Test (Kalikow et al., 1977), has as its target a single word that is the last in a sentence. In half of the sentences, the word is predictable from the context of the sentence; in the other half the word is not predictable. These signals are presented in a background of multitalker competition. The HINT, or Hearing in Noise Test (Nilsson et al., 1994),

uses sentence targets and an adaptive paradigm to determine the threshold for speech recognition in the presence of background competition. These and numerous other measures are useful in assessing speech recognition in competition.

One measure of suprathreshold ability that has stood the test of time is the SSI, or Synthetic Sentence Identification Test (Jerger et al., 1968). The SSI uses sentential approximations that are presented in a closed-set format. The patient is asked to identify the sentence from a list of ten. Sentences are presented in the presence of single-talker competition. Testing typically is carried out with the signal and the competition at the same intensity level, a **message-to-competition ratio** of 0 dB. The SSI has some advantages inherent in its design. First, because it uses sentence materials, it is relatively immune to hearing loss. Said another way, the influence of mild degrees of hearing loss on identification of these sentences is minimal, and the effect of more severe hearing loss on absolute scores is known. Second, it uses a closed-set response, thereby permitting practice that reduces learning effects and ensures that a patient's performance deficits are not task related. Third, the single-talker competition, which has no influence on recognition scores of those with normal auditory ability, can be quite interfering to sentence perception in those with auditory processing disorders. Reduced performance on the SSI has been reported in patients with brainstem disorders and in the aging population.

The ratio in dB of the presentation level of a speech target to that of background competition is called the **message-to-competition ratio** (MCR).

Another effective approach for assessing auditory processing ability is the use of dichotic tests. In the dichotic paradigm, two different speech targets are presented simultaneously to the two ears. The patient's task is usually either to repeat back both targets in either order or to report only the word heard in the precued ear. In this latter case, the right ear is precued on half the trials and the left on the other half. Two scores are determined, one for targets correctly identified from the right ear, the other for targets correctly identified from the left ear. The patterns of results can reveal auditory processing deficits, especially those due to disorders of the temporal lobe and corpus callosum.

Dichotic tests have been constructed using nonsense syllables (Berlin et al., 1972) and digits (Musiek, 1983). Although valuable

Staggered spondaic words are used in tests of dichotic listening, in which two spondaic words are presented so that the second syllable delivered to one ear is heard simultaneously with the first syllable delivered to the other ear.

measures in patients with normal hearing, interpretation can be difficult in patients with significant hearing sensitivity loss. Two other tests that have enjoyed widespread use over the years are the **Staggered Spondaic Word** (SSW) test (Katz, 1962) and the Dichotic Sentence Identification (DSI) test (Fifer et al., 1983). The SSW is a test in which a different spondaic word is presented to each ear, with the second syllable of the word presented to the leading ear overlapping in time with the first syllable of the word presented to the lagging ear. Thus, the leading ear is presented with one syllable in isolation (noncompeting), followed by one syllable in a dichotic mode (competing). The lagging ear begins with the first syllable presented in the dichotic mode and finishes with the second syllable presented in isolation. The right ear serves as the leading ear for half of the test presentations. Error scores are calculated for each ear in both the competing and noncompeting modes. A correction can be applied to account for hearing sensitivity loss. Abnormal SSW performance has been reported in patients with brainstem, corpus callosum, and temporal lobe lesions. The DSI test uses synthetic sentences from the SSI test, aligned for presentation in the dichotic mode. The response is closed set, and the subject's task is to identify the sentences from among a list on a response card. The DSI was designed in an effort to overcome the influence of hearing sensitivity loss on test interpretation and was found to be applicable for use in ears with a pure-tone average of up to 50 dB HL and asymmetry of up to 40 dB. Abnormal DSI results have been reported in aging patients.

Speech Recognition and Site of Lesion

Speech audiometric measures can be useful in predicting where the site of lesion might be for a given hearing loss. A summary is presented in Table 7-5.

If a hearing loss is conductive due to middle-ear disorder, the effect on speech recognition will be negligible, except to elevate the SRT by the degree of hearing loss in the ear with the disorder. Suprathreshold speech recognition will not be affected.

If a hearing loss is sensorineural due to cochlear disorder, the SRT will be elevated in that ear to a degree predictable by the pure-tone average. Suprathreshold word-recognition scores will be predictable from the degree of hearing sensitivity loss. Sensitized

TABLE 7-5 Probable speech-recognition results for various disorder sites

Site of Disorder	Speech-Recognition	Ipsilateral/ Contralateral
Middle ear	normal	ipsi
Cochlea	predictable	ipsi
VIIIth nerve	poor	ipsi
Brainstem	reduced	ipsi/contra
Temporal lobe	reduced	contra

speech measures will be normal or predictable from degree of loss. Dichotic measures will be normal. One exception is in the case of endolymphatic hydrops or Ménière's disease, in which the cochlear disorder causes such distortion that word-recognition scores are poorer than predicted from degree of hearing loss.

If a hearing loss is sensorineural due to an VIIIth nerve lesion, the SRT will be elevated in that ear to a degree predictable by the pure-tone average. Suprathreshold word-recognition ability is likely to be substantially affected. Maximum scores are likely to be poorer than predicted from the degree of hearing loss, and rollover of the performance-intensity function is likely to occur. Speech-in-competition measures are also likely to be depressed. Abnormal results will occur in the same, or ipsilateral, ear in which the lesion occurs. Dichotic measures will be normal.

If a hearing disorder occurs as a result of a brainstem lesion, the SRT will be predictable from the pure-tone average. Suprathreshold word-recognition ability is likely to be affected substantially. Word-recognition scores in quiet may be normal, or they may be depressed or show rollover. Speech-in-competition measures are likely to be depressed in the ear ipsilateral to the lesion. Dichotic measures will likely be normal.

If a hearing disorder occurs as the result of a temporal lobe lesion, hearing sensitivity is unlikely to be affected, and the SRT and word recognition scores are likely to be normal. Speech-in-competition measures may or may not be abnormal in the ear contralateral to the lesion. Dichotic measures are the most likely of all to show a deficit due to the temporal lobe lesion.

Predicting Speech Recognition

As you learned earlier, word-recognition ability is predictable from the audiogram in most patients. This has been known for many years. Essentially, speech recognition can be predicted based on the amount of speech signal that is audible to a patient. The original calculations for making this prediction resulted in what was referred to as an **articulation index**, a number between 0 and 1.0 that described the proportion of the average speech signal that would be audible to a patient based on his or her audiogram (French & Steinberg, 1947).

Articulation index is also known as audibility index and speech intelligibility index.

Over the years, the concept and clinical techniques have evolved into the measurement that is now referred to as the audibility index, reflecting its intended purpose of expressing the amount of speech signal that is audible to a patient. From the *audibility index* (AI), an estimate can be made of recognition scores for syllables, words, and sentences.

The audibility index is a measure of the proportion of speech cues that are audible. The AI is usually expressed as the proportion, between 0 and 1.0, of the average speech signal that is audible to a given listener. Calculations for determination of the AI are based on dividing the speech signal into frequency bands, with various weightings attributed to each band based on their likely contribution to the ability to hear speech. For example, consonant sounds are predominantly higher frequency sounds, and because their audibility is so important to understanding speech, the higher frequencies are weighted more heavily in the AI calculation.

The concept of audibility of average speech has not had much impact clinically, where word-recognition testing has prevailed as a means of estimating the ability to recognize speech. Among problems with clinical use of the AI is that it is not well understood, and it has been rather cumbersome to calculate.

Some simplified ways to calculate audibility have made the AI much more accessible clinically (Pavlovic, 1988; Mueller & Killion, 1990). One method is known clinically as the *count-the-dots* procedure. An illustration of a count-the-dots audiogram

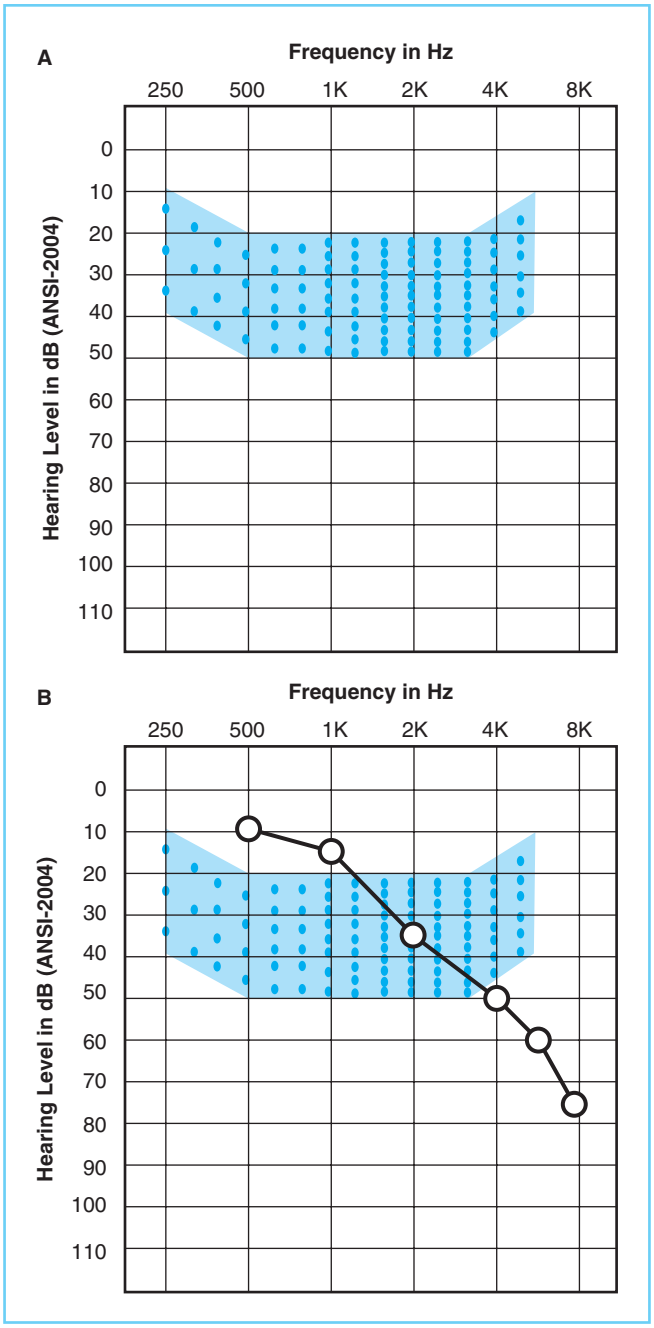


FIGURE 7-3 Illustration of a count-the-dots audiogram form (A) with results of a patient's audiogram superimposed upon it (B).

form is shown in Figure 7-3A. Here the weighting of frequency components by intensity is shown as the number of dots in the range on the audiogram.

Calculating AI from this audiogram is simple. Figure 7-3B shows a patient's audiogram superimposed on the count-the-dots audiogram. Those components of average speech that are below (or at higher intensity levels than) the audiogram are audible to the patient, and those that are above are not. To calculate the AI, simply count the dots that are audible to the patient. In this case, the AI is 60 (or 0.6). This essentially means that 60% of average speech is audible to the patient.

The AI has at least three useful clinical applications. First, it can serve as an excellent counseling tool for explaining to a patient the impact of hearing loss on the ability to understand speech. Second, the AI has a known relationship to word-recognition ability. Thus word-recognition scores can be predicted from the AI or, if measured directly, can be compared to expected scores based on the AI. Third, the AI can be useful in hearing aid fitting in serving as a metric of how much average speech is made audible by a given hearing aid.

The strategy of using the AI to describe communication impairment is a useful one. In many ways, the idea of audibility of speech information is a more useful way of describing the impact of a hearing loss than the percentage correct score on single-syllable word-recognition measures.

OTHER BEHAVIORAL MEASURES

A number of other behavioral measures are used for various purposes in the audiologic evaluation. For example, you will learn in Chapter 10 about some behavioral techniques that are useful in identifying and quantifying hearing loss that is *functional,* or exaggerated. In addition, a number of behavioral measures have been used over the years diagnostically in an effort to contribute information about the site of an auditory disorder.

Traditional Site-of-Lesion Measures

One special class of behavioral measures is important to be aware of from an historic perspective. Prior to the discovery of the objective measures that you will learn about in Chapters 8 and 9 and prior to the development of modern imaging and radiographic techniques, a battery of psychophysical measures was used to differentiate cochlear from retrocochlear disorder. This has become known as the *classic test battery*, and it is based primarily on measures of auditory *adaptation and recruitment* (Jerger, 1987).

Recall from Chapter 3 that one of the consequences of cochlear hearing loss is *recruitment*, or abnormal loudness growth. That is, loudness grows more rapidly than normal at intensity levels just above threshold in an ear with cochlear site of disorder. Clinically this means that if recruitment is present, then the site of disorder is cochlear rather than retrocochlear. Two measures, loudness balancing and difference limen for intensity, were used to assess recruitment as part of the classic test battery.

One popular measure of recruitment was the *alternate binaural loudness balance* (ABLB) test. The ABLB was designed to be used in patients with unilateral hearing loss. To carry out the ABLB test, the same tone is presented alternately between ears. The intensity level in the impaired ear is fixed at a level above threshold of 20 dB SL. The patient's task is to adjust the level of the normal hearing ear until the sounds in the two ears are of equal loudness. The intensity level in the impaired ear is then increased by 10 or 20 dB and the loudness matching is repeated. The ABLB is interpreted by assessing the nature of loudness differences at high-intensity levels. If the perception of loudness is at the same intensity level (in HL or SPL) for both ears, then *complete recruitment* occurred in the impaired ear, because the loudness caught up to the normal ear at high levels. This finding is consistent with cochlear site of disorder. In cases of retrocochlear disorder, the opposite, or *decruitment*, might occur. Here the loudness in the impaired ear grows more slowly than in the normal ear.

The measurement of difference limen for intensity was another method used to take advantage of the recruitment phenomenon.

The clinical measure was known as the *Short Increment Sensitivity Index* (SISI). To carry out the SISI test, a constant tone is presented to the ear at 20 dB SL. Superimposed on that tone is a series of 20 increments of 1 dB. The patient's task is to count the number of increments that are perceived. A patient with cochlear hearing loss can perceive those increments, whereas a patient with retrocochlear site of disorder cannot. One successful modification of the SISI involves the presentation of the signal at a high level, 75 dB HL or 20 dB SL, whichever is higher. A positive SISI, in which 70 to 100% of the increments are identified, is consistent with cochlear hearing loss or normal hearing. A negative SISI, in which only 0 to 30% of the increments are identified, is consistent with retrocochlear site.

You may also recall from Chapter 3 that one of the consequences of retrocochlear hearing loss is abnormal *auditory adaptation*. The normal auditory system tends to adapt to ongoing sound, especially at near-threshold levels, so that, as adaptation occurs, an audible signal becomes inaudible. At higher intensity levels, ongoing sound tends to remain audible without adaptation. However, in an ear with retrocochlear disorder, the audibility may diminish rapidly due to excessive auditory adaptation even at higher intensity levels.

Two popular measures of adaptation from the classic test battery are the tone decay test (TDT) and diagnostic Békésy audiometry.

The *tone decay test* is essentially a measure of the intensity level at which the perception of a tone can be sustained for 60 seconds. In its original form, a tone is presented at 5 dB SL, and the patient is asked to respond for as long as it is audible. If the patient responds for 60 seconds, testing is stopped. If not, the intensity level is increased by 5 dB and the process repeated. Tone decay is quantified in dB as the final test level minus the threshold level. Tone decay is considered positive for retrocochlear disorder if it exceeds 30 dB.

One modification of the tone decay test that is still sometimes useful today is the *suprathreshold adaptation test* (STAT). The STAT is carried out by presenting a tone at 110 dB SPL and determining if patient can hear it for 60 seconds. If not, adaptation occurred,

consistent with retrocochlear disorder. The STAT test is useful as a screening measure for retrocochlear disorder in patients with hearing loss severe enough to preclude testing with objective audiometric measures.

Another way to measure auditory adaptation is with *diagnostic Békésy audiometry*. Békésy audiometry is an automated form of hearing sensitivity assessment in which the patient controls the attenuation of the signal. By pushing a button, the patient increases intensity of the signal until it is audible. The patient then releases the button until the signal is inaudible, presses it until it is audible again, releases it, presses it, and so on. These *tracking* responses are displayed on a computer screen or plotter, and threshold is calculated as the midpoint of the excursion between audible and inaudible. While the tracking occurs, the frequency of the signal is slowly swept from low to high, so that an audiogram is measured across the frequency range.

In diagnostic Békésy audiometry, both continuous (C) and interrupted (I) tones are presented. If adaptation occurs, it will affect the continuous tone but not the interrupted tone. Results fall into one of 5 classic types. Békésy Type I, in which the I and C tracings are overlapped, is consistent with cochlear site of disorder, as is Békésy Type II, in which the C tracing is only slightly worse than the I tracing. Békésy Type III, in which the C tracing drops off the graph due to adaptation to the continuous signal, is consistent with retrocochlear site of disorder. So is Békésy Type IV, in which the C tracing is more that 20 dB below the I tracing. In Békésy Type V, the I tracing is poorer than the C tracing, indicating that the patient is probably exaggerating a hearing loss.

All of these measures, ABLB, SISI, TDT, and Békésy audiometry, were useful in the diagnosis of retrocochlear site in the days when tumors or other disorders had to reach a substantial size before they could be diagnosed radiographically. As imaging and radiographic techniques improved, smaller lesions that had less functional impact on the auditory system could be visualized, and the sensitivity of the classic test battery diminished. Today, these measures are relegated mostly to history, although, as noted above, results can occasionally be useful in patients with severe hearing loss.

Masking Level Difference

One behavioral diagnostic measure that has stood the test of time is a measure of lower brainstem function known as the *masking level difference* (MLD). The MLD measures binaural release from masking due to interaural phase relationships (Licklider, 1948). The binaural auditory system is an exquisite detector of differences in timing of sound reaching the two ears. This helps in localizing low-frequency sounds, which reach the ears at different points in time. An illustration may help you to understand how sensitive the ears are to these timing, or phase, cues. Suppose that identical low-frequency tones are presented to both of your ears and those tones are adjusted so that the phase is identical. Enough noise is then added to both ears to mask the tones. If the phase of the tone delivered to one earphone is then reversed, the tone will becomes audible again. This is called *binaural release from masking*, and it occurs as a result of processing in the brainstem at the level of the superior olivary complex.

The MLD test is the clinical strategy designed to measure binaural release from masking. To carry out the MLD, a 500 Hz interrupted tone is split and presented in phase to both ears. Narrow band noise is also presented, at a fixed level of 60 dB HL. Using the Békésy tracking procedure, threshold for the in-phase tones is determined in the presence of the noise. Then the phase of one of the tones is reversed, and threshold is tracked again. The MLD is the difference in threshold between the in-phase and the out-of-phase conditions. For a 500 Hz tone, the MLD should be greater than 7 dB and is usually around 12 dB.

The binaural masking level difference is often abnormal in patients with multiple sclerosis or other disorders that affect the auditory brainstem processing of phase differences between ears (Olsen et al., 1976). The MLD is not affected by disorders at the level of the auditory cortex.

Pure-tone audiometry, speech audiometry, and these other procedures constitute the basic *behavioral* measures available to quantify hearing impairment and determine the type and site of auditory disorder. In the next chapters, you will learn about the objective measures that are used for the same purposes.

Summary

- Speech audiometric measures are used to measure threshold for speech, to cross-check pure-tone sensitivity, to quantify suprathreshold speech-recognition ability, to assist in differential diagnosis, to assess auditory processing ability, and to estimate communicative function.
- The goal of speech audiometry is to measure patients' ability to understand everyday communication.
- Different types of speech materials are useful for different types of speech audiometric measures. The materials used in speech audiometry vary from nonsense syllables to complete sentences.
- Speech audiometric measures fall into one of four outcome categories: speech-recognition thresholds, speech awareness thresholds, word-recognition scores, and sensitized speech measures.
- The first threshold measure obtained during an audiological evaluation is usually the spondee or speech-recognition threshold.
- A speech detection threshold, sometimes referred to as speech awareness threshold, is the lowest level at which a patient can just detect the presence of a speech signal.
- The most common way to describe suprathreshold hearing ability is with word-recognition measures. Sensitized speech audiometric measures are used to quantify deficits resulting from disorders in the central auditory pathways.
- Speech audiometric measures can be useful in predicting where the site of lesion might be for a given hearing loss.
- Other behavioral measures are also helpful in diagnostic audiology. Special tests of auditory adaptation and recruitment can contribute to the identification of cochlear and retrocochlear disorders. Binaural release from masking can be used to assess brainstem disorder.

Short Answer Questions

1. The purpose of _____ _____ is to quantify a patient's ability to understand everyday communication.
2. A speech _____ _____ or speech _____ _____ is the lowest level at which speech can be detected.

3. The speech-recognition threshold is the _____ level at which speech can be _____.
4. The _____ - _____ _____ is the average of the threshold levels for the 500, 1000, and 2000 Hz frequencies.
5. The _____ _____ _____ is the percentage of correct repetitions of single-syllable words at a fixed intensity level above threshold. It provides an estimate of _____ ability to recognize speech.
6. If the word-recognition score is _____ than expected, this may be consistent with retrocochlear disorder or cochlear distortion.
7. Speech audiometry is most often used as a measure of _____ function. Speech _____ measures demonstrate what intensity level is needed for speech to be audible. Word- _____ scores demonstrate how well speech can be recognized, once made audible. Advanced speech audiometric measures demonstrate how the auditory nervous system _____ auditory information at suprathreshold levels.
8. Single-syllable words, also called _____, are generally used to measure speech _____. Word lists containing these materials are _____ _____ (PB) word lists. This means that the lists contain speech sounds that occur with the same frequency of occurrence as those speech sounds in _____ speech.
9. Speech thresholds are generally determined using two-syllable words. When these words have equal stress on both syllables, they are known as _____.
10. Sentence speech audiometry materials may have either or both high _____ or _____ predictability of target words.
11. Sentence speech audiometry materials may be presented in quiet, or against a _____ message such as multitalker babble. The level of the signal compared to the level of the competition is known at the _____ -to- _____ ratio.
12. Sentence materials may also be _____ sentences, which do not have meaning. These types of materials,

such as the Synthetic Sentence _____ test, provide measures of speech recognition without the listener's use of linguistic _____.

13. Methods of reducing _____ redundancy, such as frequency filtering, time _____, high-level testing, speech-in-noise testing, and dichotic measures are used to assess central auditory nervous system disorders.
14. A different, but similar, signal presented to both ears simultaneously is known as a _____ listening condition.
15. Response sets for speech audiometry materials may be _____ set, where the response set is all available targets in a language, or _____ set, where the response set is limited to choices provided.
16. Speech _____ threshold measures may be used in cases where there is a lack of language competency. These thresholds are typically 5-10 dB better than speech-_____ thresholds.
17. The use of a _____ phrase, such as "Say the word...," is shown to improve word-recognition scores.
18. The use of _____ materials is preferred over monitored live-voice presentation of speech audiometry materials. Because speech audiometry materials are often compared over time, recorded materials provide _____, which is not available with monitored live-voice testing.
19. The _____/_____ (PI) function is a plot of word-recognition scores as a function of presentation intensity level. The shape of the PI function may have diagnostic significance.
20. When speech recognition decreases from maximum score at higher intensity, _____ _____ is said to occur. This phenomenon may occur in cases of retrocochlear disorder.
21. The _____ _____ is a number between 0 & 1 that describes the proportion of average speech signals that would be audible to a patient based on the audiogram.
22. With a "_____- _____-_____" audiogram, the weighting of frequency components of speech by intensity is determined by the number of dots in the audible range on an audiogram. This type of measure can serve as a

_____ tool to explain impact of hearing loss on speech understanding.

23. An abnormal growth of loudness due to cochlear hearing loss is known as _____.
24. The presence of recruitment indicates a _____ disorder.
25. When the perception of sound is diminished over time at near-threshold levels, _____ _____ is said to occur.

Discussion Questions

1. Compare and contrast the various types of speech audiometry measures used clinically.
2. What is the benefit of using speech-recognition threshold measures as a cross-check for pure-tone threshold measures?
3. Explain why the use of recorded materials is preferred over monitored live voice for presentation of speech audiometry materials.
4. Explain why sensitized speech measures are used to assess auditory processing abilities.
5. How do the qualities of speech audiometry materials used for testing impact outcome of scores?

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8

THE AUDIOLOGIST'S ASSESSMENT TOOLS: IMMITTANCE MEASURES

Learning Objectives

Immittance Audiometry

Instrumentation

Measurement Technique

Basic Immittance Measures
- Tympanometry
- Static Immittance
- Acoustic Reflexes

Principles of Interpretation

Clinical Applications
- Middle-Ear Disorder
- Cochlear Disorder
- Retrocochlear Disorder

Summary

Short Answer Questions

Discussion Questions

Resources

LEARNING OBJECTIVES

After reading this Chapter, you should be able to:

- Define the terms admittance, impedance, and immittance, and explain how these physical concepts relate to the middle-ear system.
- Know the purpose of immittance measures.
- Describe how immittance measures are made.
- List and describe the immittance measures that are used clinically.
- Understand how immittance results are used together and interpreted.
- Explain how immittance measures can be useful in differentiating middle ear, cochlear, and retrocochlear disorders.

IMMITTANCE AUDIOMETRY

IMMITTANCE audiometry is one of the most powerful tools available for the evaluation of auditory disorder. It serves at least three functions in audiologic assessment:

1. it is sensitive in detecting middle-ear disorder,
2. it can be useful in differentiating cochlear from retrocochlear disorder, and
3. it can be helpful as a cross-check to pure-tone audiometry.

As a result of its comprehensive value, immittance audiometry is a routine component of the audiologic evaluation and is often the first assessment administered in the test battery. When immittance audiometry was first introduced into clinical practice during the 1970s, the tendency was to use it to assess middle-ear function only if the possibility of middle-ear disorder was indicated by the presence of an air-bone gap on the audiogram. That is, the audiologist would assess pure-tone audiometry by air conduction and bone conduction. If an air-bone gap did not exist, the loss was thought to be purely sensorineural. The assumption was made that middle-ear function was normal. In contrast, if an air-bone gap existed, indicating a conductive component to the hearing loss, the assumption was made that middle-ear disorder was present and should be investigated by immittance audiometry. As the utility of immittance measures became clear, however, this practice changed. The realization was made that the presence of middle-ear disorder and the existence of a conductive

component to the hearing loss, although related, are independent phenomena. That is, middle-ear disorder can be present without a measurable conductive hearing loss or, the opposite, a minor abnormality in middle-ear function can result in a significant conductive component.

As a result of the relative independence of the measurement of middle-ear function and that of air- and bone-conducted hearing thresholds, immittance audiometry became a routine component of the audiologic assessment. In fact, many audiologists choose to begin the evaluation process with immittance measures, before pure-tone or speech audiometry. The overall strategy is a simple one: the goal of audiologic testing is to rehabilitate; the first question is whether the problem is related to middle-ear disorder that is medically treatable; the best measure of middle-ear disorder is immittance audiometry; therefore, the first question is best addressed by immittance audiometry. If middle-ear disorder is identified, the next question is whether it is causing a conductive hearing loss, which is determined by air- and bone-conduction testing. If middle-ear function is normal, the next question is whether a sensorineural hearing loss exists, which is determined by air-conduction testing. Some audiologists even take the approach that if immittance measures are normal, there is no need to test by bone conduction.

One other benefit of starting with immittance audiometry is that results can provide a useful indication of what to expect from pure-tone audiometry. This can be particularly valuable when evaluating pediatric patients or other patients who might be difficult to test behaviorally.

INSTRUMENTATION

An immittance meter is used for these measurements. A simplified schematic drawing of the components is shown in Figure 8-1, and a photograph of an immittance meter is shown in Figure 8-2.

One major component of an immittance meter is an oscillator that generates a probe tone. The probe-tone frequency used

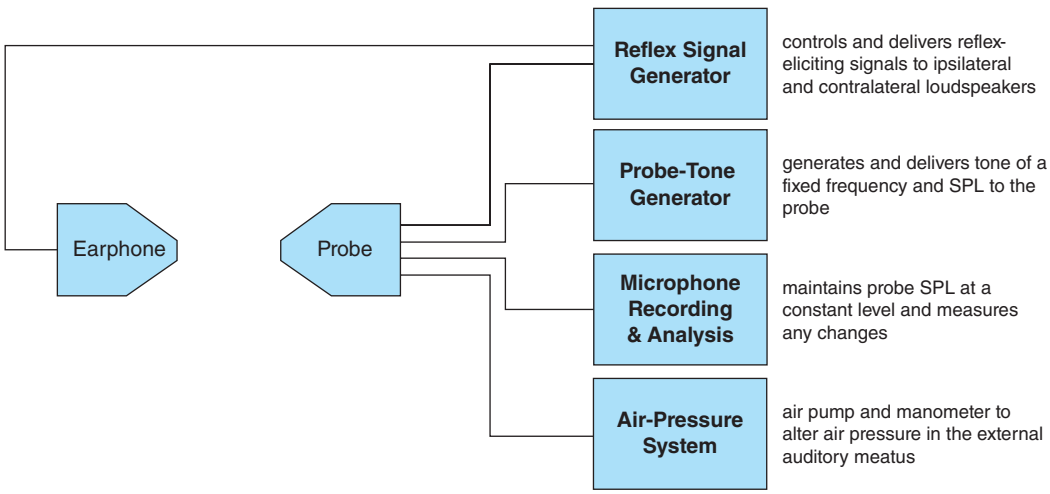


FIGURE 8-1 Schematic representation of the instrumentation used in immittance measurement.



FIGURE 8-2 Photograph of an immittance meter. (Courtesy of Cardinal Health©.)

most commonly is 226 Hz, or for newborns or very young infants, 1000 Hz.

The probe tone is delivered to a transducer that converts the electronic signal into the acoustic signal, which in turn is delivered to a probe that is sealed in the ear canal. The probe also contains a microphone that monitors the level of the probe tone. The immittance instrument is designed to maintain the level of the probe tone in the ear canal at a constant SPL and to record any changes in that SPL on a meter or other recording device.

Another major component of the immittance meter is an air pump that controls the air pressure in the ear canal. Tubing from the probe is attached to the air pump. A manometer measures the air pressure that is being delivered to the ear canal.

An immittance meter also contains a signal generator and transducers for delivering high-intensity signals to the ear for eliciting acoustic reflexes, which you will learn about later in this chapter. The signal generator produces pure tones and broad-band noise. The transducer that is used is either an earphone on the ear opposite to the probe ear or a speaker within the probe itself.

MEASUREMENT TECHNIQUE

Immittance is a physical characteristic of all mechanical vibratory systems. In very general terms, it is a measure of how readily a system can be set into vibration by a driving force. The ease with which energy will flow through the vibrating system is called its **admittance**. The reciprocal concept, the extent to which the system resists the flow of energy through it, is called its **impedance**. If a vibrating system can be forced into motion with little applied force, we say that the admittance is high and the impedance is low. On the other hand, if the system resists being set into motion until the driving force is relatively high, then we say that the admittance of the system is low and the impedance is high. *Immittance* is a term that is meant to encompass both of these concepts.

Admittance is the total energy flow through a system.

Impedance is the total opposition to energy flow or resistance to the absorption of energy.

Immittance audiometry can be thought of as a way of assessing the manner in which energy flows through the outer and middle ears

to the cochlea. The middle-ear mechanism serves to transform energy from acoustic to hydraulic form. Air-pressure waves from the acoustic signal set the tympanic membrane into vibration, which in turn sets the ossicles into motion. The footplate of the stapes vibrates and sets the fluids of the cochlea into motion.

Immittance measurement serves as an indirect way of assessing the appropriateness of energy flow through this system. If the middle-ear system is normal, energy will flow in a predictable way. If it is not, then energy will flow either too well (high admittance) or not well enough (high impedance).

Immittance is measured by delivering a pure-tone signal of a constant sound pressure level into the ear canal through a mechanical probe that is seated at the entrance of the ear canal. The signal, which is referred to by convention as the probe tone, is a 226 Hz pure tone that is delivered at 85 dB SPL. The SPL of the probe tone is monitored by an immittance meter, and any change is noted as a change in energy flow through the middle-ear system.

BASIC IMMITTANCE MEASURES

Three immittance measures are commonly used in the clinical assessment of middle-ear function:

1. tympanometry,
2. static immittance, and
3. acoustic reflex thresholds.

Tympanometry

Tympanometry is a way of measuring how acoustic immittance of the middle-ear vibratory system changes as air pressure is varied in the external ear canal. Transmission of sound through the middle-ear mechanism is maximal when air pressure is equal on both sides of the tympanic membrane. For a normal ear, maximum transmission occurs at, or near, atmospheric pressure. That is, when the air pressure in the external ear canal is the same as the air pressure in the middle-ear cavity, the immittance of the normal middle-ear vibratory system is at its optimal peak, and energy flow through the system is maximal. Middle-ear pressure is assessed by varying pressure

in the sealed ear canal until the SPL of the probe tone is at its minimum, reflecting maximum transmission of sound through the middle-ear mechanism. But, if the air pressure in the external ear canal is either more than (positive pressure) or less than (negative pressure) the air pressure in the middle-ear space, the immittance of the system changes, and energy flow is diminished. In a normal system, as soon as the air pressure changes even slightly below or above the air pressure that produces maximum immittance, the energy flow drops quickly and steeply to a minimum value. As the pressure is varied above or below the point of maximum transmission, the SPL of the probe tone in the ear canal increases, reflecting a reduction in sound transmission through the middle ear (Figure 8-3).

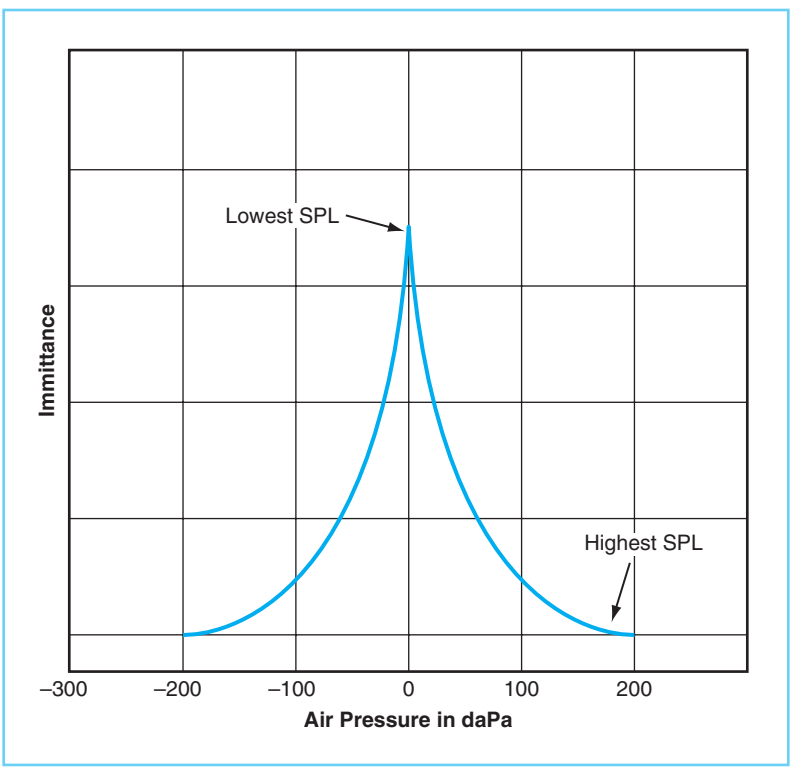


FIGURE 8-3 A tympanogram, showing that as the pressure is varied above or below the point of maximum transmission, the soundpressure level (SPL) of the probe tone in the ear canal increases, reflecting a reduction in sound transmission through the middle-ear mechanism.

decaPascals or **daPa** = unit of pressure in which 1 daPa equals 10 Pascals.

millimho or **mmho** = one-thousandth of a mho, which is a unit of electrical conductance, expressed as the reciprocal of ohm.

The clinical value of tympanometry is that middle-ear disorder modifies the shape of the tympanogram in predictable ways. Various patterns of tympanometric shapes are related to various auditory disorders. The conventional classification system designates three tympanogram types, Types, A, B, and C (Jerger, 1970).

Figure 8-4 is an example of the results of tympanometry from a person with normal middle-ear function. Air pressure is expressed as negative or positive relative to atmospheric pressure. The unit of measure of air pressure is the **decaPascal**, or **daPa**. The unit of measure of immittance is the **millimho**, or **mmho**.

This plot of immittance against air pressure is referred to as a tympanogram. In the case of the normal system, the tympanogram has a characteristic shape. There is a sharp peak in immittance

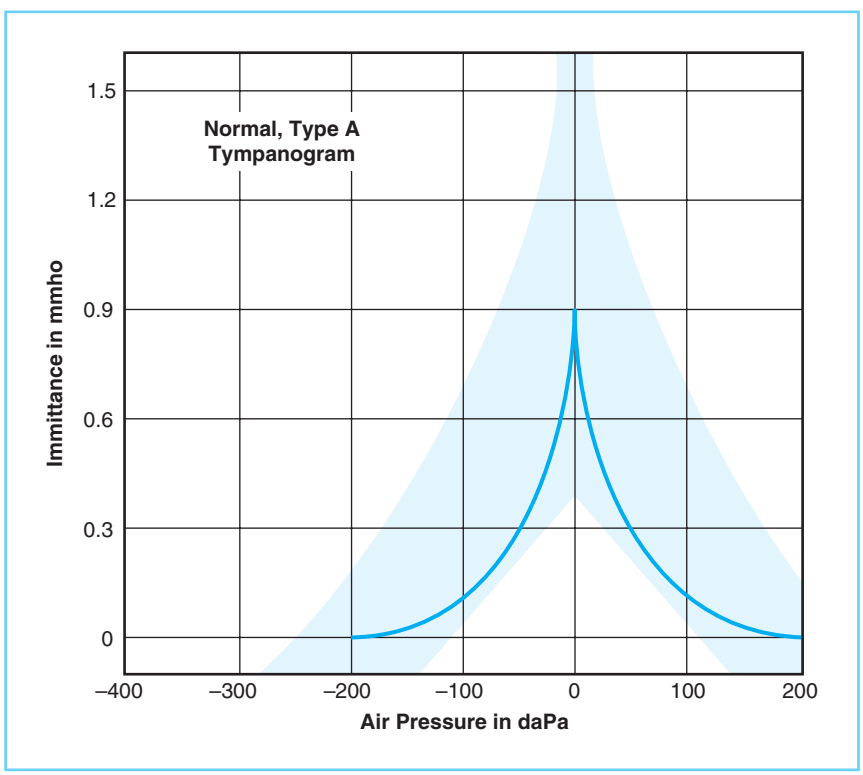


FIGURE 8-4 A Type A tympanogram, representing normal middle-ear function.

in the vicinity of 0 daPa of air pressure and a rapid decline in immittance as air pressure moves away from 0, either in the negative or positive direction. This characteristically normal shape is designated **Type A**.

Type A = normal.

If the middle-ear space is filled with fluid, as is an ear with otitis media with effusion, the tympanogram will lose its sharp peak and become relatively flat or rounded. This is due to the mass added to the ossicular chain by the fluid. This tympanogram's shape is designated **Type B** and is depicted in Figure 8-5. In this case, the SPL in the ear canal remains fairly constant, regardless of the change in air pressure. Because of the increase in mass behind the tympanic membrane, varying the air pressure in the ear canal has little effect on the amount of energy that flows through the middle ear, and the SPL of the probe tone in the ear canal does not change.

Type B = flat.

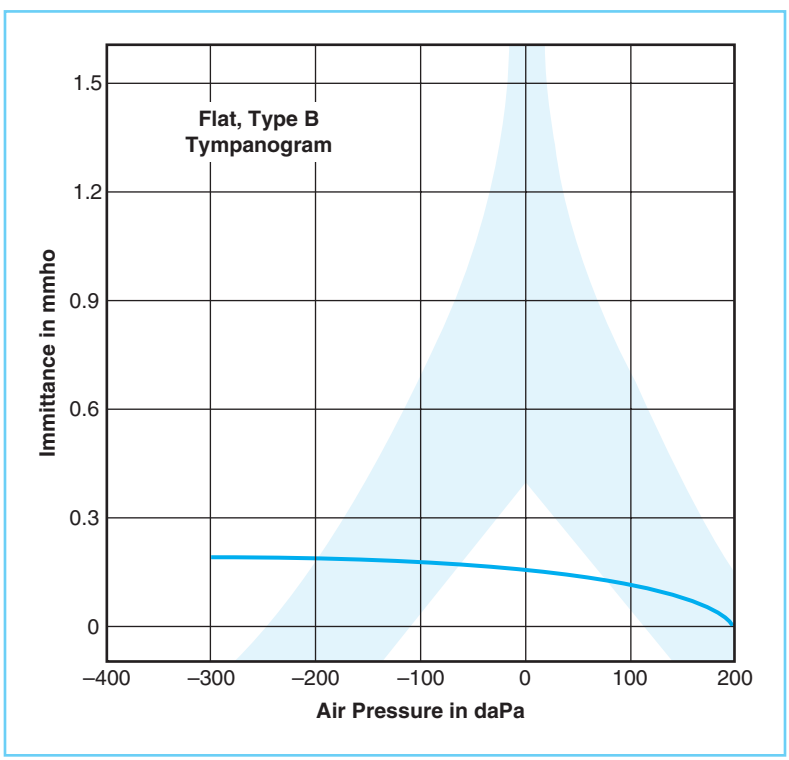


FIGURE 8-5 A Type B tympanogram, representing middle-ear disorder characterized by an increased mass in the middle-ear system.

A common cause of middle-ear disorder is faulty Eustachian tube function. The Eustachian tube connects the middle-ear space to the nasopharynx and is ordinarily closed. The tube opens briefly during swallowing, and fresh air is allowed to reach the middle ear. Sometimes the tube does not open during swallowing. This often occurs as a result of swelling in the nasopharynx that blocks the orifice. When the Eustachian tube does not open, the air that is trapped in the middle ear is absorbed by the mucosal lining. This results in a reduction of air pressure in the middle-ear space relative to the pressure in the external ear canal. This pressure differential will retract the tympanic membrane inward. The effect on the tympanogram is to move the sharp peak away from 0 daPa and into the negative air pressure region. The reason for this is simple. Remember that energy flows maximally through the system when the air pressure in the ear canal is equal to the air pressure in the middle-ear cavity. In normal ears this occurs at atmospheric pressure. But, if the pressure in the middle-ear space is less than atmospheric pressure, because of the absorption of trapped air, then the maximum energy flow will occur when the pressure in the ear canal is negative and matches that in the middle-ear space. When this balance has been achieved, energy flow through the middle-ear system will be at its maximum and the tympanogram will be at its peak. This tympanogram, normal in shape, but with a peak at substantial negative air pressure, is designated **Type C**.

Type C = negative pressure.

Anything that causes the ossicular chain to become stiffer than normal can result in a reduction in energy flow through the middle ear. The added stiffness simply attenuates the peak of the tympanogram. The shape will remain normal Type "A," but the entire tympanogram will become shallower. Such a tympanogram is designated **Type A_s** to indicate that the shape is normal, with the peak at or near 0 daPa of air pressure, but with significant reduction in the height at the peak. The subscript "s" denotes *stiffness* or *shallowness*. The disorder most commonly associated with a Type A_s tympanogram is otosclerosis, a disease of the bone surrounding the footplate of the stapes.

Type A_s = normal shape, but height is significantly decreased or shallow.

Anything that causes the ossicular chain to lose stiffness can result in too much energy flow through the middle ear. For example, if there is a break or discontinuity in the ossicles connecting the

tympanic membrane to the cochlea, the tympanogram will retain its normal shape, but the peak will be much greater than normal. With the heavy load of the cochlear fluid system removed from the chain, the tympanic membrane is much more free to respond to forced vibration. The energy flow through the middle ear is greatly enhanced, resulting in a very deep tympanogram. This shape is designated $\mathbf{A_d}$ to indicate that the shape of the tympanogram is normal, with the peak at or near 0 daPa of air pressure, but the height is significantly increased. The subscript "d" denotes *deep* or *discontinuity*.

Type A_d = normal shape, but height is significantly increased or deep.

The four abnormal tympanogram types are shown in Figure 8-6. Their diagnostic value lies in the information that they convey about middle-ear function, which provides valuable clues about changes in the physical status of the middle ear. The usefulness of tympanometry is enhanced when it is viewed in combination with two other components of the total battery, static immittance and the acoustic reflex.

Classifying tympanograms based on descriptive types is a simple, effective approach to describing tympanometric outcomes. There are, however, other ways to analyze the tympanogram with more refinement. For example, a tympanogram can be described by its peak pressure (tympanometric peak pressure or TPP), which is simply the number in daPa that corresponds to the peak of the tympanogram trace. Another way is to try to describe the actual shape of the tympanometric curve, which is done either by quantifying its gradient, which is the relationship of its height and width, or by measuring the tympanometric width. Tympanometric width is measured by calculating the daPa at the point corresponding to 50% of the static immittance value, as shown in Figure 8-7. This is a very effective way to describe a rounded tympanogram, and excessive widths are often found in ears with middle-ear effusion (Koebsell & Margolis, 1986).

One other important consideration in tympanometry is probe-tone frequency, especially in the testing of infants. The use of multifrequency, multicomponent tympanograms has been studied for a number of years (Vanhuyse et al., 1975; Margolis & Hunter, 1999). The addition of tympanograms obtained with high-frequency probe

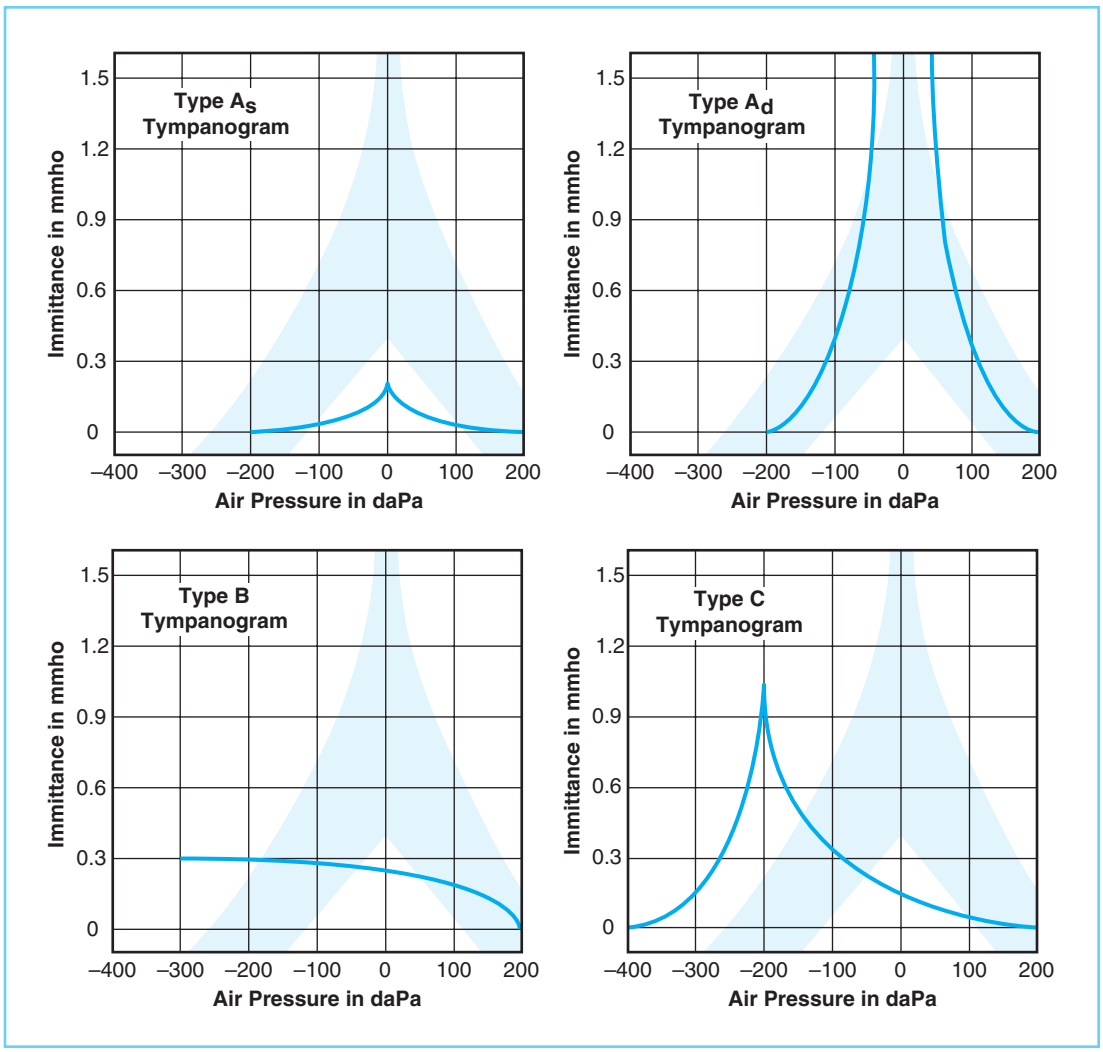


FIGURE 8-6 The four abnormal tympanogram types.

tones has been shown to enhance the sensitivity of tympanometry to certain middle-ear disorders. The value of high-frequency tympanograms has become increasingly clear in the measurement of middle-ear function in infants. Indeed, it is now common clinical practice to use a 1000 Hz probe tone when testing newborns and young infants (Baldwin, 2006). The reason is probably best demonstrated by the results shown in Figure 8-8. Tympanograms from a 5-week-old infant, measured with both 226 Hz and 1000 Hz probe tones, are

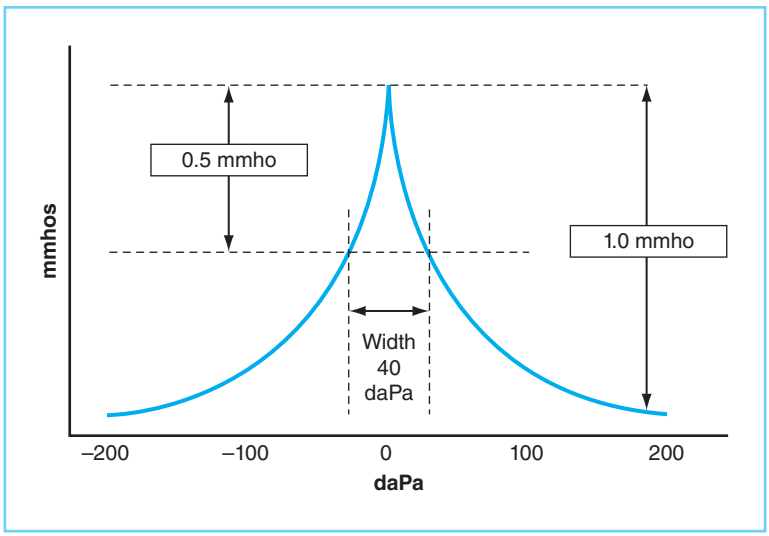


FIGURE 8-7 Illustration of the measurement of tympanogram width. Width is calculated by determining the daPa corresponding to 50% of the peak status immittance.

shown. One ear of the child has middle-ear effusion, while the other is clear, as judged by otoscopy. Results show fairly normal, peaked tympanograms in both ears with the 226 Hz probe but a clearly different picture with the 1000 Hz probe. The use of higher frequency probe tones has become routine in modern audiology practice.

Static Immittance

Static immittance is the measure of the contribution of the middle ear to acoustic impedance.

In contrast to the dynamic measure of middle-ear function represented by the tympanogram, the term **static immittance** refers to the isolated contribution of the middle ear to the overall acoustic immittance of the auditory system. It can be thought of as simply the absolute height of the tympanogram at its peak. The static immittance is measured by comparing the probe-tone SPL or immittance when the air pressure is at 0 daPa, or at the air pressure corresponding to the peak, with the immittance when the air pressure is raised to positive 200 daPa. It is convenient to express these immittance measures as equivalent volumes of air in cubic centimeters (cc). The idea is a simple one. When a signal of equivalent intensity is placed into different sized cavities, the SPL of the signal varies. The SPL of the signal in a small cavity is

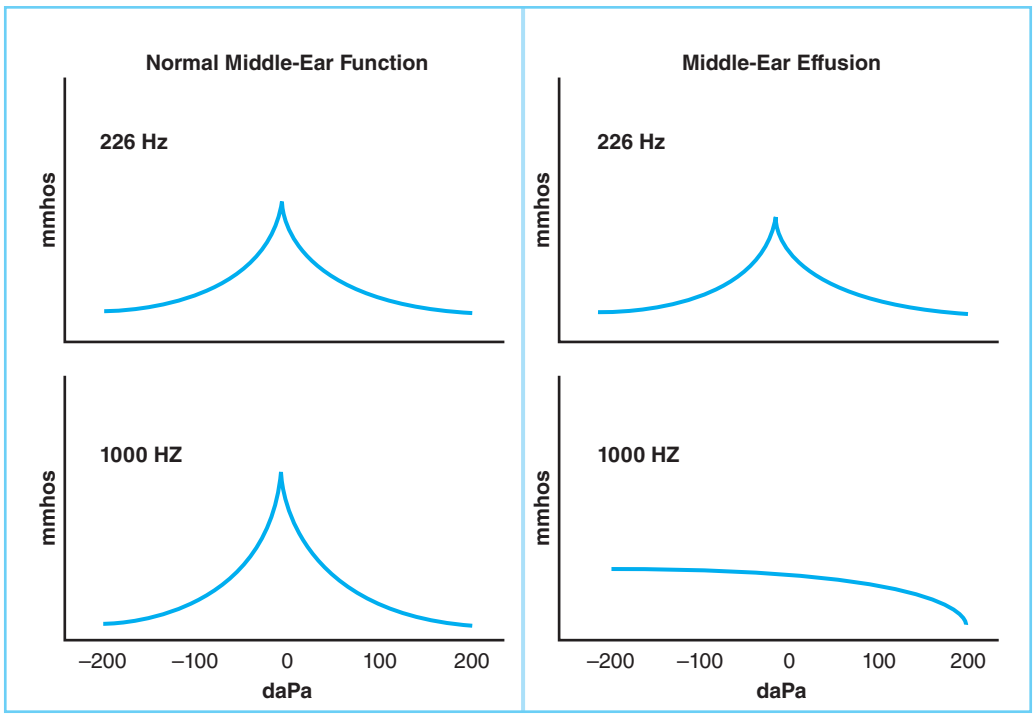


FIGURE 8-8 226 Hz and 1000 Hz probe-tone tympanograms of a 5-week-old infant in whom one ear has normal middle-ear function and the other has middle-ear effusion.

relatively higher and in a large cavity is relatively lower. Therefore, if the probe-tone SPL increases when the air pressure is raised to +200 daPa as less energy flows through the middle ear, it is as if the cavity is smaller. Conversely, if the SPL decreases at 0 daPa as more energy flows through the middle ear, it is as if the cavity is larger. Thus these changes in SPL can be converted to the notion of volume changes and expressed in units of *equivalent volume*. It is important to remember that little actual volume change occurs. Only the SPL of the probe-tone changes due to energy flowing through the middle ear, *as if* the volume changed. When the air pressure is at +200 daPa, this measure is equivalent to the volume of air in the external ear canal. The contribution from the middle-ear system is negligible. Volume of air in the external ear canal varies from 0.5 cc to 1.5 cc in children and adults. When the air pressure is at 0 daPa, however, the measured volume is larger because it includes the equivalent volume of the middle-ear system. Remember that, as the air pressure is adjusted from +200

to 0, the energy flow through the normal middle-ear system is enhanced, resulting in a decrease in probe-tone SPL, as if the volume of the system had increased. The static immittance, then, is the difference between the volume measurement at the two different air pressures. In adults with normal middle-ear function, the difference ranges from 0.3 to 1.6 cc.

There are two diagnostic applications of the static immittance. First, values lying below 0.3 cc or above 1.6 cc are strong evidence of middle-ear disorder. This information is useful in deciding whether a Type A tympanogram is normal, shallow, or deep. For example, if the tympanogram is Type A and the static immittance is 0.2, then the tympanogram can be considered shallow and indicative of increased stiffness of the middle-ear mechanism. Unfortunately, the range of normal static immittance is so large that many of the milder forms of middle-ear disorder will fall within the normal boundaries. Thus, the test lacks transitivity in that only one outcome is meaningful. That is, if the static immittance falls outside the normal range, it is safe to predict middle-ear disorder. But, values within the normal range do not necessarily exclude the possibility of middle-ear disorder.

The second, and perhaps more useful clinical application of the static immittance measure lies in its ability to detect small perforations of the tympanic membrane. Recall that the first volume measurement taken, with the air pressure in the external canal at +200 daPa, is indicating the equivalent volume of air in the external ear canal. If there is any hole in the tympanic membrane through which air can travel, then the measurement will be of both the ear canal and the much larger volume of air in the middle-ear space. Therefore, if the initial volume measurement in the static immittance procedure is considerably larger than 1.5 cc, such as 4.5 or 5.0 cc, it means that there is a perforation in the tympanic membrane through which air can pass. This method for detecting perforations can be more sensitive to small perforations than visual inspection of the tympanic membrane.

Acoustic Reflexes

When a sound is of sufficient intensity, it will elicit a reflex of the middle-ear musculature. In humans, the reflex consists primarily of

The two muscles of the middle ear are the **stapedius** and the **tensor tympani**.

the **stapedius muscle**. In other animals, the **tensor tympani muscle** contributes to a greater degree to the overall reflex.

The stapedius muscle is attached by a tendon from the posterior wall of the middle ear to the head of the stapes. When the muscle contracts, the tendon exerts tension on the stapes, stiffens the ossicular chain, and reduces low-frequency energy transmission through the middle ear. The result of this reduced energy transmission is an increase in probe-tone SPL in the external ear canal. Therefore, when the stapedius muscle contracts in response to high-intensity sounds, a slight change in immittance can be detected by the circuitry of the immittance instrument.

Ipsilateral = uncrossed;
Contralateral = crossed

Both the right and left middle-ear muscles contract in response to sound delivered to either ear. Therefore, **ipsilateral** (uncrossed) and **contralateral** (crossed) reflexes are recorded with sound presented to each ear. For example, when a signal of sufficient magnitude is presented to the right ear, a stapedius reflex will occur in both the right (ipsilateral or uncrossed) and the left (contralateral or crossed) ears. These are called the *right uncrossed* and the *right crossed* reflexes, respectively. When a signal is presented to the left ear and a reflex is measured in that ear, it is referred to as a *left uncrossed* reflex. When a signal is presented to the left ear and a reflex is measured in the right ear, it is referred to as a *left crossed* reflex.

Threshold Measures

The threshold is the most common measure of the acoustic stapedial reflex and is defined as the lowest intensity level at which a middle-ear immittance change can be detected in response to sound. In people having normal hearing and normal middle-ear function, reflex thresholds for pure tones will be reached at levels ranging from 70 to 100 dB HL. The average threshold level is approximately 85 dB (Wiley et al., 1987). These levels are consistent across the frequency range from 500 to 4000 Hz. Threshold measures are useful for at least two purposes: (1) differential assessment of auditory disorder and (2) detection of hearing sensitivity loss.

Reflex threshold measurement has been valuable in both the assessment of middle-ear function and the differentiation of cochlear

from retrocochlear disorder. In terms of the latter, whereas reflex thresholds occur at reduced sensation levels in ears with cochlear hearing loss, they are typically elevated or absent in ears with VIIIth nerve disorder (Anderson et al., 1970). Similarly, reflex thresholds are often abnormal in patients with brainstem disorder. Comparison of crossed and uncrossed thresholds has also been found to be helpful in differentiating VIIIth nerve from brainstem disorders (Jerger & Jerger, 1977).

Although threshold measures are valuable, interpretation of the absence or abnormal elevation of an acoustic reflex threshold can be difficult because the same reflex abnormality can result from a number of pathologic conditions. For example, the absence of a right crossed acoustic reflex can result from:

- a substantial conductive loss on the right ear that keeps sound from being sufficient to cause a reflex,
- a severe sensorineural hearing loss on the right ear that keeps sound from being sufficient to cause a reflex,
- right VIIIth nerve tumor that keeps sound from being sufficient to cause a reflex,
- a lesion of the crossing fibers of the central portion of the reflex arc,
- left facial nerve disorder that restricts neural impulses from reaching the stapedius muscle, or
- left middle-ear disorder that keeps the stapedius contraction from having an influence on middle-ear function.

A schematic example of these six possibilities is shown in Figure 8-9. It is for this reason that the addition of uncrossed reflex measurement, tympanometry, and static immittance is important in reflex threshold interpretation.

Acoustic reflex thresholds have also been used for the detection of cochlear hearing loss (Niemeyer & Sesterhenn, 1974). Cochlear bandwidth effects on the acoustic reflex have been exploited to predict the presence of hearing loss and have been applied successfully in the clinic. Although not altogether precise, use of acoustic reflexes for the general categorization of normal versus abnormal cochlear sensitivity is clinically useful as a powerful cross-check to behavioral audiometry, especially in children.

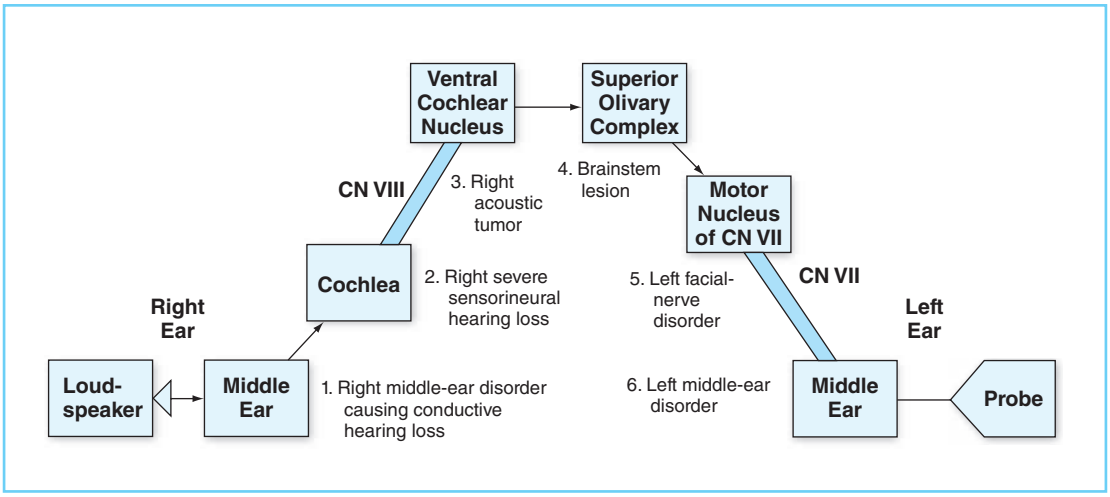


FIGURE 8-9 Schematic representation of the auditory and nervous system structures involved in a crossed acoustic reflex, with six possible causes for the absence of a right crossed acoustic reflex.

Decay is the diminution of the physical properties of a stimulus or response.

Latency is the time interval between two events, as a stimulus and a response.

Amplitude is the magnitude of a sound wave, acoustic reflex, or evoked potential.

Suprathreshold Measures

Suprathreshold analysis of the acoustic reflex includes such measures as **decay**, **latency**, and **amplitude**. Acoustic reflex decay is often a component of routine immittance measurement used to differentiate cochlear from VIIIth nerve disorder (Anderson et al., 1970). Although various measurement techniques and criteria for abnormality have been developed, reflex decay testing is typically carried out by presenting a 10-second signal at 10 dB above the reflex threshold. Results are considered abnormal if amplitude of the resultant reflex decreases to less than half of its initial maximum value, reflecting abnormal auditory adaptation (Figure 8-10). Reflex decay has been shown to be a sensitive measure of VIIIth nerve, brainstem, and neuromuscular disorders. One of the problems associated with reflex decay testing, however, is a high false-positive rate in patients with cochlear hearing loss (Jerger & Jerger, 1983). For example, positive reflex decay has been reported in as many as 27% of patients with cochlear loss due to Ménière's disease. This is considered a false-positive result in that it is positive for retrocochlear disorder when the actual disorder is cochlear in nature.

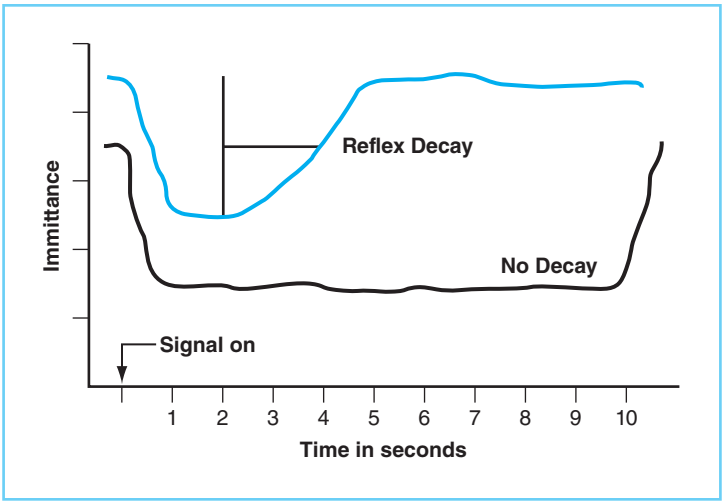


FIGURE 8-10 Examples of no acoustic reflex decay and abnormal acoustic reflex decay. Abnormal decay occurs when the amplitude of the reflex decreases to at least half of its initial maximum value.

Other suprathreshold measures include latency and amplitude. Various studies have suggested that these measures may provide additional sensitivity to the immittance battery, especially in the differentiation of retrocochlear disorder (for a review, see Stach & Jerger, 1984; Stach, 1987). Reflex latency and rise time have been used as diagnostic measures and have been shown to be abnormal in ears with VIIIth nerve disorder, multiple sclerosis, and other brainstem disorders. Similarly, depressed reflex amplitudes have been reported in patients with VIIIth nerve tumors, multiple sclerosis, and other brainstem disorders.

PRINCIPLES OF INTERPRETATION

The key to the successful interpretation of immittance data lies not in the examination of individual results, but in the examination of the pattern of results characterizing the entire audiometric assessment. Within this frame of reference the following observations are relevant.

1. **Certain tympanometric shapes are diagnostically useful.** The Type C tympanogram, for example, clearly indicates reduced air pressure in the middle-ear space. Similarly the Type B tympanogram suggests mass loading of the vibratory mechanism. The Type A tympanogram, however, may be ambiguous to interpret.
2. **Static immittance is also subject to ambiguous interpretation**. Certain pathologies of the middle-ear act to render the static immittance abnormally low, while others should have the opposite effect. But the distribution of static immittance in normal ears is so broad (95% interval from 0.3 to 1.6 cc) that only very extreme changes in immittance are sufficient to drive the static immittance outside the normal boundaries.
3. **The acoustic reflex is exceedingly sensitive to middle-ear disorder.** Only a 5 to 10 dB air-bone gap is usually sufficient to eliminate the reflex when the immittance probe is in the ear with conductive loss. As a corollary, the most common reason for an abnormality of the acoustic reflex is middle-ear disorder. Thus, the possibility of middle-ear disorder as an explanation for any reflex abnormality must always be considered.
4. **Crossed reflex threshold testing is usually carried out at frequencies of 500, 1000, 2000, and 4000 Hz**. However, even in normal ears, results are unstable at 4000 Hz. Apparent abnormality of the reflex threshold at this test frequency may not be diagnostically relevant. Uncrossed reflex threshold testing is usually carried out at frequencies of 1000 and 2000 Hz.
5. **Reflex-eliciting stimuli should not exceed 110 dB HL, for any signal, unless there is clear evidence of a substantial air-bone gap in the ear to which sound is being delivered**. Duration of presentation must be carefully controlled and kept short (i.e., less than 1 second). There is a danger that stimulation at these exceedingly high levels will be upsetting to the patient. Several case reports have documented temporary or permanent auditory changes in patients following reflex testing. It is for this reason that very judicious use be made of the reflex decay test, in which stimulation is continuous for 5 to 10 seconds.

CLINICAL APPLICATIONS

Middle-Ear Disorder

Principles of Clinical Application

Middle-ear function is assessed by measurement of static immittance, tympanometry, and acoustic reflexes. Each measure is evaluated in isolation against normative data and then in combination to determine the pattern. The typical immittance pattern associated with middle-ear disorder includes:

1. some abnormality of the normal tympanometric shape,
2. some abnormality of the static immittance, and
3. no observable acoustic reflex to either crossed or uncrossed stimulation when the probe is in the affected ear.

In addition, if the middle-ear disorder results in a substantial conductive hearing loss, no crossed reflex will be observed when the reflex-eliciting signal is presented to the affected ear. Patterns fall into one of six categories, which are described in Table 8-1. The six patterns include:

1. results consistent with normal middle-ear function,
2. results consistent with an increase in the mass of the middle-ear mechanism,
3. results consistent with an increase in the stiffness of the middle-ear mechanism,

TABLE 8-1 Patterns of immittance measurement result in various middle-ear disorders

Middle-Ear Condition	Tympanogram	Static Immittance	Acoustic Reflex
Normal	A	normal	normal
Increased mass	B	low	absent
Increased stiffness	A_s	low	absent
Excessive compliance	A_d	high	absent
Negative pressure	C	normal	abnormal
TM perforation	B	high	absent

4. results consistent with excessive compliance of the middle-ear system,
5. results consistent with significant negative pressure in the middle-ear space, and
6. results consistent with tympanic-membrane perforation.

Normal Middle-Ear Function

Figure 8-11 shows immittance results on a young adult. Both ears are characterized by Type A tympanograms, normal static immittance, and normal reflex thresholds.

Increased Mass

Figure 8-12 shows immittance results on a young girl. The right ear results are characterized by a Type B tympanogram, excessively low static immittance, and absent right uncrossed and left crossed acoustic reflexes. These results are consistent with increased mass of the right middle-ear mechanism. The left ear immittance results are normal. The tympanogram is a Type A, static immittance is within normal limits, and left uncrossed reflexes are present. The absence of right crossed reflexes in the presence of left uncrossed reflexes suggests that the right middle-ear disorder has produced a substantial conductive hearing loss on the right ear. The middle-ear disorder characterized here was caused by otitis media with effusion.

Increased Stiffness

Figure 8-13 shows immittance results on a middle-aged woman. Both the right and left ears are characterized by Type A tympanograms, relatively low static immittance, and absent acoustic reflexes. These results are consistent with an increase in stiffness of both middle-ear mechanisms. This middle-ear disorder was caused by otosclerosis.

Excessive Immittance

Figure 8-14 shows immittance results on a 24-year-old man who was evaluated following mild head trauma. The left ear results are characterized by a Type A tympanogram, excessively high static immittance, and absent acoustic reflexes, probe left (left uncrossed and right crossed). The right ear immittance results are normal.

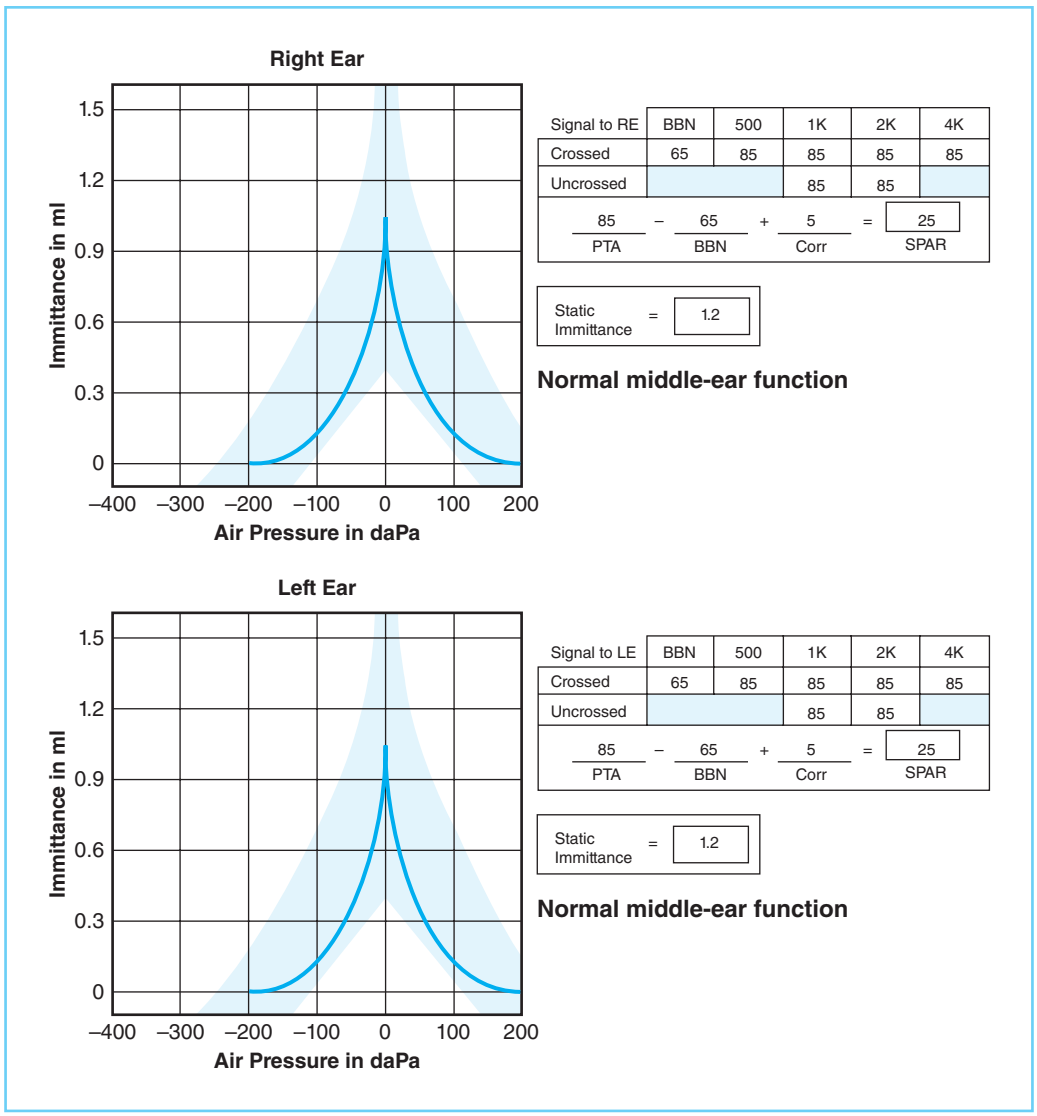


FIGURE 8-11 Immittance results consistent with normal middle-ear function.

The tympanogram is a Type A, static immittance is within normal limits, and right uncrossed reflexes are present. The absence of left crossed reflexes in the presence of right uncrossed reflexes suggests that the left middle-ear disorder is causing a substantial conductive hearing loss on the left ear. This middle-ear disorder was caused by ossicular discontinuity.

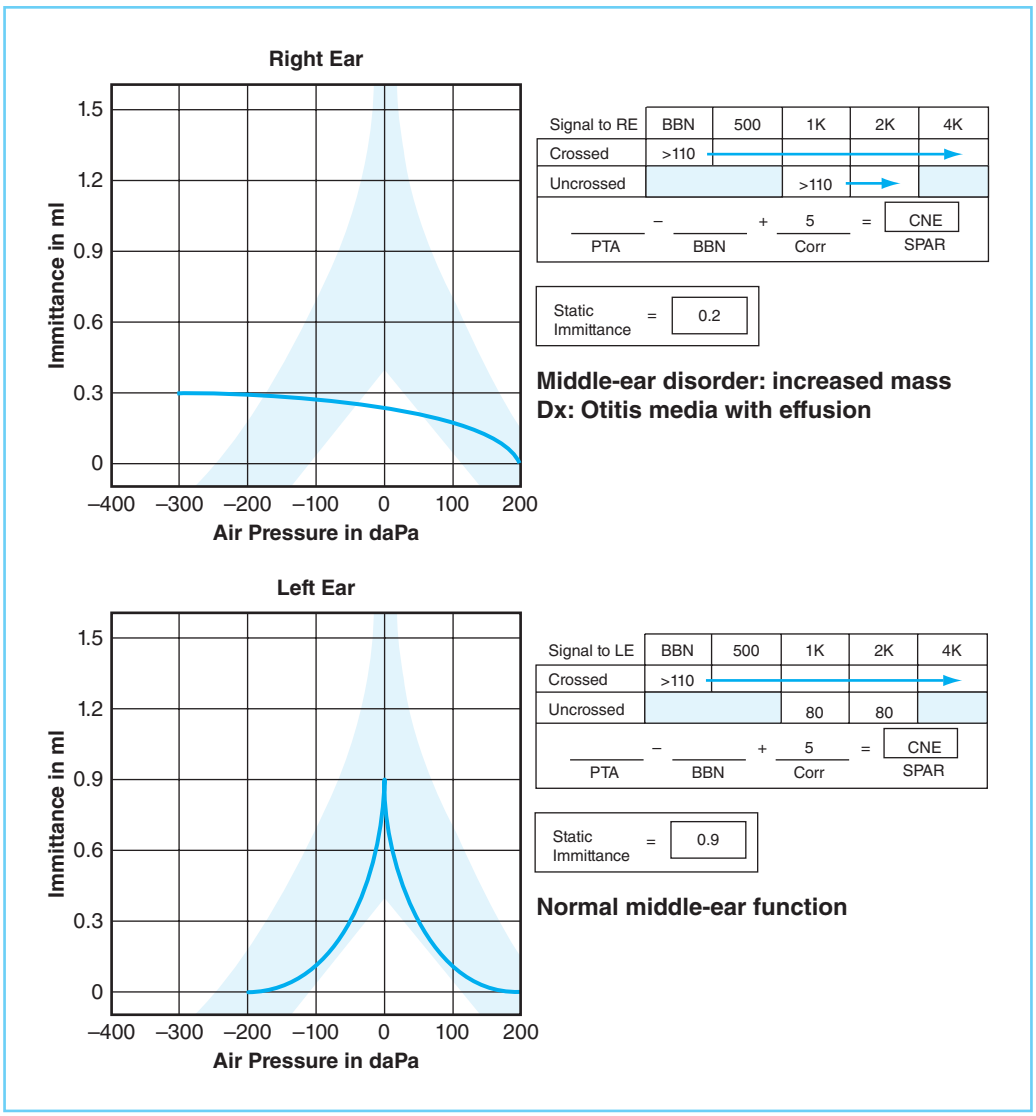


FIGURE 8-12 Immittance results consistent with right middle-ear disorder, characterized by increased mass of the middle-ear system caused by otitis media with effusion.

Tympanic-Membrane Perforation

Figure 8-15 shows immittance results on a young boy. The right ear results are characterized by an inability to measure a tympanogram, excessive volume, and unmeasurable acoustic reflexes from the right probe (right uncrossed and left crossed). These results are consistent with a perforated tympanic membrane.

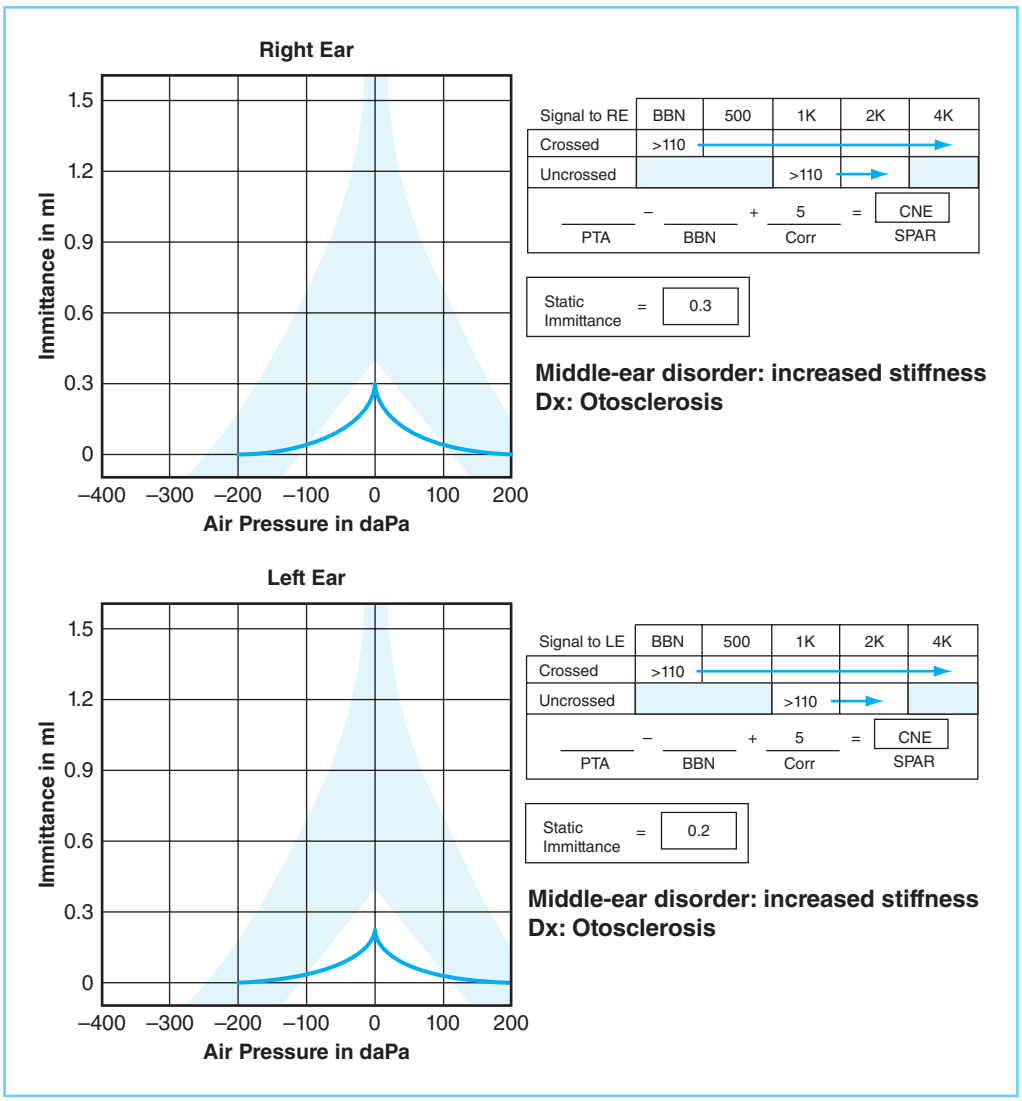


FIGURE 8-13 Immittance results consistent with bilateral middle-ear disorder, characterized by increased stiffness of the middle-ear system caused by otosclerosis.

The left ear immittance results are normal. The tympanogram is a Type A, static immittance is within normal limits, and left uncrossed reflexes are present. The slight elevation of right crossed reflexes in the presence of normal left uncrossed reflexes suggests that the right middle-ear disorder is causing a mild conductive hearing loss on the right ear.

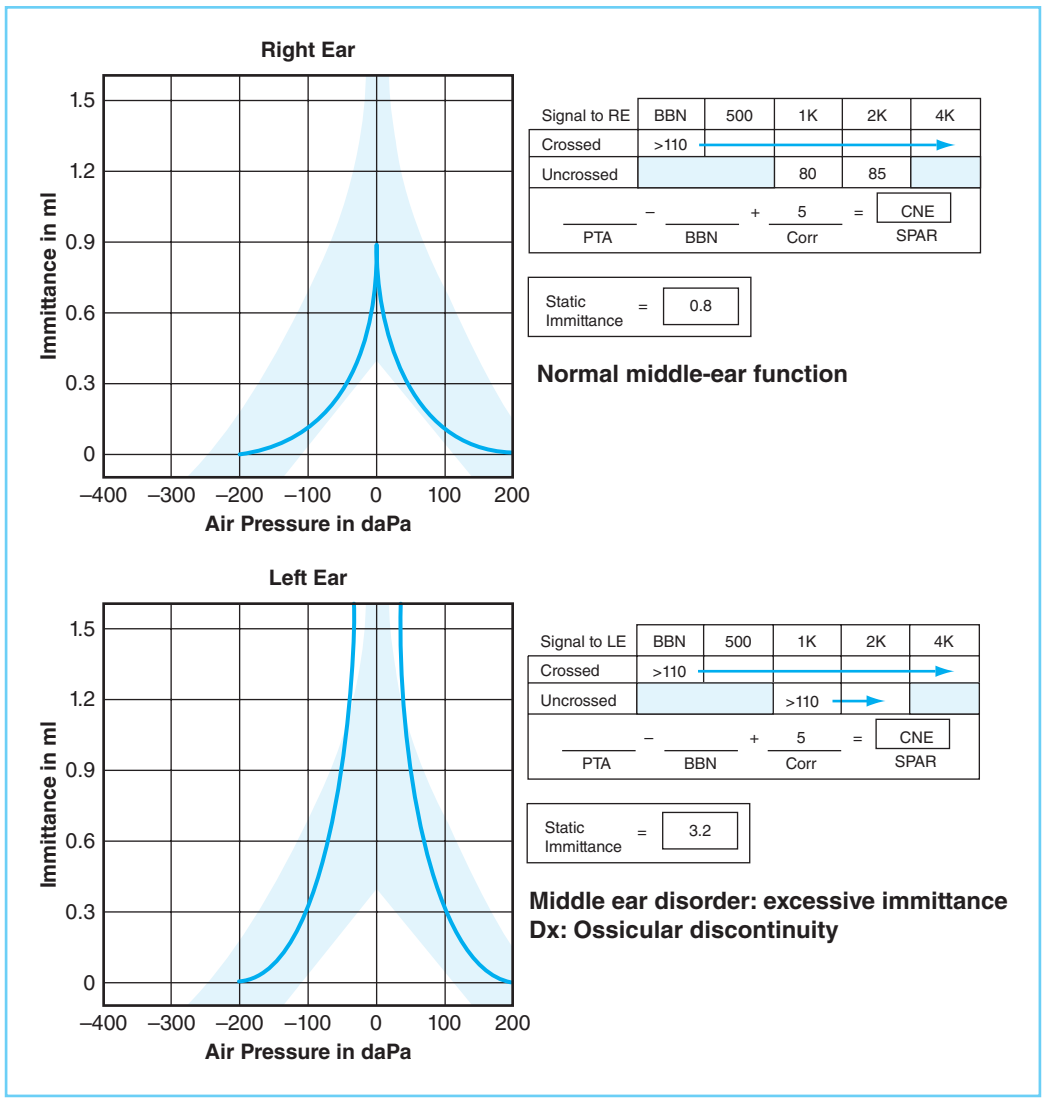


FIGURE 8-14 Immittance results consistent with left middle-ear disorder, characterized by excessive immittance caused by ossicular discontinuity.

Negative Middle-Ear Pressure

Figure 8-16 shows immittance results on a 2-year-old boy. Results are identical on both ears and are characterized by Type C tympanograms (peak at −200 and −250 daPa in the right and left ear respectively), normal static immittance, and absent acoustic reflexes. These results are consistent with significant negative pressure in the middle-ear space.

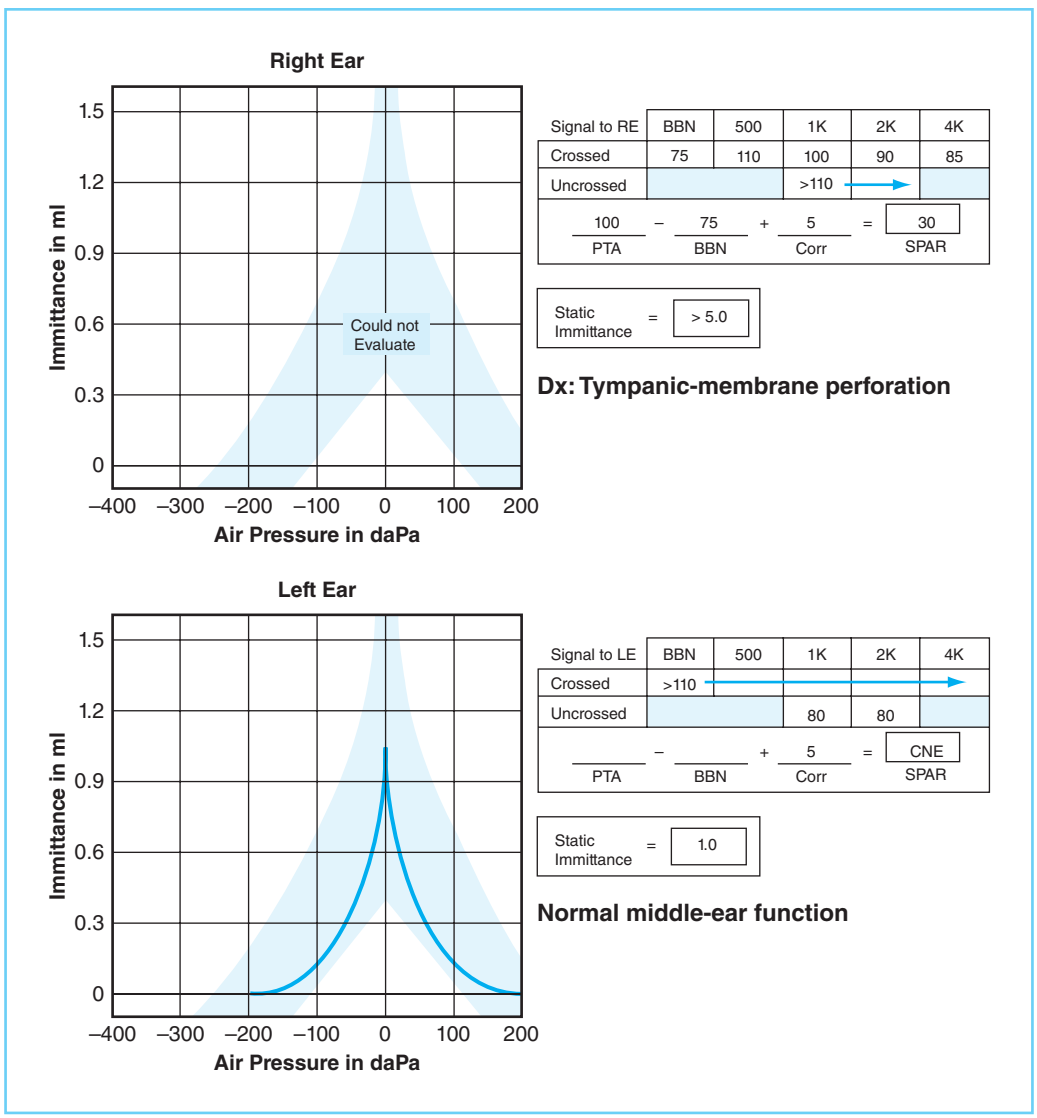


FIGURE 8-15 Immittance results consistent with right middle-ear disorder, characterized by excessive volume caused by tympanic membrane perforation.

Cochlear Disorder

The typical immittance pattern associated with cochlear disorder includes:

- normal tympanogram,
- normal static immittance, and
- normal reflex thresholds.

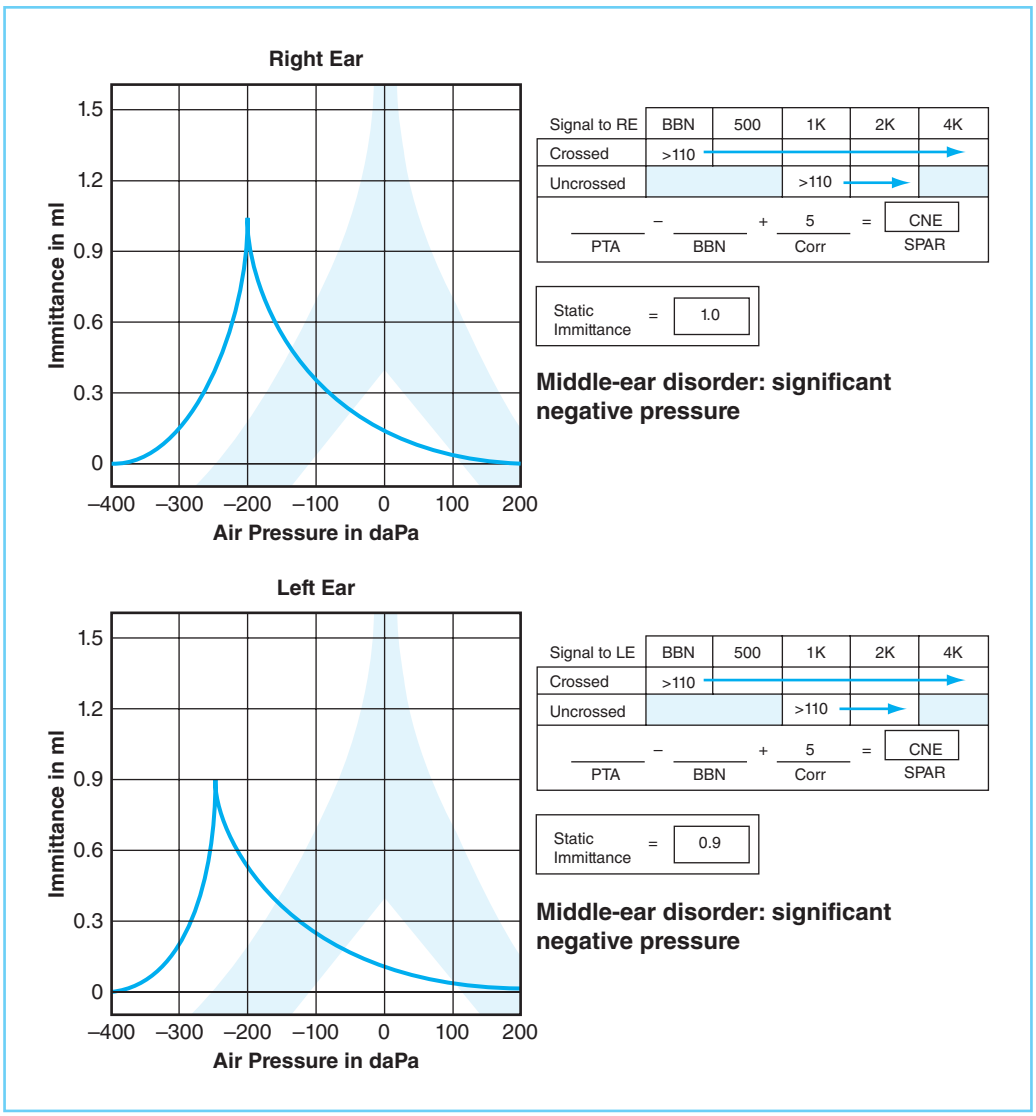


FIGURE 8-16 Immittance results consistent with bilateral middle-ear disorder, characterized by significant negative pressure in the middle-ear space.

Reflex thresholds will only be normal, however, as long as the sensitivity loss by air conduction does not exceed 50 dB HL. Above this level, the reflex threshold is usually elevated in proportion to the degree of loss. Once a behavioral threshold exceeds 70 dB, the absence of a reflex is equivocal, because it can be due to the degree of peripheral hearing loss as well as to retrocochlear disorder (Jerger et al., 1972).

In ears with cochlear hearing loss, acoustic reflex thresholds are present at reduced sensation levels. In normal-hearing ears, behavioral threshold to pure tones are, by definition, at or around 0 dB HL. Acoustic reflex thresholds occur at or around 85 dB HL, or at a sensation level of 85 dB. In a patient with a sensorineural hearing loss of 40 dB, reflex thresholds still occur at around 85 dB HL, or at a sensation level of 45 dB. This reduced sensation level of the acoustic reflex threshold is characteristic of cochlear hearing loss.

Several methods have been developed for using acoustic reflex thresholds to detect hearing loss. One method that has gained some popularity is the Sensitivity Prediction by the Acoustic Reflex (SPAR) test (Jerger et al., 1974). The SPAR test is based on the well-documented difference between acoustic reflex thresholds to pure tones versus broad-band noise (BBN) and on the change in BBN thresholds but not pure-tone thresholds as a result of sensorineural hearing loss. That is, thresholds to BBN signals are lower (better) than thresholds to pure-tone signals. However, sensorineural hearing loss has a differential effect on the two signals, raising the threshold to BBN signals, but not to pure-tone signals. The SPAR test capitalizes on this effect to provide a general prediction of the presence or absence of hearing loss.

SPAR = Reflex PTA – BBN

To compute the **SPAR** value, the BBN threshold is subtracted from the average reflex threshold to pure tones of 500, 1000, and 2000 Hz. The magnitude of this difference will vary according to the specific equipment used to carry out the measures. A correction factor is then applied to yield a SPAR value of 20 in normal hearing subjects. If a patient's SPAR value is less than 15, there is a high probability of a sensorineural hearing loss. An example of the SPAR calculation in a normal hearing individual is shown in Figure 8-17. Note the low value of the BBN threshold in comparison to the thresholds for pure tones. The difference between the average pure-tone thresholds and BBN threshold is large, resulting in a large or normal SPAR. An example of the SPAR calculation in a patient with a high-frequency sensorineural hearing impairment is shown in Figure 8-18. Note the higher BBN threshold and how it affects the SPAR value.

Crossed Reflex Thresholds	BBN	500	1K	2K	4K
	65	85	85	85	85

$$\underset{\text{PTA}}{85} - \underset{\text{BBN}}{65} + \underset{\text{Corr}}{5} = \underset{\text{SPAR}}{25}$$

FIGURE 8-17 The SPAR calculation in a normal-hearing ear, calculated by subtracting the broad-band noise (BBN) threshold from the pure-tone average (PTA) and adding a correction (Corr) factor.

Crossed Reflex Thresholds	BBN	500	1K	2K	4K
	80	80	85	95	100

$$\underset{\text{PTA}}{85} - \underset{\text{BBN}}{80} + \underset{\text{Corr}}{5} = \underset{\text{SPAR}}{10}$$

FIGURE 8-18 The SPAR calculation in an ear with a high-frequency sensorineural hearing loss.

Use of the SPAR or other techniques based on acoustic reflex thresholds is only effective at predicting general degree of hearing loss. Clinical application of such techniques appears to be most effective when used to predict presence or absence of a sensorineural hearing loss.

Prediction of hearing sensitivity by acoustic reflex thresholds can be very valuable in testing a child on whom behavioral thresholds cannot be obtained. Figure 8-19 shows immittance results of a 2-year-old child who fits this description. Regardless of the nature or intensity of effort, behavioral audiometry could not be completed, and a startle reflex could not be elicited at equipment intensity limits. Tympanograms were Type A, with maximum immittance at 0 daPa. Static immittance was symmetric and within normal limits. Crossed acoustic reflex thresholds were present and normal at 500 and 1000 Hz, elevated at 2000 Hz, and absent at 4000 Hz, bilaterally. The SPAR value was only 4 dB bilaterally, suggesting a sensorineural hearing loss. Based on the SPAR and on the configuration of the crossed threshold pattern,

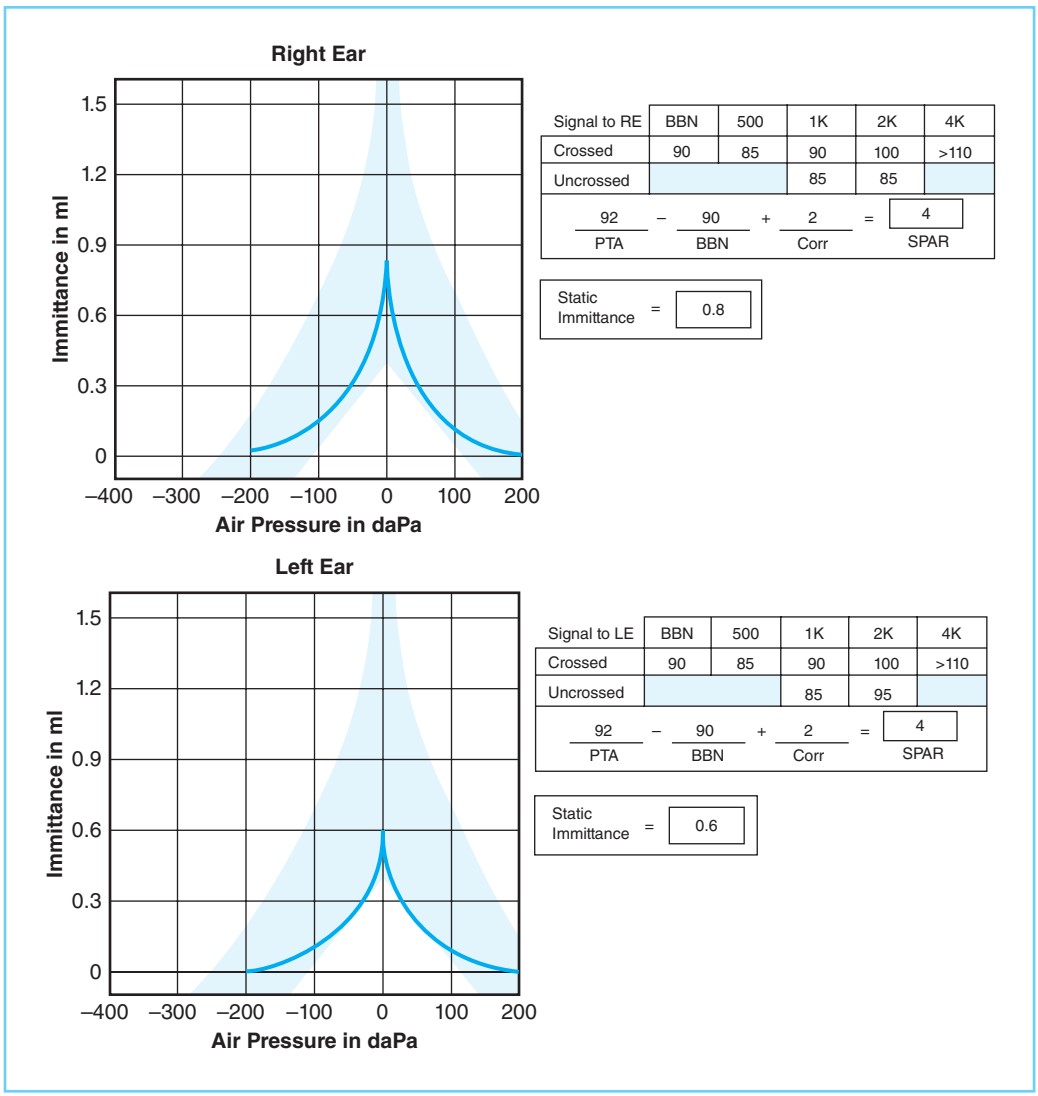


FIGURE 8-19 Immittance results, with SPARs predicting significant sensorineural hearing loss, on a 2-year-old child from whom behavioral thresholds could not be obtained.

these immittance measures predicted a sensorineural hearing loss, greater in the high-frequency region of the audiogram than in the low.

A second application of reflex measurement for sensitivity prediction is in the case of a patient who is feigning hearing loss. Figure 8-20 shows immittance results on a 34-year-old male

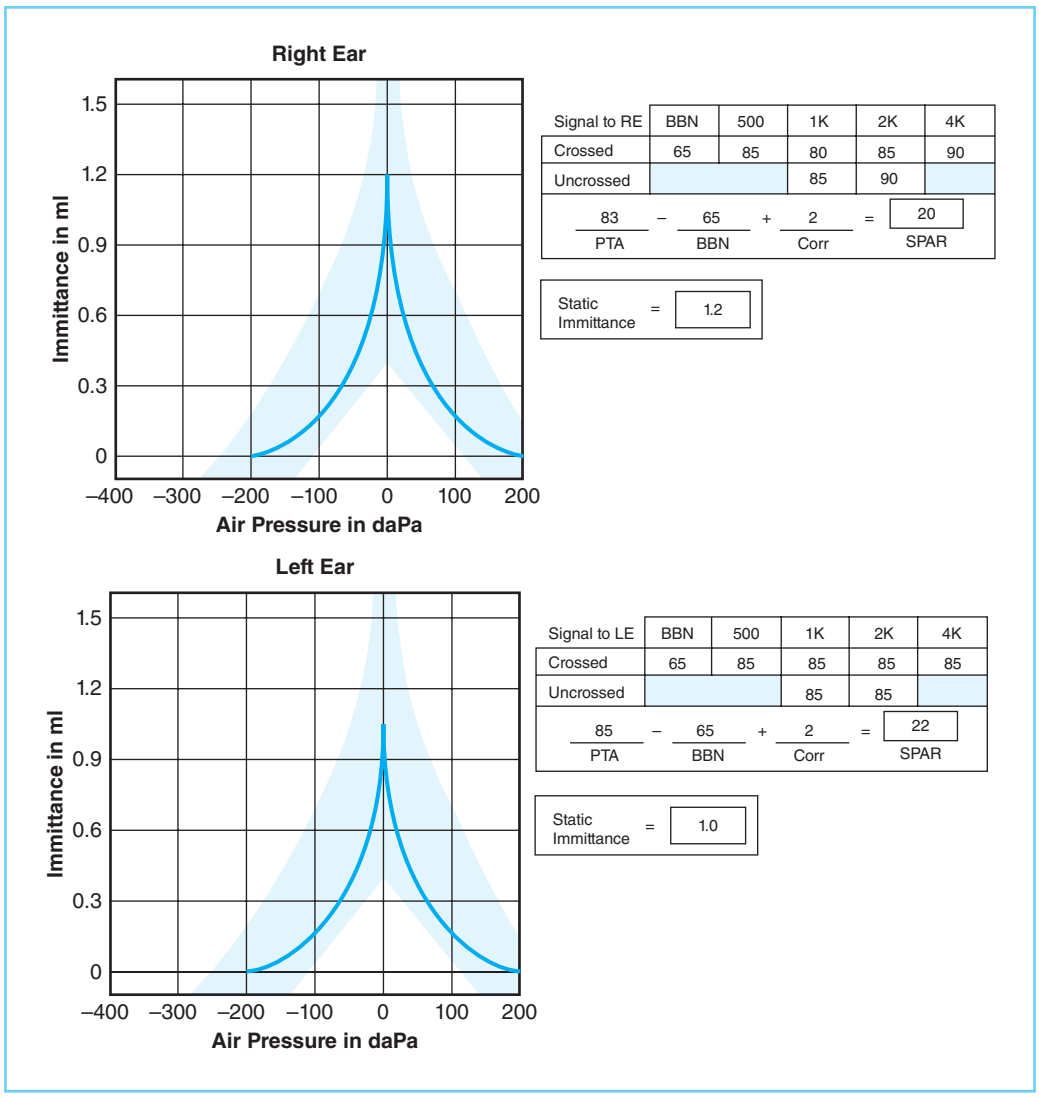


FIGURE 8-20 Immittance results, with SPARs predicting normal hearing sensitivity, from a patient who was feigning a right-ear hearing loss.

patient who was evaluated for a right ear hearing loss. He reported that the loss occurred as the result of an industrial accident, during which he was exposed to high-intensity noise as a result of steam release from a broken pipe at an oil refinery. The tympanogram, static immittance, and acoustic reflex thresholds

were all within normal limits. SPARs of 20 and 22 dB and a flat reflex threshold configuration predicted normal hearing sensitivity bilaterally.

Retrocochlear Disorder

Acoustic reflex threshold or suprathreshold patterns can be helpful in differentiating cochlear from retrocochlear disorder. The typical immittance pattern associated with retrocochlear disorder includes:

- normal tympanogram,
- normal static immittance, and
- abnormal elevation of reflex threshold, or absence of reflex response, whenever the reflex-eliciting signal is delivered to the suspect ear in either the crossed or the uncrossed mode.

For example, in the case of a right-sided acoustic tumor, the tympanograms and static immittance would be normal. Abnormality would be observed for the right uncrossed and the right-to-left crossed reflex responses. The key factor differentiating retrocochlear from cochlear elevated reflex thresholds is the audiometric level at the test frequency. As you learned previously, in the case of cochlear loss, reflex thresholds are not elevated at all until the audiometric loss exceeds 50 dB HL, and even above this level the degree of elevation is proportional to the audiometric level. In the case of retrocochlear disorder, however, the elevation is more than would be predicted from the audiometric level. The reflex threshold may be elevated by 20 to 25 dB even though the audiometric level shows no more than a 5 or 10 dB loss. If the audiometric loss exceeds 70 to 75 dB, then the absence of the acoustic reflex is ambiguous. The abnormality could be attributed either to retrocochlear disorder or to cochlear loss.

For diagnostic interpretation, acoustic reflex measures are probably best understood if viewed in the context of a three-part reflex arc:

1. the sensory or input portion (afferent),
2. the central nervous system portion that transmits neural information (central), and
3. the motor or output portion (efferent).

An *afferent* abnormality occurs as the result of a disordered sensory system on one ear. An example of a pure afferent effect would result from a profound unilateral sensorineural hearing loss on the right ear. Both reflexes with signal presented to the right ear (right uncrossed and right-to-left crossed) would be absent. An *efferent* abnormality occurs as the result of a disordered motor system or middle-ear mechanism on one ear. An example of a pure efferent effect would result from right unilateral facial nerve paralysis. Both reflexes measured by the probe in the right ear (right uncrossed and left-to-right crossed) would be absent. A *central pathway* abnormality occurs as the result of brainstem disorder and is manifested by the elevation or absence of one or both of the crossed acoustic reflexes in the presence of normal uncrossed reflex thresholds.

Cochlear Hearing Loss

Labyrinthitis is the inflammation of the labyrinth, affecting hearing, balance, or both.

Figure 8-21 shows the immittance results of a patient with a sensorineural hearing loss. The patient was diagnosed as having acute **labyrinthitis** resulting in a unilateral hearing loss and dizziness. Tympanograms, static immittance, and acoustic reflex thresholds are within normal limits. Even though the patient has a substantial sensorineural hearing loss in the left ear, reflex thresholds remain within normal limits. The presence of left uncrossed and left-to-right crossed reflexes argues for a cochlear site of disorder.

Afferent Abnormality

Figure 8-22 shows the immittance results of a patient with an afferent acoustic reflex abnormality resulting from retrocochlear disorder. The patient was diagnosed as having a right acoustic tumor. Tympanograms and static compliance are normal. Acoustic reflexes, with sound presented to the left ear (left uncrossed and left-to-right crossed), are normal. However, reflexes with sound presented to the right ear (right uncrossed and right-to-left crossed) are absent. This pattern of abnormality suggests an afferent disorder which, in the absence of a severe degree of hearing loss, is consistent with retrocochlear disorder.

Efferent Abnormality

Figure 8-23 shows the immittance results of a patient with an efferent acoustic reflex abnormality resulting from facial nerve

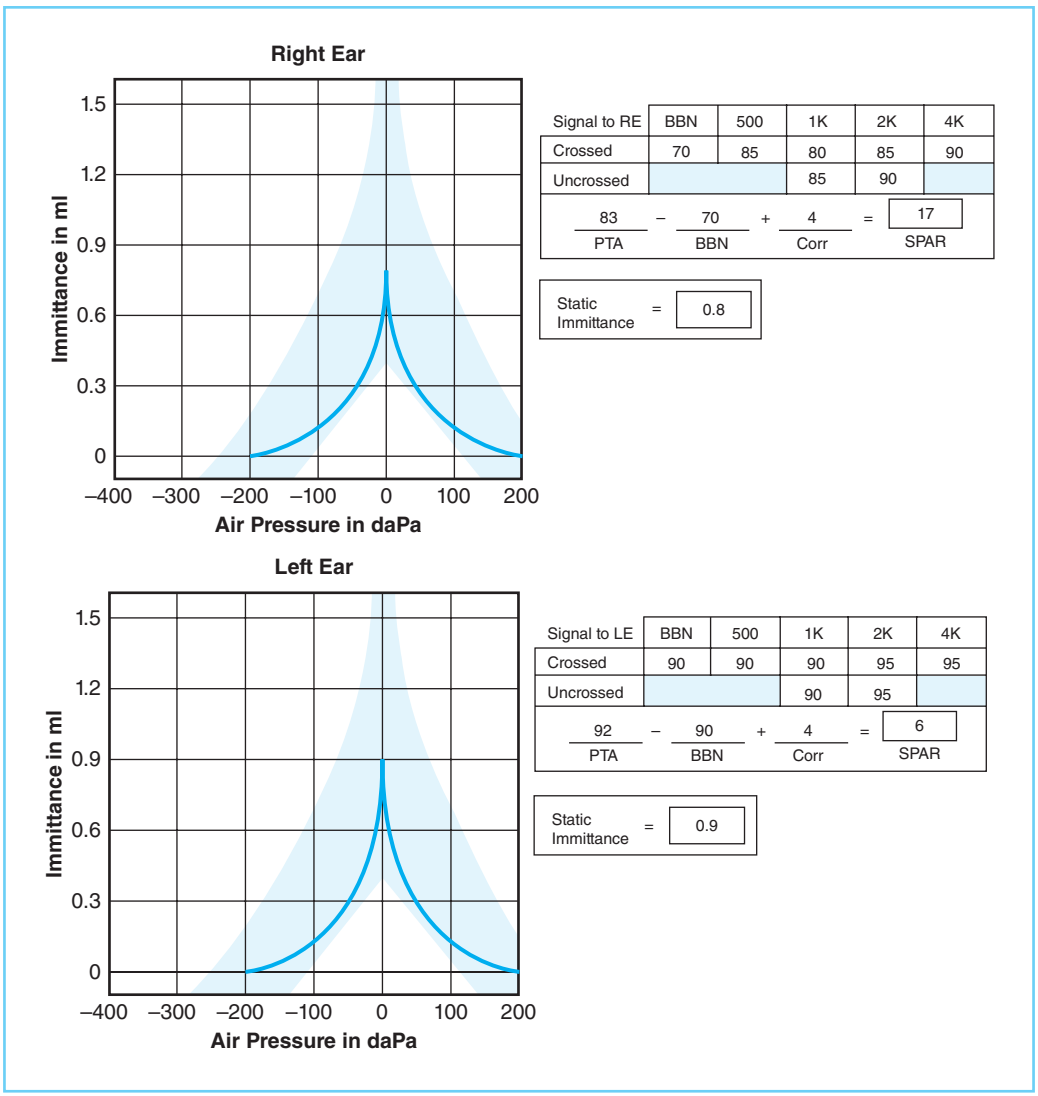


FIGURE 8-21 Immittance results consistent with normal middle-ear function and a left sensorineural hearing loss.

disorder. The patient had experienced a sudden left-sided facial paralysis of unknown etiology. She had no history of previous middle-ear disorder and no auditory complaints. The tympanogram and static immittance are normal on both ears. Acoustic reflexes are present at normal intensity levels when recorded from the right probe (right uncrossed and left-to-right crossed). However, no reflexes could be measured from the left

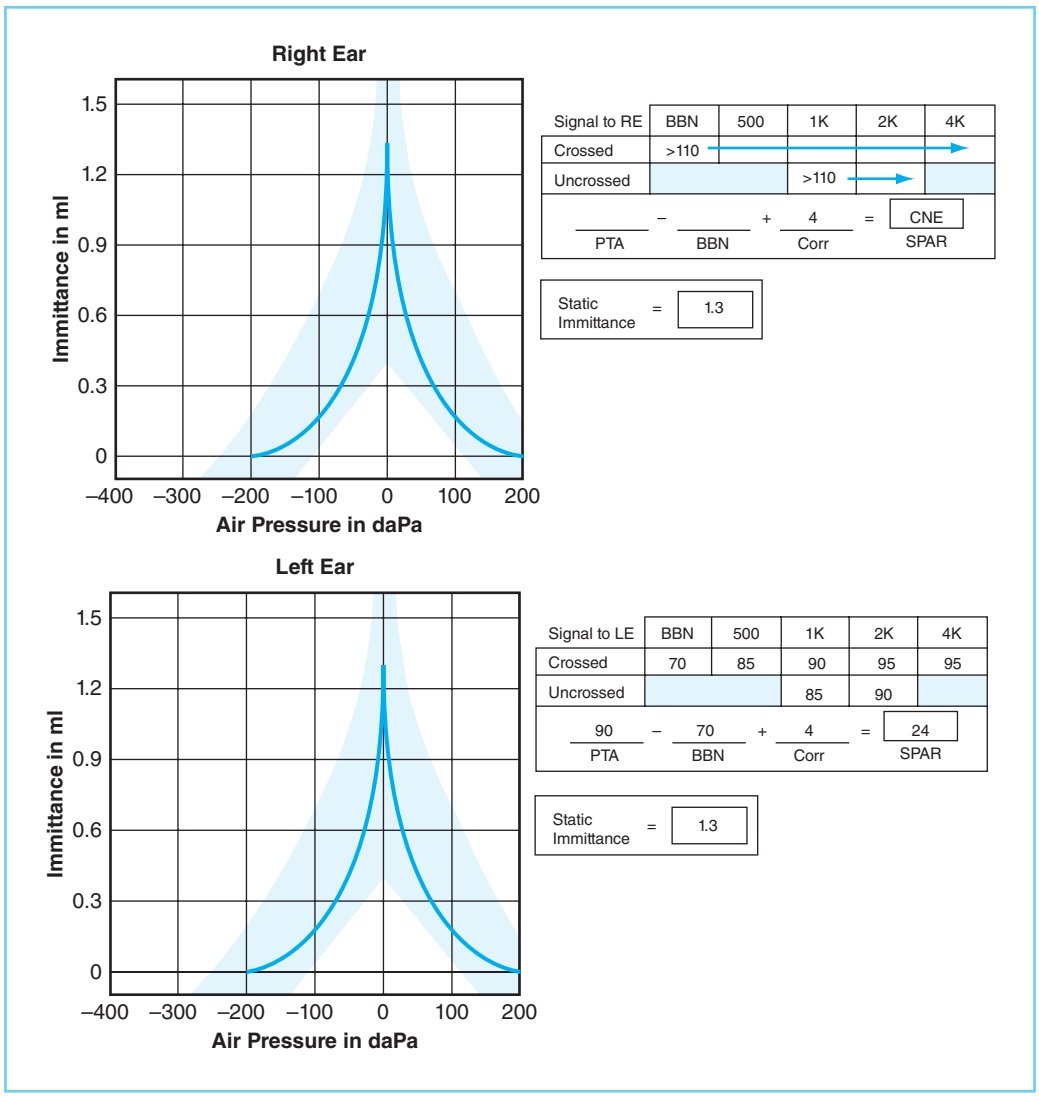


FIGURE 8-22 Immittance results consistent with normal middle-ear function and a right afferent acoustic reflex abnormality resulting from a right acoustic tumor.

VIIth cranial nerve = facial nerve

ear, regardless of which ear was being stimulated (absent left uncrossed and right-to-left crossed). This pattern of abnormality suggests an efferent disorder which, in the absence of any middle-ear disorder, is consistent with a neurologic disorder affecting the **VIIth cranial nerve**.

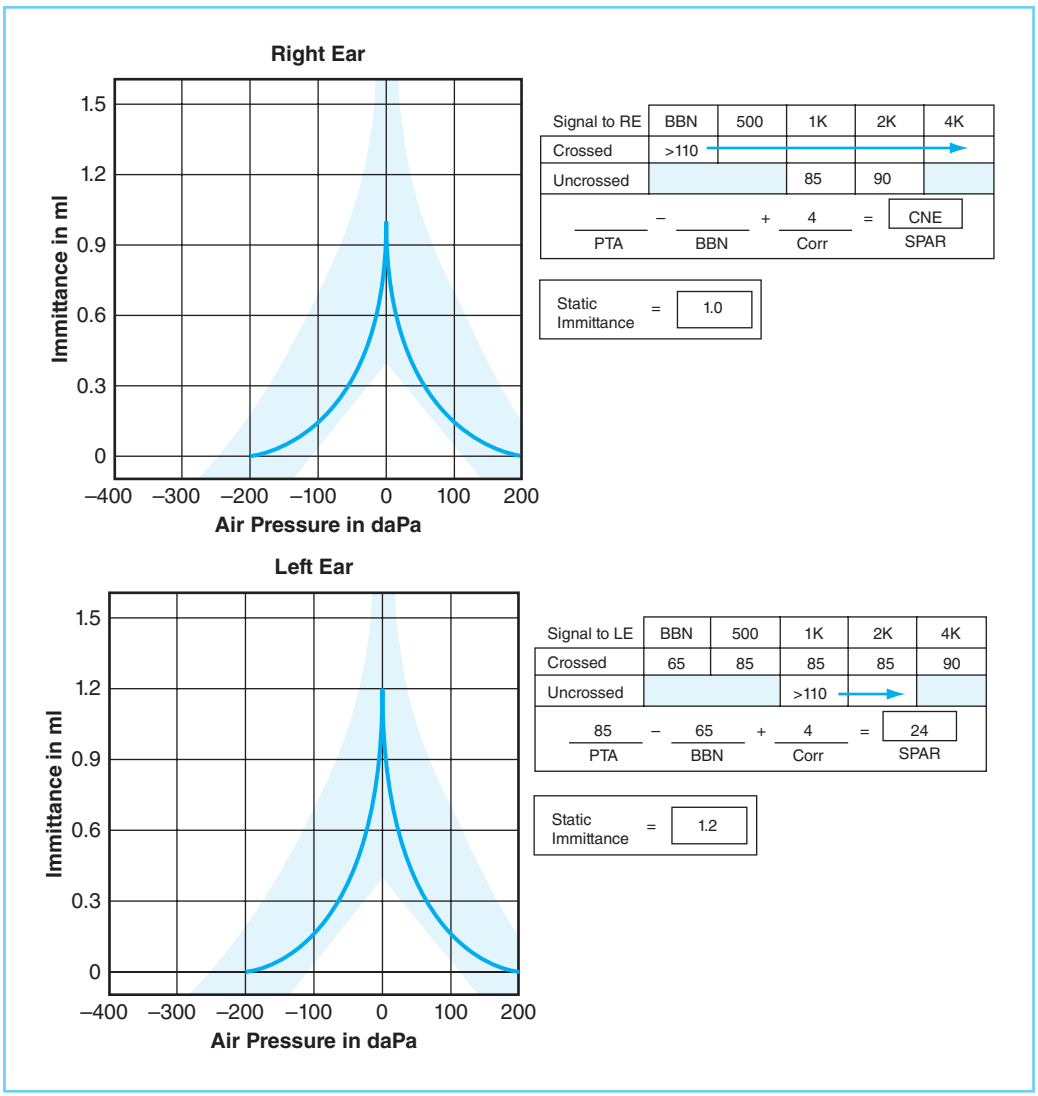


FIGURE 8-23 Immittance results consistent with a left efferent acoustic reflex abnormality, resulting from a left facial nerve paralysis of unknown cause.

Central Pathway Abnormality

Figure 8-24 shows immittance results of a patient with a central pathway abnormality resulting from brainstem disorder. The patient has multiple sclerosis, a disease that causes lesions throughout the brainstem and often results in auditory system abnormalities. Static immittance and tympanograms are normal bilaterally.

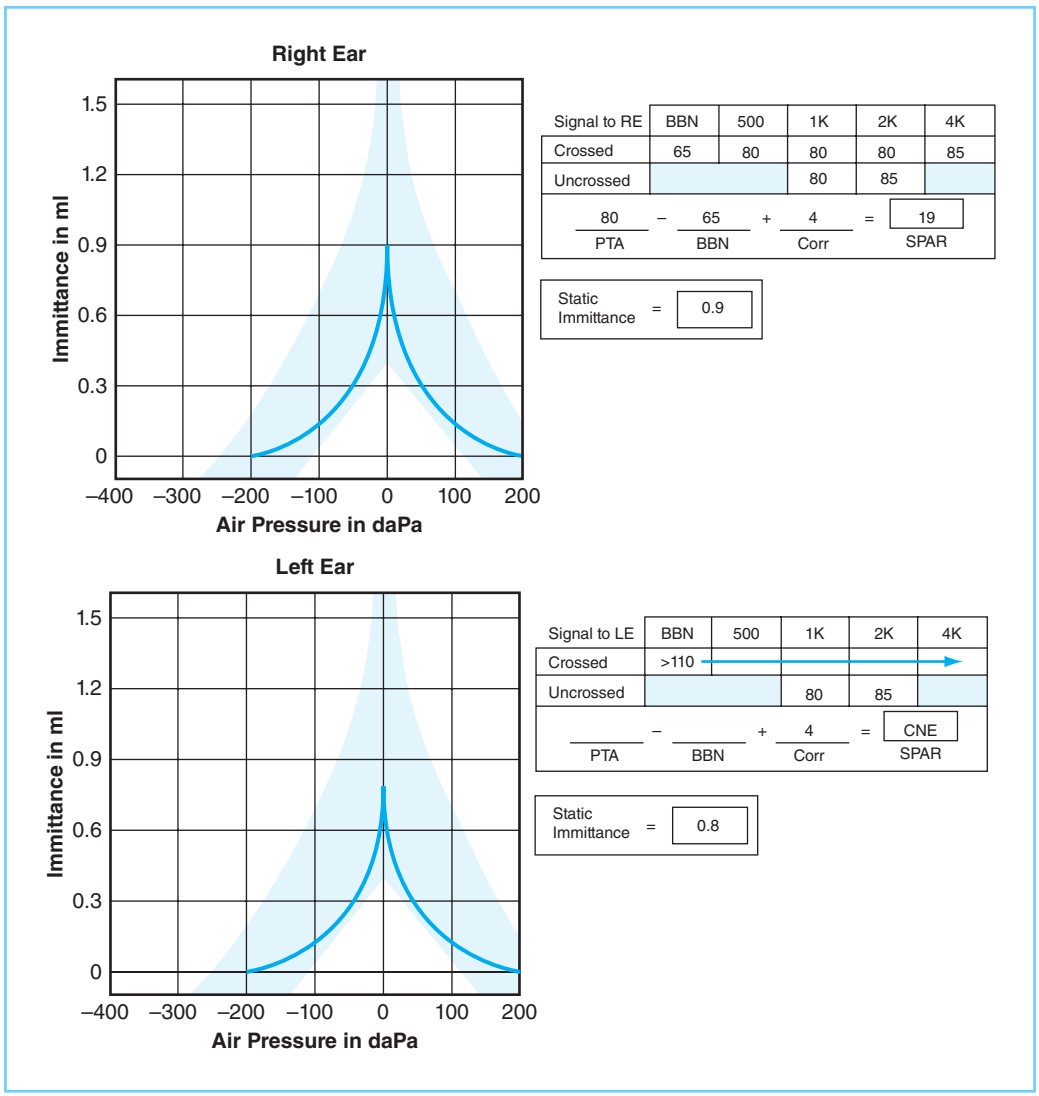


FIGURE 8-24 Immittance results consistent with a central pathway abnormality, resulting from brainstem disorder secondary to multiple sclerosis.

Uncrossed reflexes are normal for both ears. In addition, right-to-left crossed reflexes are present at normal levels. However, left-to-right crossed reflexes are absent. The presence of a left uncrossed reflex rules out the possibility of either a substantial hearing loss or an acoustic tumor on the left side. The presence of a right uncrossed reflex rules out the possibility of middle-ear disorder on the right side. The absence of a left crossed reflex, then, can only be explained as the result of a brainstem disorder.

Summary

- Immittance is a physical characteristic of all mechanical vibratory systems. In very general terms, it is a measure of how readily a system can be set into vibration by a driving force.
- Immittance audiometry is a way of assessing the manner in which energy flows through the outer and middle-ears to the cochlea.
- Immittance audiometry is a powerful tool for the evaluation of auditory disorder.
- Three immittance measures are commonly used in the clinical assessment of middle-ear function: tympanometry, static immittance, and acoustic reflex thresholds.
- The key to successful use of the immittance battery in clinical evaluation is to view the results in combination with the totality of the audiometric examination rather than in isolation.
- Immittance measures are useful in quantifying middle-ear disorders and in differentiating cochlear from retrocochlear disorders.

Short Answer Questions

1. The functions of _____ audiometry include: the detection of _____ ear disorder; differentiation of cochlear from _____ disorder; and a cross-check of pure-tone audiometry.
2. The term _____ describes the total flow of energy through a system. The term _____ describes the opposition to energy flow through a system. The term encompassing both concepts is _____ .
3. Immittance measures provide an indirect way of assessing appropriateness of energy flow through the _____ _____ mechanism.
4. The basic immittance measures consist of _____, _____ immittance, and acoustic _____.
5. The measure of how acoustic immittance of the middle-ear system changes as air pressure is varied in the external ear canal is known as _____.
6. A _____ is a graph of the level of immittance measured as a function of air pressure in daPa.

7. The conventional classification of tympanograms depends on the _____ of the tympanogram, and is classified as being Type _____, Type B, or Type _____.
8. In the case of a Type _____ tympanogram, peak immittance occurs at normal atmospheric pressure. This represents _____ middle-ear function.
9. In the case of a Type _____ tympanogram, there is a loss of a sharp peak due to added mass in middle-ear system. This type of tympanogram is consistent with _____ in the middle-ear space.
10. In the case of a Type _____ tympanogram, the peak immittance occurs at a value negative to atmospheric pressure. This type of tympanogram is consistent with _____ dysfunction.
11. The most common cause of middle-ear disorder is _____ _____ dysfunction. As the Eustachian tube does not open properly to _____ the middle-ear space, trapped air is absorbed by mucosal lining. The relatively negative pressure in this space causes the tympanic membrane to retract in toward middle-ear space.
12. When the peak immittance of a tympanogram occurs at normal atmospheric pressure, but its height is significantly decreased or _____, it is classified as a Type _____ tympanogram. This type of tympanogram is consistent with a middle-ear disorder of increased _____, such as otosclerosis.
13. When the peak immittance of a tympanogram occurs at normal atmospheric pressure but its height is significantly increased or deep, it is classified as a Type _____ tympanogram. This type of tympanogram is consistent with a middle-ear disorder of increased energy flow through system, such as a _____ of the ossicular chain.
14. The value that corresponds to the pressure level where the peak of a tympanogram trace occurs is known as the _____ _____ _____.
15. The value of relative pressure in daPa at the point corresponding to 50% of static immittance value is known as the _____ _____ .

16. The frequency of the probe tone that is typically used for immittance testing is _____ Hz. In infants and very young newborns, it is necessary to use a _____ Hz probe tone.
17. The difference between volume measurement of space between +200 daPa and immittance peak is known as the _____ _____ measurement.
18. The use of the _____ _____ measurement can help to provide information regarding the presence of a perforation in the tympanic membrane.
19. The _____ _____ occurs when a sound of sufficient intensity elicits a reflex of the middle-ear musculature.
20. In humans, the acoustic reflex is primarily caused by activation of the _____ muscle.
21. The acoustic reflex is a _____ response, meaning that both ears respond reflexively, even when the sound is only heard in one ear.
22. Ipsilateral (_____) reflexes occur when the sound is presented and the reflex is measured in the same ear. Contralateral (_____) reflexes occur when the sound is presented to one ear, and the reflex is measured in the opposite ear.
23. The acoustic reflex arc can be divided into _____ (sensory), central, and _____ (motor) components.
24. The _____ _____ _____ is the lowest intensity level at which middle-ear immittance change can be detected in response to sound that elicits an acoustic reflex.
25. Above the level of a 50 dB cochlear hearing loss, the acoustic reflex is usually _____ in proportion to degree of hearing loss. At threshold levels above _____ dB HL, absence of reflex is equivocal.
26. The _____ _____ by the _____ _____ test compares the acoustic reflex thresholds of broad-band noise signals to pure-tone signals in order to predict the presence or absence of a cochlear hearing loss.

Discussion Questions

1. Many audiologists conduct immittance measures as the first component of the hearing test battery. Why might this be beneficial?
2. Considering the goal of audiologic testing, what role do immittance measures play in achieving that goal?
3. Describe the instrumentation that is used in making immittance measurements.
4. How does middle-ear dysfunction affect the immittance of the middle ear?
5. What type of tympanometric findings might be characteristic of Eustachian tube dysfunction? How does Eustachian tube dysfunction result in these characteristic tympanometric findings?
6. Describe the pathway involved in the acoustic reflex response.

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9

THE AUDIOLOGIST'S ASSESSMENT TOOLS: PHYSIOLOGIC MEASURES

Learning Objectives

Auditory Evoked Potentials
- Measurement Techniques
- The Family of Auditory Evoked Potentials
- Clinical Applications

Summary

Otoacoustic Emissions
- Types of Otoacoustic Emissions
- Relation to Hearing Sensitivity
- Clinical Applications

Summary

Short Answer Questions

Discussion Questions

Resources

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- Describe the various auditory evoked potentials, including the electrocochleogram, the auditory brainstem response, the middle latency response, the late latency response, and the auditory steady-state response.
- Explain the commonly used techniques for extracting the auditory evoked potential from ongoing electrical activity.
- List and describe the common uses for auditory evoked potentials.
- Describe otoacoustic emissions.
- Explain how evoked otoacoustic emissions are used clinically.

AUDITORY EVOKED POTENTIALS

BY means of computer averaging, it is possible to extract the tiny electrical voltages, or potentials, evoked in the brain by acoustic stimulation. These electrical events are quite complex and can be observed over a fairly broad time interval after the onset of stimulation. An auditory evoked potential (AEP) is a waveform that reflects the electrophysiologic function of a certain portion of the central auditory nervous system in response to sound (for an overview, see Burkard et al., 2007, Hall, 2007).

For audiologic purposes, it is convenient to group the AEPs into categories based loosely on the latency ranges over which the potentials are observed. The earliest of the evoked potentials, occurring within the first 5 msec following signal presentation, is referred to as an *electrocochleogram* (ECoG) and reflects activity of the cochlea and VIIIth nerve. The most commonly used evoked potential is referred to as the *auditory brainstem response* (ABR) and occurs within the first 10 msec following signal onset. The ABR reflects neural activity from the VIIIth nerve to the midbrain. The *middle latency response* (MLR) occurs within the first 50 msec following signal onset and reflects activity at or near the auditory cortex. The *late latency response* (LLR) occurs within the first 250 msec following signal onset and reflects activity of the primary-auditory and association areas of the cerebral cortex.

These measures, the EcoG, ABR, MLR, and LLR are known as transient potentials in that they occur and are recorded in response to a

single stimulus presentation. The response is allowed to end before the next signal is presented. The process is then repeated numerous times, and the responses are averaged. A different type of evoked potential, called the *auditory steady-state response* (ASSR), is measured by evaluating the ongoing activity of the brain in response to a modulation, or change, in an ongoing stimulus. The ASSR reflects activity from different portions of the brain, depending on the modulation rate used. Responses from slower rates emanate from more central structures of the brain, while responses from faster rates emanate from the more peripheral auditory nerve and brainstem structures.

Auditory evoked potentials provide an objective means of assessing the integrity of the peripheral and central auditory systems. For this reason, evoked potential audiometry has become a powerful tool in the measurement of hearing of young children and others who cannot or will not cooperate during behavioral testing. It also serves as a valuable diagnostic tool in measuring the function of auditory nervous system structures.

There are four major applications of auditory evoked potential measurement:

1. prediction of hearing sensitivity,
2. infant hearing screening,
3. diagnostic assessment of central auditory nervous system function, and
4. monitoring of auditory nervous system function during surgery.

The use of auditory evoked potentials for prediction of hearing sensitivity and infant hearing screening has had a major impact on our ability to identify hearing impairment in children. The ABR is used to screen newborns to identify those in need of additional testing. Both the ABR and ASSR are used to predict hearing sensitivity levels in children with suspected hearing impairment.

Diagnostic assessment is usually made with the ABR, MLR, and LLR. The ABR is highly sensitive to disorders of the VIIIth nerve and auditory brainstem and is often used in conjunction with imaging and radiologic measures to assist in the diagnosis of acoustic tumors and brainstem disorders. Surgical monitoring

of evoked potentials is usually carried out with ECoG and ABR. These evoked potentials are monitored during VIIIth nerve tumor removal surgery in an effort to preserve hearing.

Measurement Techniques

The brain processes information by sending small electrical impulses from one nerve to another. This electrical activity can be recorded by placing sensing electrodes on the scalp and measuring the ongoing changes in electrical potentials throughout the brain. This technique is called *electroencephalography*, or EEG, and is the basis for recording evoked potentials. The passive monitoring of EEG activity reveals the brain in a constant state of activity; electrical potentials of various frequencies and amplitudes occur continually. If a sound is introduced to the ear, the brain's response to that sound is just another of a vast number of electrical potentials that occur at that instant in time. Evoked potential measurement techniques are designed to extract those tiny signals from the ongoing electrical activity.

Recording evoked potentials requires sophisticated amplification of the electrical activity, computer signal averaging, proper stimuli to evoke an auditory response, and precise timing of stimulus delivery and response recording. A schematic representation of the instrumentation is shown in Figure 9-1. Basically, at the same moment in time that a stimulus is presented to an earphone, a computer measures electrical activity from electrodes affixed to the scalp over a fixed period of time. The process is repeated many times, and the computer averages the responses. This results in a series of waveforms that reflect synchronized electrical activity from various structures of the peripheral and central auditory nervous system.

Recording EEG Activity

To record EEG activity, electrodes are affixed to the scalp. These electrodes are usually gold or silver plated and are pasted to the scalp with a gel that facilitates electrical conduction. For measuring auditory evoked potentials, electrodes are placed on the center of the scalp, called the vertex, and on both earlobes, in the ear canals, or behind the ears on the mastoid area. A ground electrode is usually placed on the forehead. The electrical activity measured at the vertex is compared to that measured at the earlobe.

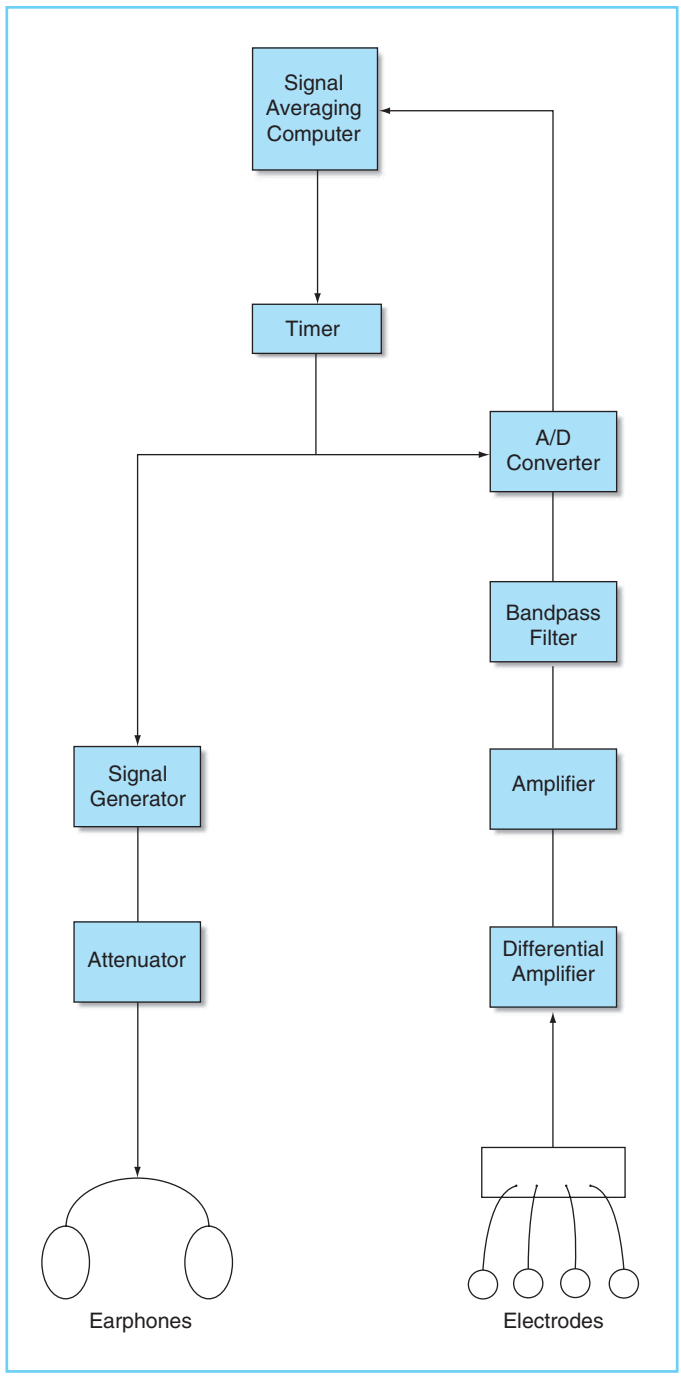


FIGURE 9-1 Schematic representation of the instrumentation used in recording auditory evoked potentials.

Electrical potentials related specifically to an auditory signal are quite small in comparison to other electrical activity that is occurring at the same moment in time. The electrodes pick up all electrical activity, and activity related to the auditory stimulation need to be extracted from the other activity. The process involved is designed to enhance the signal in relation to the noise or the **signal-to-noise ratio (SNR)**. The first step in the extraction process occurs at the preamplifier stage. The preamplifier is known as a *differential amplifier*, and is designed to provide **common-mode rejection**. A differential amplifier cancels out activity that is common to both electrodes. For example, 60 Hz noise from lights or electrical fixtures is quite large in amplitude in comparison to the auditory evoked potential. This noise will be seen identically at both the vertex and the earlobe electrodes. The differential amplifier takes the activity measured at the earlobe, inverts it, and adds it to the activity measured at the vertex. If the activity is identical or common to both electrodes, it will be eliminated. This process is shown in Figure 9-2. So the first step in the process of extracting the auditory evoked potential is to

The difference in dB between a sound of interest and background noise is called the **signal-to-noise ratio**.

Common-mode rejection is a noise-rejection strategy used in electrophysiologic measurement in which noise that is identical at two electrodes is subtracted by a differential amplifier.

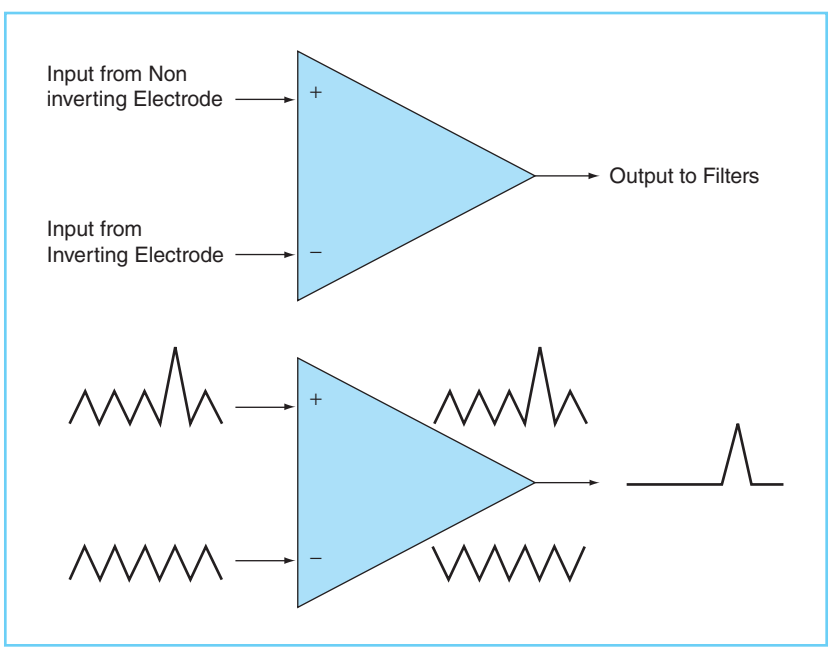


FIGURE 9-2 Schematic representation of the process of common-mode rejection. Activity that is identical or common to both electrodes is eliminated by inverting the input from one electrode and subtracting it from the input to the other.

differentially amplify in a way that eliminates some of the potential background noise. The remaining electrical activity is then amplified significantly, up to 100,000 times its original voltage.

The next step in reducing electrical noise not related to the auditory evoked potential is to filter the EEG activity. Electrical potentials that emanate from the structures of the brain cover a wide range of frequencies. For each of the auditory evoked potentials, we are interested in only a narrow band of frequencies surrounding those that are characteristic of that evoked potential. For example, the auditory brainstem response has five major peaks of interest, referred to as waves I through V, which occur about 1 msec apart. Any waveform that repeats every 1 msec has a frequency component of 1000 Hz. Similarly, the largest peaks of the ABR are I, III, and V, which occur at 2 msec intervals. Any waveform that repeats every 2 msec has a frequency component of 500 Hz. As a result, the ABR has two major frequency components, approximately 500 and 1000 Hz. By filtering, electrical activity that occurs above and below these frequencies is reduced in a further effort to focus on the response of interest. Even after differentially amplifying the signal and filtering around the frequencies of interest, the auditory evoked responses remain buried in a background of ongoing electrical activity of the brain. It is only through signal averaging of the response that these potentials can be effectively extracted.

Signal Averaging

The averaging of samples of EEG activity designed to enhance the response is called **signal averaging**.

Signal averaging is a technique that extracts a signal from a background of noise. The signal that we are pursuing here is a small electrical potential that is buried in a background of ongoing electrical activity of the brain. The purpose of signal averaging is to eliminate the unrelated activity and reveal the auditory evoked potential.

Signal averaging is a computer-based technique in which multiple samples of electrical activity are taken over a fixed time base. A key component of the signal averaging process is time-locking of the signal presentation to the recording of the response. That is, a stimulus is delivered to the earphone at the same moment in time that electrical activity is recorded from the electrodes. The sequence is

then repeated. For example, when recording an ABR, a click stimulus is presented, and the electrical activity is recorded for 10 msec following stimulus onset. Another click is then presented, and another 10 msec segment of electrical activity is recorded. This process is repeated 1000 to 2000 times.

The segment of time that is designated for electrical-activity recording is sometimes referred to as an *epoch*, after the Greek word meaning a period of time. Some prefer a more common term such as *window* to describe the time segments. The number of time segments that are signal averaged are often referred to as *samples* or *sweeps*.

During each sampling period, the EEG activity is preamplified, filtered, and amplified. It is then converted from its analog (A) form to digital (D) form by analog-to-digital (A/D) conversion. Essentially, the A/D converter is activated at the same instant that the stimulus is delivered to the earphone. The A/D converter samples the amplifier and converts the amplitude of the EEG activity at that moment in time to a number. The converter then dwells momentarily and samples again. This continues for the duration of the sample. The process is then repeated for a predetermined number of samples. In the case of the ABR, 1000 to 2000 samples are collected and then averaged.

The averaging process is critical to measuring evoked potentials. The concept is a fairly simple one. EEG activity that is not related to the auditory stimulus is being measured at the electrodes along with the EEG activity that is related to the stimulus. This activity is expressed in **microvolts** and will appear as either positive or negative voltage, centering around 0 μV. The unrelated activity is much larger in amplitude, but it is occurring randomly with regard to the stimulus onset. The related activity is much smaller, but it is time-locked to the stimulus. Therefore, over a large number of samples, the randomly occurring activity will be averaged out to near 0 μV. That is, if the activity is random, it is as likely to have a positive voltage as a negative voltage. Averaging enough samples of random activity will result in an average that is nearly zero. Alternatively, if a response is occurring to the presentation of the signal, that response will occur each time and will begin to add to itself with each successive sample. In this way, any true

Microvolts = μV

auditory activity that is time-locked to the stimulus will begin to emerge from the background of random EEG. Figure 9-3 shows the concept of signal averaging. Here, sequential ABRs are shown that were collected with progressively greater numbers of samples. As the number of samples increases, the noise is reduced, and the waveform becomes increasingly apparent.

The result of all of this signal averaging will be a waveform that reflects activity of auditory nervous system structures. The waveform has a series of identifiable positive and negative peaks that serve as landmarks for interpreting the normalcy of a response.

The Family of Auditory Evoked Potentials

For audiologic purposes, it is convenient to group the transient auditory evoked potentials into four categories, based loosely on the latency ranges over which the potentials are observed. The earliest is the ECoG, and it reflects activity of the most peripheral structures of the auditory system. The remaining three categories are often labeled as *early*, *middle*, and *late*. These responses

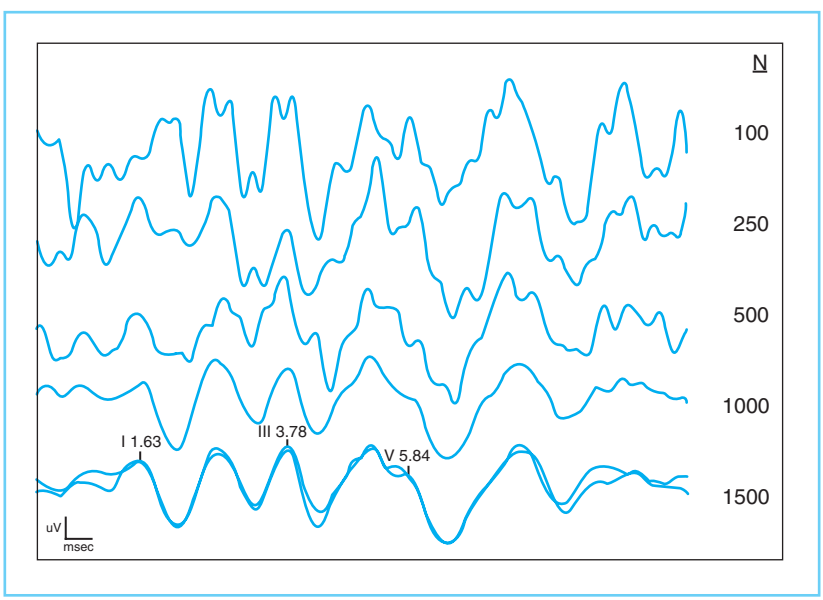


FIGURE 9-3 Auditory brainstem response from a 26-year-old female, elicited with an alternating click at 80 dBnHL, as a function of number of samples.

measure neural function at successively higher levels in the auditory nervous system.

Electrocochleogram

The ECoG is a response comprised mainly of the **compound action potential (AP)** that occurs at the **distal** portion of the VIIIth nerve (Figure 9-4). A click stimulus is used to elicit this response. The rapid onset of the click provides a stimulus that is sufficient to cause the fibers of the VIIIth nerve to fire in synchrony. This synchronous discharge of nerve fibers results in the AP. There are two other, smaller components of the ECoG. One is referred to as the cochlear microphonic (CM), which is a response from the cochlea that mimics the input stimulus. The other is the summating potential (SP), which is a direct current response that reflects the **envelope** of the input stimulus.

A **compound action potential** is the synchronous change in electrical potential of nerve or muscle tissue.

Distal means away from the center of origin.

In acoustics, an **envelope** is the representation of a waveform as a smooth curve joining the peaks of the oscillatory function.

The ECoG is best recorded as a *near-field* response, with an electrode close to the source. Unlike the ABR, MLR, LLR, and ASSR, which can readily be recorded as far-field responses with remote electrodes, it is more difficult to record the ECoG from surface electrodes. Thus, the best recordings of the ECoG are made from electrodes that are placed, invasively, through the tympanic membrane and onto the promontory of the temporal bone. An alternative arrangement is the use of an electrode in the ear canal placed near the tympanic membrane. Regardless, because of

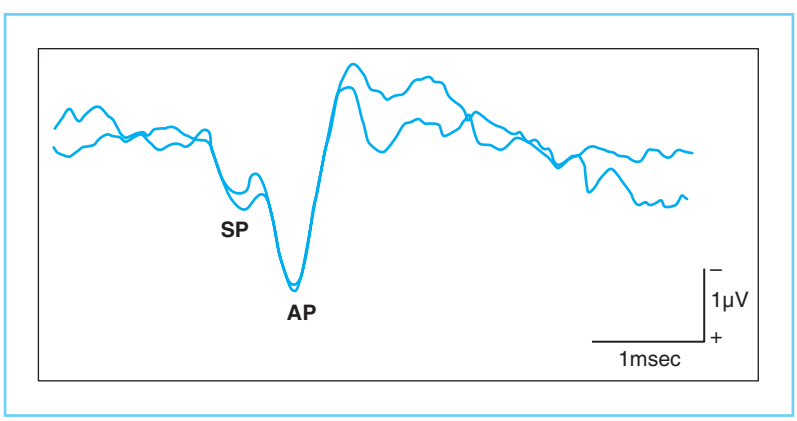


FIGURE 9-4 A normal electrocochleogram. (AP = action potential; SP = summating potential)

the relatively invasive nature of this technique and because the ECoG measures only the most peripheral function of the auditory system, its clinical use remains limited to a small number of specialized diagnostic applications. However, it has proven to be a very useful response for monitoring cochlear function in the operating room where electrode placement is simplified.

Auditory Brainstem Response

The ABR occurs within the first 10 msec following signal onset and consists of a series of five positive peaks or waves. An ABR waveform is shown in Figure 9-5. The ABR has properties that make it very useful clinically:

- the response can be recorded from surface electrodes;
- the waves are robust and can be recorded easily in patients with adequate hearing and normal auditory nervous system function;
- the response is immune to the influences of patient state, so that it can be recorded in patients who are sleeping, sedated, comatose, etc.;
- the latencies of the various waves are quite stable within and across people, so that they serve as a sensitive measure of brainstem integrity;
- the time intervals between peaks are prolonged by auditory disorders central to the cochlea, which makes the ABR useful for differentiating cochlear from retrocochlear sites of disorder; and
- the most robust component, wave V, can be observed at levels very close to behavioral thresholds so that it can be used effectively to estimate hearing sensitivity in infants, young children, and other difficult-to-test patients.

The ABR is generated by the auditory nerve and by structures in the auditory brainstem. Wave I originates in the distal, or peripheral, portion of the VIIIth nerve near the point at which the nerve fibers leave the cochlea. Wave II originates from the proximal portion of the nerve near the brainstem. Wave III has contribution from this proximal portion of the nerve and from the cochlear nucleus. Waves IV and V have contributions from the cochlear nucleus, superior olivary complex, and lateral lemniscus.

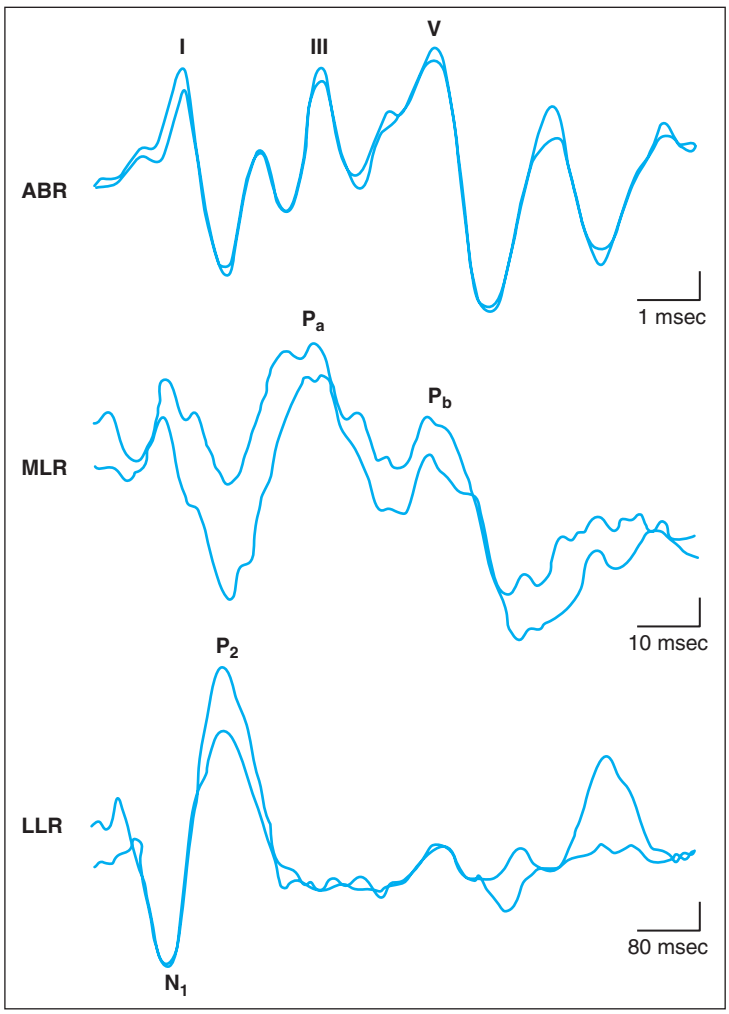


FIGURE 9-5 Normal auditory brainstem response (ABR), middle latency response (MLR), and late latency response (LLR) waveforms.

Middle Latency Response

The *middle latency response* (MLR) is characterized by two successive positive peaks, the first (Pa) at about 25 to 35 msec and the second (Pb) at about 40 to 60 msec following stimulus presentation. The MLR is probably generated by some combination of projections to the primary auditory cortex and the cortical area itself.

Although the MLR is the most difficult AEP to record in clinical patients, it is sometimes used diagnostically and as an aid to the identification of auditory processing disorder.

Late Latency Response

The *late latency response* (LLR) is characterized by a negative peak (N1) at a latency of about 90 msec followed by a positive peak (P2) at about 180 msec following stimulus presentation. This potential is greatly affected by subject state. It is best recorded when the patient is awake and carefully attending to the sounds being presented. There is an important developmental effect on the LLR during the first 8 to 10 years of age. In older children or adults, however, it is robust and relatively easy to record. In children or adults with relatively normal hearing sensitivity, abnormality or absence of the LLR is associated with auditory processing disorder.

Auditory Steady-State Response

The auditory steady-state response (ASSR) is an auditory evoked potential, elicited with modulated tones that can be used to predict hearing sensitivity in patients of all ages (Dimitrijevic et al., 2002; Rance & Rickards, 2002). The response itself is an evoked neural potential that follows the envelope of a complex stimulus. It is evoked by the periodic modulation of a tone. The neural response is a brain potential that closely follows the time course of the modulation. The response can be detected objectively at intensity levels close to behavioral threshold. The ASSR can yield a clinically acceptable, frequency-specific prediction of behavioral thresholds.

The ASSR is elicited by a tone. In clinical applications, the frequencies of 500, 1000, 2000, and 4000 Hz are commonly used. The pure tone is either modulated in the amplitude domain or modulated in both the amplitude and frequency domains; you might think of amplitude modulation as turning the tone on and off periodically and frequency modulation as warbling it. The concept of modulation is shown in Figure 9-6. Electrodes are placed on the scalp at locations typical for the recording of other auditory evoked potentials. Brain electrical activity is preamplified, filtered, sampled, and then subjected to automated analysis.

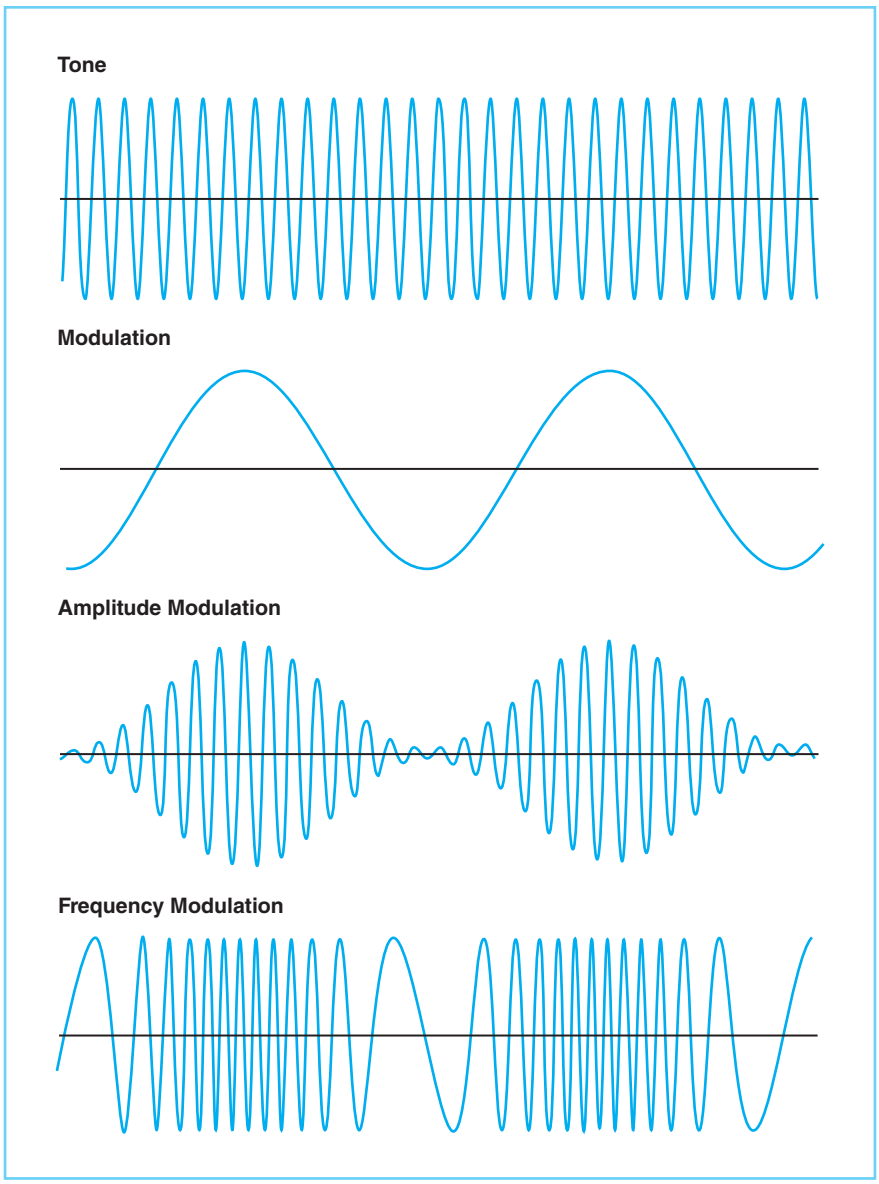


FIGURE 9-6 Schematic representation of modulation. A carrier tone is modulated in both the amplitude and frequency domain at a rate determined by the modulation frequency.

The frequency of interest in the brain waves is that corresponding to the modulation rate. For example, when a tone of any frequency is modulated periodically at a rate of 90/s, the 90 Hz component of the brain electrical activity is measured. Measurement is of the

amplitude or variability of the phase of the EEG component to see if it is "following" the modulation envelope. When the modulated tone is at an intensity above threshold, the brain activity at the modulation rate is enhanced and time-locked to the modulation. If the tone is below a patient's threshold, the brain activity is not enhanced and is random in relation to the modulation.

The ASSR has several properties that make it useful clinically:

- If the modulation rate is high enough (over 60/s), the ASSR response is present and readily measurable in newborns, sleeping infants, and sedated babies.
- The stimulus is a tone that is only slightly distorted by modulation, so it can be useful in predicting an audiogram.
- The tone can be presented at high intensity levels, which makes the ASSR useful in predicting hearing of patients with severe and profound hearing loss.
- The response is periodic in nature and can therefore be objectively detected by the computer.

Taken as a whole, this family of evoked potentials is quite versatile. The ABR, ASSR, and LLR can be used to estimate auditory sensitivity independently of behavioral response. In addition, ABR can be used to differentiate cochlear from retrocochlear site of disorder. Finally, the array of ABR, MLR, and LLR is an effective tool for exploring auditory processing disorders.

Clinical Applications

Evoked potentials are used for several purposes in evaluating the auditory system. Because early evoked potentials can be recorded without regard to subject state of consciousness, they have become an invaluable part of pediatric assessment. The ABR is now used routinely to screen the hearing of babies who are at risk for hearing loss. The ABR and ASSR are used to assess the degree of hearing loss in those who have failed a screening or are otherwise at risk for hearing loss. The ABR also provides a window for viewing the function of the brain's response to sound, which has proven to be useful in the diagnostic assessment of neurologic function. Finally, auditory evoked potentials can be recorded during surgery to provide a functional

Audiologist Profile

Susan H. Morgan, M.Ed.



Where I Live: Falls Church, Virginia

Where I Work: Georgetown University Hospital, Washington, D.C. Georgetown University Hospital is a 609-bed hospital founded in 1898 to promote health through education, research, and patient care. Georgetown is one of eight nonprofit hospitals in the Baltimore/Washington area operated by MedStar Health. Audiology is a division of the Department of Otolaryngology, Head & Neck Surgery. The division is staffed with five faculty audiologists, two audiology students, and two newborn hearing screening technicians. We provide diagnostic and rehabilitative services to outpatients and inpatients of all ages.

What I Do: I manage the Division of Audiology. Most of my time is spent in direct patient care. Additionally, I teach Georgetown medical students and otolaryngology residents, as well as supervise audiology doctoral students. I am also responsible for the overall management and performance of the Division.

Why Audiology? Audiology has been a challenging and rewarding career for me. I enjoy viewing each patient contact as a puzzle to be solved. There is much to be gained from investing your time and energy into a profession that improves the quality of life of others.

measure of structural changes that occur during VIIIth nerve tumor removal.

Prediction of Hearing Sensitivity

The audiologist is faced with two challenges that often require the use of auditory evoked potentials to predict hearing sensitivity. The main challenge is trying to measure the hearing sensitivity of infants or young children who cannot or will not cooperate enough to permit assessment by behavioral techniques. The other challenge is assessing hearing sensitivity in older individuals who are feigning or exaggerating some degree of hearing impairment. Regardless, the goal of testing is to obtain an electrophysiologic prediction of both degree and slope of hearing loss.

The process in hearing-sensitivity prediction is simply determining the lowest intensity level at which an auditory evoked potential can be identified. Click or tone-burst stimuli are presented at an intensity level that evokes a response. The level is then lowered, and the response is tracked until an intensity is reached at which the response is no longer observable (Figure 9-7). This level corresponds closely to behavioral threshold.

Evaluation of infants and young children must be carried out in natural sleep or with sedation. Thus, testing is best accomplished with use of the ABR or ASSR, which are not affected by patient state. There are several approaches that can used to predict an audiogram. The goal is to predict both the degree and slope of the hearing loss. Audiologists will often use click-evoked ABR thresholds to estimate higher frequency hearing in the 2000 to 4000 Hz region of the audiogram and tone-burst ABR to estimate lower frequency hearing. For example, once an ABR click threshold has been established, an ABR tone-burst threshold at 500 or 1000 Hz can be obtained. If time permits, of course, tone-burst ABR thresholds can be obtained across the frequency range. The accompanying Clinical Note describes a clinical technique for rapid estimation of thresholds with the ABR.

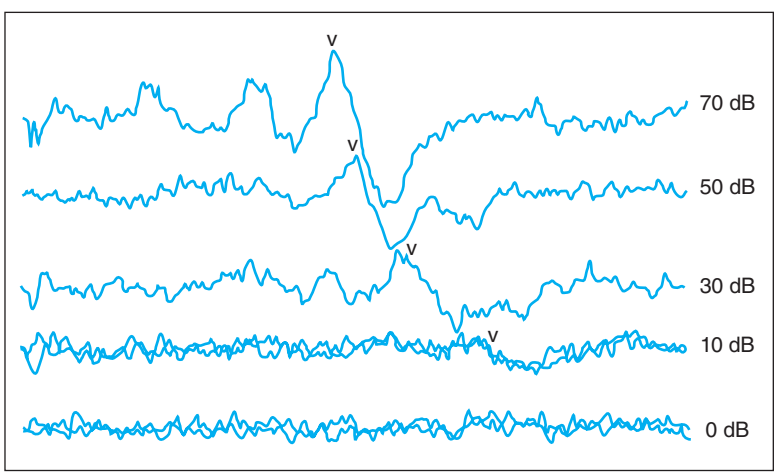


FIGURE 9-7 The prediction of hearing sensitivity with the ABR, showing the tracking of wave V as click intensity level is reduced.

Clinical Note

A Rapid Approach to Threshold Prediction

When testing young children, the challenge is simple: get as much information as you can as quickly as possible before the baby wakes up from natural sleep or before the sedation wears off. Many a clinician has been caught with only partial ABR information about one ear when a child awakened. No one wants to repeat the pediatric ABR procedure, especially if sedation is involved. Clinical techniques designed for rapid assessment are important in this population.

One technique that works particularly well is the binaural approach to ABR threshold prediction. The idea here is simple. If you establish an ABR threshold with clicks presented to both ears and the baby wakes up, at least you know the hearing of the better-hearing ear. For example, suppose that a child has no cochlear function in the left ear, but the right ear is normal. The binaural ABR threshold search will yield a prediction of normal hearing because of responses from the good right ear. If the baby wakes up at that point, you at least know how the better-hearing ear is functioning. If you had the misfortune of testing the left ear first, you would still probably be searching for a threshold when the baby awakened, and you would have learned little about the baby's overall hearing ability.

Once you have established the binaural threshold, the next step is to test each ear independently at 10 to 20 dB above the binaural threshold. If the waveforms are present and symmetric, you are finished testing. If responses are obtained in only

continues

Clinical Note

continued

one ear, then the binaural threshold reflects that ear, and you can spend the rest of your time pursuing threshold in the other ear.

An example of the binaural approach is shown in Figure 9-8. You can learn a lot about a child's hearing in a short period of time using this approach.

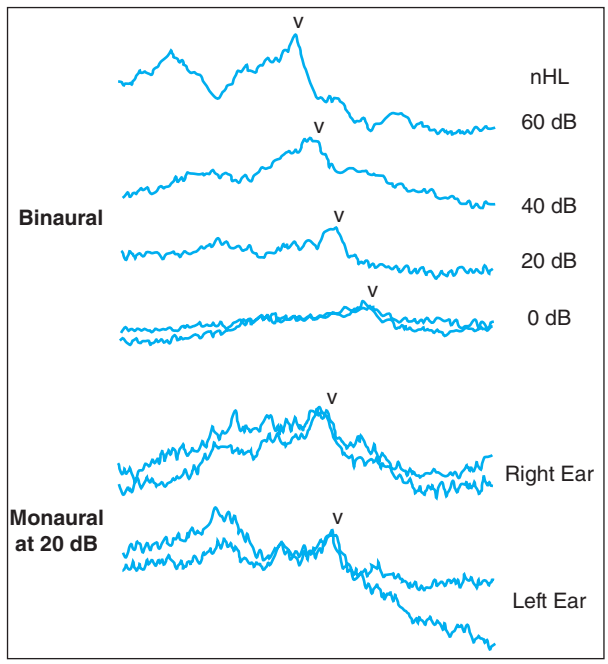


FIGURE 9-8 An example of the binaural approach to ABR prediction of hearing sensitivity.

Another approach to audiogram estimation in infants and young children is the use of ASSR. With this technique, tonal thresholds can be estimated across the audiometric frequencies. An example of threshold estimation with ASSR in an infant is shown in Figure 9-9. At each frequency, an ASSR threshold is established by determining the lowest level at which a response can be detected. A correction

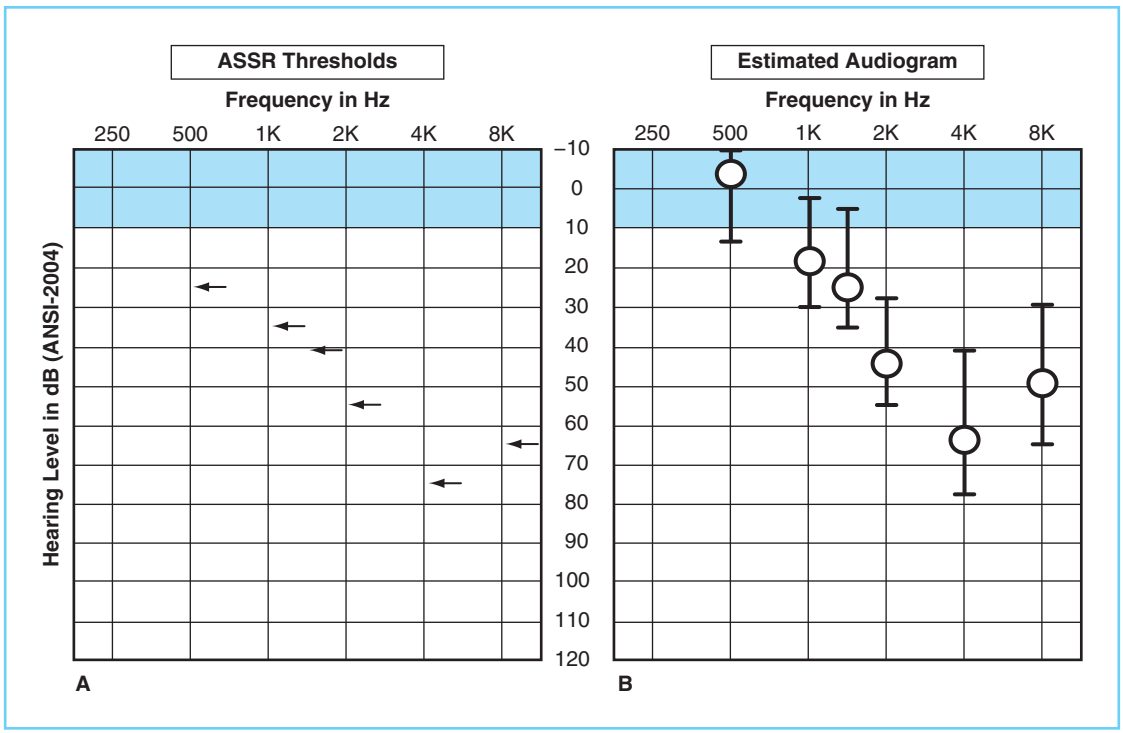


FIGURE 9-9 Auditory steady-state response (ASSR) threshold prediction on the right ear of a 3-month-old infant. The left audiogram (A) shows the lowest level at which ASSR responses are measured: the right audiogram (B) shows the estimated pure-tone audiogram and the range in which each threshold estimate is likely to fall.

factor is then applied to predict the audiometric threshold. ASSR may provide a more accurate estimation of the configuration of a hearing loss than tone-burst ABR because of the nature of the signal used. This is because a modulated tone usually has a narrower spectrum than a tone-burst, thus providing a more frequency-specific audiometric prediction.

Evaluation of older patients is probably best accomplished by use of the late latency response to tonal stimuli. A typical strategy is to determine LLR thresholds to tonal stimuli across the audiometric frequency range. A response is usually identified at some suprathreshold level and then tracked as the intensity level is lowered until the response can no longer be identified (Figure 9-10). This level is considered threshold and corresponds well with behavioral thresholds. LLR testing is relatively time

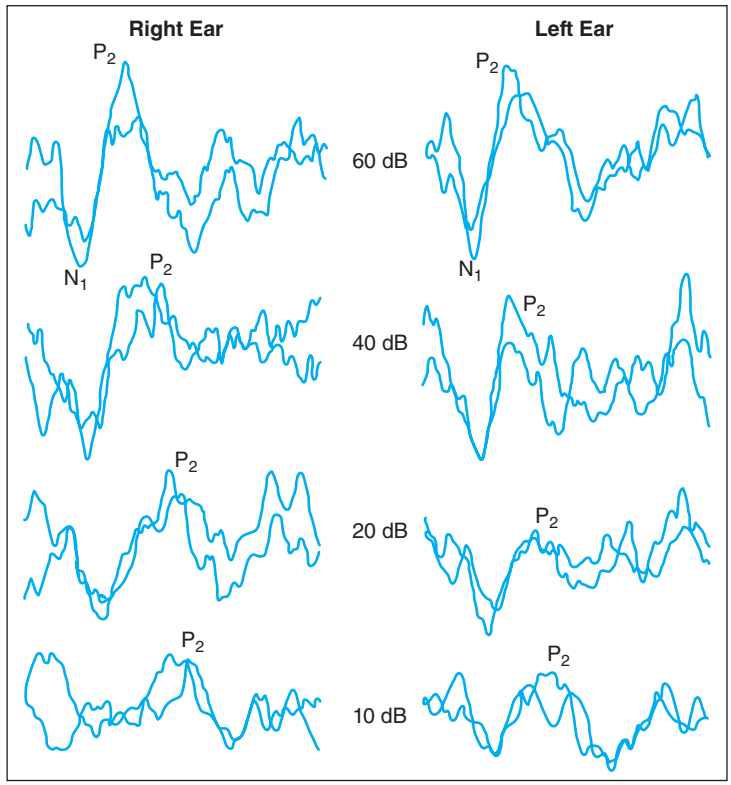


FIGURE 9-10 The prediction of hearing sensitivity with the late latency auditory evoked potential, showing the tracking of the N1/P2 component as intensity of a 500 Hz tone is reduced.

consuming, and some clinicians opt for using a combined approach wherein click ABR thresholds are used to predict high-frequency hearing and ASSR or LLR thresholds to predict low-frequency hearing.

Infant Hearing Screening

The goal of infant hearing screening is to categorize auditory function as either normal or abnormal in order to identify infants who have significant permanent hearing loss. By screening hearing, those with normal auditory function are eliminated from further consideration, and those with a suspicion of hearing loss are referred for clinical testing.

The ABR is the evoked-potential method of choice for infant hearing screening (for a review, see Sininger, 2007). Surface electrodes are used to record the ABR and can easily be affixed to the infant's scalp. Because of its immunity to subject state, the ABR can be recorded reliably in sleeping neonates.

A typical screening strategy is to present click stimuli at a fixed intensity level, usually 30 to 40 dB, and determine whether a reliable response can be recorded. If an ABR is present, the child is likely to have normal or nearly normal hearing sensitivity in the 1000 to 4000 Hz frequency region of the audiogram. The underlying assumption here is that such hearing is sufficient for speech and oral language development and that children who pass the screening are at low risk for developing communication disorders due to hearing loss. If an ABR is absent, it is concluded that the child is at risk for significant sensorineural hearing loss and further audiologic assessment is warranted.

Conventional ABR testing of infants has been largely replaced by *automated* ABR testing. The driving force behind the development of automated testing is that the number of babies who require screening far exceeds the highly skilled personnel available to carry out conventional ABR measures. One commonly used automated screener is designed to present click stimuli at fixed intensity levels, record ABR tracings, and compare the recorded tracings to a template that represents expected results in infants. The system was designed with several fail-safe mechanisms that halt testing in the presence of excessive environmental or physiologic noise. When all conditions are favorable, the device proceeds with testing until it reaches a decision regarding the presence of an ABR. It then alerts the screener as to whether the infant has passed or needs to be referred for additional testing. This automated system has proven to be a valid and reliable way to screen the hearing of infants.

In the early days of newborn screening, ABR testing was restricted largely to those infants in the **intensive care nursery (ICN)**, where the prevalence of auditory disorder is much higher than in the newborn population in general. Although children in the ICN are at increased risk for hearing loss, estimates suggest that risk factors alone identify only about one half of all children with significant sensorineural hearing loss. As a result, screening is now carried

The hospital unit designed to take care of newborns needing special care is the **intensive care nursery**.

out on all newborns in many countries, regardless of whether the infant is in the regular care nursery or the ICN. Automated ABR strategies are an integral part of the comprehensive screening process and are often used in conjunction with otoacoustic-emissions screening for identification purposes.

Two variables unrelated to significant sensorineural hearing loss can interfere with correct identification of these infants. One is the presence of middle-ear disorder that is causing conductive hearing loss. If the loss is of a sufficient magnitude, the infant may fail the screening and be referred for additional testing. The other is **neuromaturational delay** or disorder that results in an abnormal ABR. That is, some children's brainstem function has not matured to a point, or is disordered to an extent, that it cannot be measured adequately to provide an estimate of hearing sensitivity. These children will also fail the screening and be referred for additional testing. Although their problems may be important, they are considered false-alarms from the perspective of identifying significant sensorineural hearing loss. In these cases, follow-up services are important to identify normal cochlear function as soon as possible following discharge from the hospital.

Neuromaturational delay occurs when a nervous system function has not developed as rapidly as normal.

The opposite problem, failure to identify a child with significant hearing loss, or false negative, is seldom an issue with ABR testing. If it does occur, it is usually in children who have reverse-slope hearing loss, wherein low-frequency hearing is poorer than high-frequency hearing. The click stimulus used in ABR measurement is effective in assessing higher audiometric frequencies. Thus, an infant with normal high-frequency hearing and abnormal low-frequency hearing would likely pass the screening, and the loss would go undetected. Such losses are rare and are considered to have minimal impact on communication development. Thus, the failure to identify these children, although important, is a small cost in comparison to the value of identifying those with significant high-frequency sensorineural hearing loss.

Diagnostic Applications

One of the most important applications of evoked potentials is in the area of diagnosis of disorders of the peripheral and central auditory nervous system (for a review, see Musiek et al., 2007).

In fact, at one time in the late 1970s and early 1980s, the ABR was probably the most sensitive diagnostic tool available for identifying the presence of VIIIth nerve tumors. However, imaging and radiographic assessment of structural changes has advanced to a point where functional measures such as the ABR have lost some of their sensitivity and, thus, importance. That is, imaging studies have permitted the visualization of ever smaller lesions in the brain. Sometimes the lesions are of a small enough size or are in such a location that they result in little or no measurable functional consequence. Thus, measures of function, such as the ABR, may not detect their presence. Although this trend has been occurring over the past several decades, evoked potentials are still used for diagnostic testing, often for screening purposes.

The ABR is a sensitive indicator of functional disorders of the VIIIth nerve and lower auditory brainstem. It is often the first test of choice if such a disorder is suspected. For example, a cochleovestibular schwannoma is a tumor that develops on the VIIIth nerve. A patient with a cochleovestibular schwannoma will often complain of tinnitus, hearing loss, or both, in the ear with the tumor. Based on audiometric data and a physical examination, further testing to rule out this tumor may be pursued. It is likely that the physician who is making the diagnosis will request a magnetic resonance imaging (MRI) scan of the brain, which is sensitive in identifying these space-occupying lesions. However, depending on the level of suspicion of a tumor, ABR testing may be carried out as a screening tool to decide on further imaging studies or as an adjunct to these studies. These basic strategies also apply to other types of disorders that affect the VIIIth nerve or auditory brainstem, such as multiple sclerosis or brainstem neoplasms.

The ABR component waves, especially waves I, III, and V are easily recordable and are very reliable in terms of their latency. For example, depending on the equipment and recording parameters, we expect to see a wave I at about 2 msec following signal presentation, a wave III at 4 msec, and a wave V at 6 msec. Although these absolute numbers will vary across clinics, the latencies are quite stable across individuals. The I-V interpeak interval in most adults is approximately 4 msec, and the standard deviation of this interval is about 0.2 msec. Thus, 95% of the adult population

have I-V interpeak intervals of 4.4 or less. If the I-V interval exceeds this amount, it can be considered abnormal.

These latency measures are amazingly consistent across the population. In newborns, they are prolonged compared to adult values, but in a reasonably predictable way. Once a child reaches 18 months, we expect normal adult latency values that continue throughout life. Because of the consistency of latencies within an individual over time and across individuals in the population, we can rely confidently on assessment of latency as an indicator of integrity of the VIIIth nerve and auditory brainstem. The decision about whether an ABR is normal is usually based on the following considerations:

- interaural difference in I-V interpeak interval,
- I-V interpeak interval,
- interaural difference in wave V latency,
- absolute latency of wave V,
- interaural differences in V/I amplitude ratio,
- V/I amplitude ratio,
- selective loss of late waves, and
- grossly degraded waveform **morphology**.

Morphology is the qualitative description of an auditory evoked potential, related to the replicability of the response and the ease with which component peaks can be identified.

Again, the ABR is used to assess integrity of the VIIIth nerve and auditory brainstem in patients who are suspected of having acoustic tumor or other neurologic disorders. In interpreting ABRs, we exploit the consistency of the response across individuals and ask whether our measured latencies compare well between ears and with the population in general. With this strategy, the ABR has become a useful adjunct in diagnosis of neurological disease.

The MLR and LLR are less useful than the ABR in identifying discrete lesions. Sometimes the influence of an acoustic tumor that affects the ABR will also affect the MLR. Also, sometimes a cerebral vascular accident or other type of discrete insult to the brain will result in an abnormality in the MLR. However, these measures have tended to be more useful as indicators of generalized disorders of auditory processing ability than in the diagnosis of a specific disease process. For example, MLRs and LLRs have been found to be abnormal in patients with multiple sclerosis (Stach & Hudson, 1990) and Parkinson's disease. Although neither response has proven to be

particularly useful in helping to diagnose these disorders, the fact that MLR and LLR abnormalities occur has proven to be valuable in describing the resultant auditory disorders. That is, patients with neurologic disorders often have auditory complaints that cannot be measured on an audiogram or with simple speech audiometric measures. The MLR and LLR are sometimes helpful in quantifying such auditory complaints.

Surgical Monitoring

Auditory evoked potentials are also useful in monitoring the function of the cochlea and VIIIth nerve during surgical removal of a tumor on or near the nerve (for a review, see Martin & Yong-bing Shi, 2007). Surgery for removal of acoustic tumors often results in permanent loss of hearing due to the need to remove the cochlea to reach the tumor. If the tumor is small enough, however, a different surgical approach can be used that may spare hearing in that ear. During this latter type of surgery, monitoring of auditory function can be very helpful to the surgeon.

During surgical removal of an acoustic tumor or other mass that impinges on the VIIIth nerve, hearing is quite vulnerable. One potential problem is that the blood supply to the cochlea can be interrupted. Another is that the tumor can be intertwined with the nerve, resulting in damage to or severing of the nerve during tumor removal. Sometimes, however, hearing can be spared by carefully monitoring the nerve during the course of such a surgery.

Auditory evoked potential monitoring involves measurement of the compound action potential (AP) of the VIIIth nerve. This is the major component of the ECoG and corresponds to wave I of the ABR. The AP is usually measured using one of two approaches, ECoG or cochlear nerve action potential (CNAP) measures. Both approaches measure essentially the same function. The ECoG approach uses a needle electrode that is placed on the promontory outside of the cochlea. The CNAP approach uses a ball electrode that is placed directly on the VIIIth nerve. In either case, click stimuli are presented to the ear throughout surgery, and the latency and amplitude of the AP are assessed. Because the recording electrode is so close to the source of the potential, especially in the case of CNAP measurement, the function of the cochlea and VIIIth nerve can be assessed

rapidly, providing valuable feedback to the surgeon about the effects of tumor manipulation or other surgical actions.

SUMMARY

- An auditory evoked potential is a waveform that reflects the electrophysiologic function of a certain portion of the central auditory nervous system in response to sound.
- For audiologic purposes, it is convenient to group the AEPs into categories based loosely on the latency ranges over which the potentials are observed.
- The earliest of the evoked potentials, occurring within the first 5 msec following signal presentation, is referred to as an electrocochleogram (ECoG) and reflects activity of the cochlea and VIIIth nerve.
- The most commonly used evoked potential is referred to as the auditory brainstem response (ABR) and occurs within the first 10 msec following signal onset. The ABR reflects neural activity from the VIIIth nerve to the midbrain.
- The middle latency response (MLR) occurs within the first 50 msec following signal onset and reflects activity at or near the auditory cortex.
- The late latency response (LLR) occurs within the first 250 msec following signal onset and reflects activity of the primary-auditory and association areas of the cerebral cortex.
- The auditory steady-state response (ASSR) is measured by evaluating the ongoing activity of the brain in response to a modulation, or change, in an ongoing stimulus. The ASSR reflects activity from different portions of the brain, depending on the modulation rate used.
- One of the most important applications of auditory evoked potentials is the prediction of hearing sensitivity in infants and young children.
- The ABR is the evoked-potential method of choice for infant hearing screening.
- Another important application of evoked potentials is the diagnosis of disorders of the peripheral and central auditory nervous system.

- Auditory evoked potentials are also useful in monitoring the function of the cochlea and VIIIth nerve during surgical removal of a tumor on or near the nerve.

OTOACOUSTIC EMISSIONS

We tend to think of sensory systems as somewhat passive receivers of information that detect and process incoming signals and send corresponding neural signals to the cortex. We know that sound impinges on the tympanic membrane, setting the middle-ear ossicles in motion. The stapes footplate, in turn, creates a disturbance of the fluid in the scala vestibuli, resulting in a traveling wave of motion that displaces the basilar membrane maximally at a point corresponding to the frequency of the signal. The active processes of the outer hair cells are stimulated, translating the broadly tuned traveling wave into a narrowly tuned potentiation of the inner hair cells. Inner hair cells, in turn, create neural impulses that travel through the VIIIth nerve and beyond.

The active processes of the outer hair cells make this sensory system somewhat more complicated than a passive receiver of information. These outer hair cells are stimulated in a manner that causes them to act on the signal that stimulates them. One by-product of that action is the production of a sound, which travels back out of the cochlea, through the middle ear, and into the ear canal. This sound is referred to as an otoacoustic emission or OAE (Kemp, 1978).

Otoacoustic emissions are low-intensity sounds that are generated by the cochlea and emanate into the middle ear and ear canal. They are frequency specific in that emissions of a given frequency arise from the place on the cochlea's basilar membrane responsible for processing that frequency. OAEs are probably not essential to hearing, but rather are the by-product of active processing by the outer hair cell system. Of clinical interest is that OAEs are present when outer hair cells are healthy and absent when outer hair cells are damaged. Thus, OAE measures have tremendous potential for revealing, with exquisite sensitivity, the integrity of cochlear function.

Types of Otoacoustic Emissions

There are two broad categories of otoacoustic emissions, spontaneous OAEs (SOAEs) and evoked OAEs (EOAEs) (for an overview, see Lonsbury-Martin et al., 1993; Robinette & Glattke, 1997; Hall, 2000).

Spontaneous Otoacoustic Emissions

Spontaneous OAEs are narrow-band signals that occur in the ear canal without the introduction of an eliciting signal. Spontaneous emissions are present in 50 to 70% of all normal-hearing ears and absent in all ears at frequencies where sensorineural hearing loss exceeds approximately 30 dB (Penner et al., 1993). It appears that spontaneous OAEs originate from outer hair cells corresponding to that portion of the basilar membrane tuned to their frequency.

A sensitive, low-noise microphone housed in a probe is used to record spontaneous OAEs. The probe is secured into the external auditory meatus with some type of flexible cuff. Signals detected by the microphone are routed to a spectrum analyzer, which is a device that provides real-time frequency analysis of the signal. Usually the frequency range of interest is swept several times, and the results are signal averaged to reduce background noise. Spontaneous OAEs, when they occur, appear as peaks of energy along the frequency spectrum.

Because spontaneous OAEs are absent in many ears with normal hearing, clinical applications have not been forthcoming. Efforts to relate SOAEs to tinnitus have revealed a relationship in some, but not many, subjects who have both. Other clinical applications await development. Evoked OAEs, in contrast, enjoy widespread clinical use.

Evoked Otoacoustic Emissions

Evoked OAEs occur during and after the presentation of a stimulus. That is, an EOAE is elicited by a stimulus. There are several classes of evoked OAEs, two of which have proven to be useful clinically, transient-evoked otoacoustic emissions (TEOAE) and distortion-product otoacoustic emissions (DPOAE).

TEOAEs are elicited by a transient signal or click. A schematic representation of the instrumentation used to elicit a TEOAE is shown in

Figure 9-11. A probe is used to deliver the click signal and to record the response. The probe is secured into the external auditory meatus with some type of flexible cuff. Series of click stimuli are presented, usually at an intensity level of about 80–85 dB SPL. Output from the microphone is signal averaged, usually within a time window of 20 msec. In a typical clinical paradigm, alternating samples of the emission are placed into separate memory locations, so that the final result includes two traces of the response for comparison purposes.

TEOAEs occur about 4 msec following stimulus presentation and continue for about 10 msec. An example of a TEOAE is shown in Figure 9-12. Depicted here are two replications of

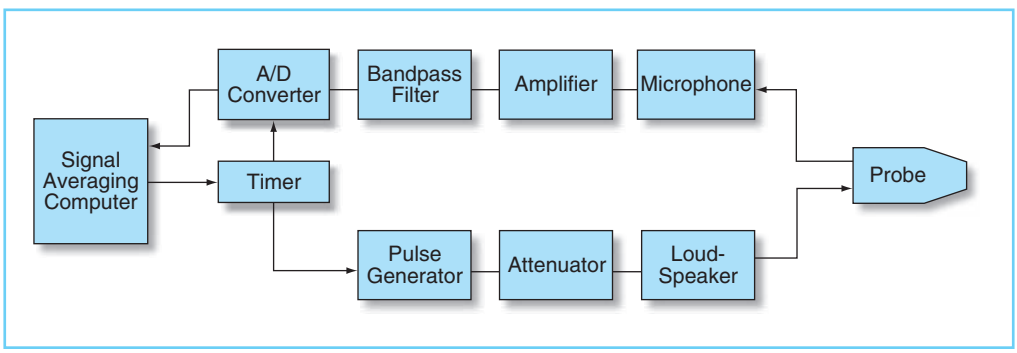


FIGURE 9-11 Schematic representation of the instrumentation used to elicit and measure transient-evoked OAEs.

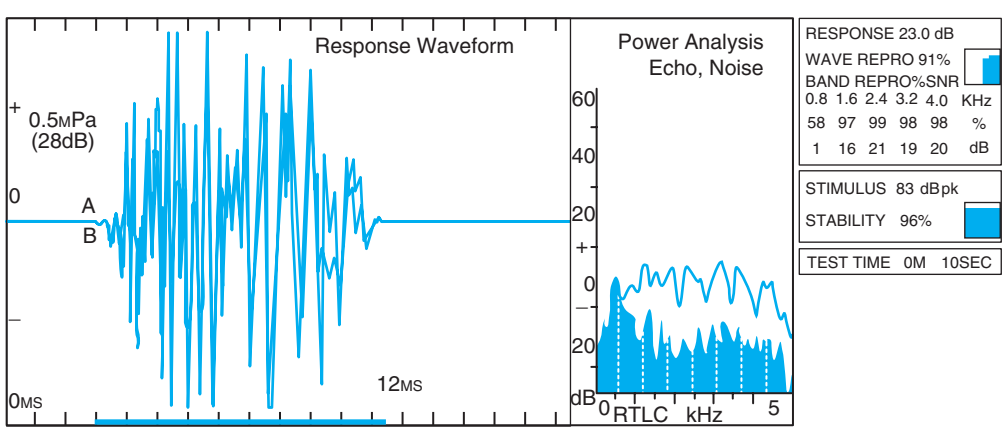


FIGURE 9-12 A transient-evoked OAE.

the signal-averaged emission, designated as A and B. Because a click is a broad-spectrum signal, the response is similarly broad in spectrum. By convention, these waveforms are subjected to spectral analysis, the results of which are often shown in a graph depicting the amplitude-versus-frequency components of the emission. Also by convention, an estimate of the background noise is made by subtracting waveform A from waveform B, and a spectral analysis of the resultant waveform is plotted on the same graph. Another important aspect of TEOAE analysis is the reproducibility of the response. An estimate is made of how similar A is to B by correlating the two waveforms. This similarity or reproducibility is then expressed as a percentage, with 100% being identical. If the magnitude of the emission exceeds the magnitude of the noise and if the reproducibility of the emission exceeds a predetermined level, then the emission is said to be present. If an emission is present, it is likely that the outer hair cells are functioning in the frequency region of the emission.

Distortion-product OAEs occur as a result of nonlinear processes in the cochlea. When two tones are presented to the cochlea, distortion occurs in the form of other tones that are not present in the two-tone eliciting signals. These distortions are combination tones that are related to the eliciting tones in a predictable mathematical way. The two tones used to elicit the DPOAE are, by convention, designated f_1 and f_2. The most robust distortion product occurs at the frequency represented by the equation $2f_1 - f_2$. A schematic representation of the instrumentation used to elicit a DPOAE is shown in Figure 9-13. As with TEOAEs, a probe is used to deliver the tone pairs and to record the response. The probe is secured into the external auditory meatus with a flexible cuff. Pairs of tones are presented across the frequency range to elicit distortion products from approximately 1000 to 6000 Hz. The tone pairs that are presented are at a fixed frequency and intensity relationship. Typically, the pairs are presented from high frequency to low frequency. As each pair is presented, measurements are made at the $2f_1 - f_2$ frequency to determine the amplitude of the DPOAE and also at a nearby frequency to provide an estimate of the noise floor at that moment in time. An example of a DPOAE is shown in Figure 9-14.

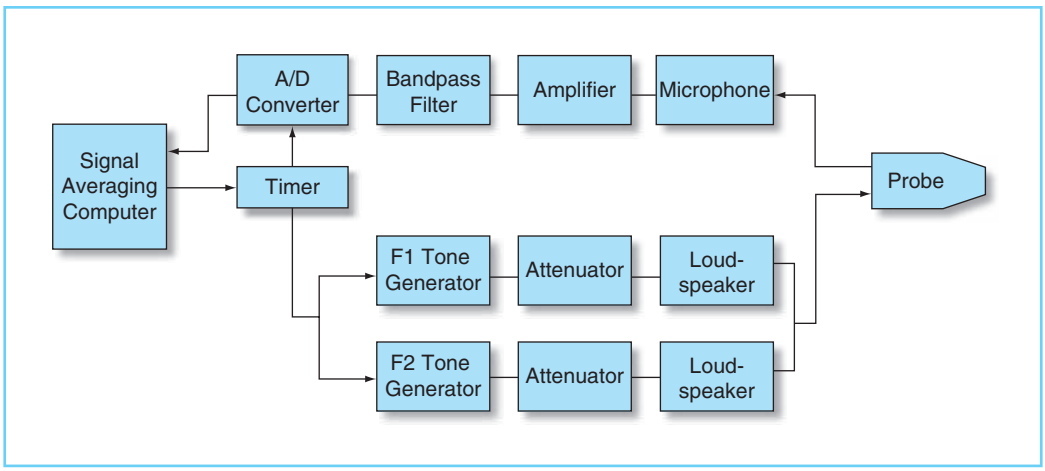


FIGURE 9-13 Schematic representation of the instrumentation used to elicit and measure distortion-product OAEs.

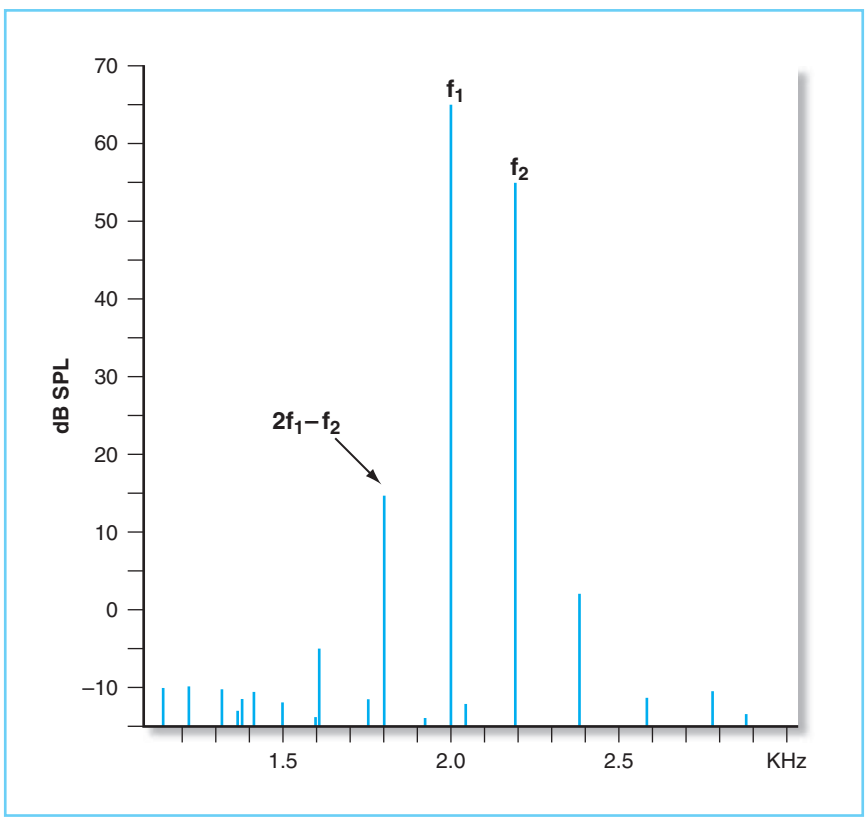


FIGURE 9-14 A distortion-product OAE.

DPOAEs are typically depicted as the amplitude of the distortion product ($2f_1 - f_2$) as a function of frequency of the f_2 tone (Figure 9-15). The shaded area in this figure represents the estimate of background noise. If the amplitude exceeds the background noise, the emission is said to be present. If an emission is present, it is likely that the outer hair cells are functioning in the frequency region of the f_2 tone.

Results of TEOAE and DPOAE testing provide a measure of the integrity of outer hair cell function. Both approaches have been successfully applied clinically as objective indicators of cochlear function. TEOAEs are likely to be used when rapid assessment is necessary, such as in infant hearing screening. DPOAEs are also used in infant testing and when frequency information is important, such as during the monitoring of cochlear function.

Relation to Hearing Sensitivity

Assuming normal outer- and middle-ear function, OAEs can be consistently recorded in patients with normal hearing sensitivity. Once outer hair cells of the cochlea sustain damage, OAEs begin to be affected. A rule of thumb for comparing OAEs to hearing thresholds is that OAEs are present if thresholds are better than

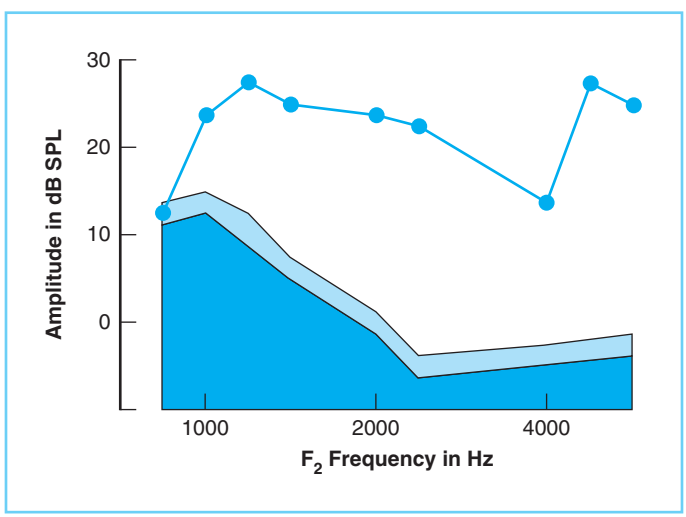


FIGURE 9-15 DPOAE amplitude as a function of frequency of the f_2 tone.

about 30 dB HL and absent if thresholds are poorer than 30 dB HL. Although this varies among individuals, it holds generally enough to be a useful clinical guide (Probst & Harris, 1993).

OAEs are present if hearing thresholds are normal and disappear as hearing thresholds become poorer. As a result, OAEs tend to be used for screening of cochlear function rather than for prediction of degree of hearing sensitivity. Efforts to predict degree of loss have probably been most successful with use of DPOAEs (Gorga et al., 1997). In general, though, they tell us more about the degree of hearing loss that a patient *does not have* than about the degree of loss that a patient has. For example, if a patient has a DPOAE amplitude of 10 dB SPL at 1000 Hz, it is likely that hearing sensitivity loss at that frequency does not exceed 20 dB HL. Although this information is quite useful, the absence of an OAE reveals little about degree of loss. Recent efforts to harness OAE technology to provide more information about hearing loss prediction have been encouraging, particularly with the use of DPOAEs. If patients have normal hearing or mild sensitivity loss, thresholds can be predicted with a fair degree of accuracy. However, presently OAEs are not generally applied as threshold tests.

Clinical Applications

OAEs are useful in at least four clinical areas:

1. infant screening,
2. pediatric assessment,
3. cochlear function monitoring, and
4. certain diagnostic cases.

Infant Screening

OAEs are used most effectively as a screening measure and have been used in infant screening programs (Maxon et al., 1995). Several test characteristics make OAEs particularly useful for this clinical application. First, the very nature of OAEs makes the technique an excellent one for screening. When present, OAEs provide an indicator of normal cochlear function or, at most, a mild sensitivity loss. When absent, OAEs provide an indicator that cochlear function is not normal, although degree of abnormality cannot be assessed. Second, measurement techniques have been simplified

to an extent that screening can be carried out simply and rapidly. Third, OAEs are not affected by neuromaturation of the central auditory nervous system and can be obtained in newborns regardless of gestational age.

There are two drawbacks to OAE use in infant screening. One is that outer- and middle-ear disorders often preclude measurement of an OAE. Thus, if an infant's ear canal is obstructed or if the infant has middle-ear effusion, OAEs will not be recorded even though cochlear function may be normal. This results in a large number of false-positive errors, in that children who have normal hearing fail the screening. Perhaps an even greater drawback is one related to false-negative errors, or those infants who have significant sensorineural disorder but who pass the OAE screening. These are infants who have significant permanent hearing loss due to inner hair cell disorder or auditory neuropathy. In both cases, outer hair cells may be functioning, producing OAEs, even though the child has a significant loss in hearing sensitivity. For these reasons, OAE screening is usually done in combination with ABR screening rather than as the only screening technique.

Pediatric Assessment

One of the most important applications of OAEs is as an additional part of the pediatric audiologic assessment battery. Prior to the availability of OAE measures, the audiologist relied on behavioral assessment and immittance audiometry in the initial pediatric hearing consultation. In a cooperative young child, behavioral measures could be obtained that provided adequate audiometric information. When these results were corroborated by SPAR testing, assessment was completed without the need for additional testing. Unfortunately, many young children are not altogether cooperative, and failure to establish audiometric levels by behavioral means usually led to AEP testing that required sedation. OAE measures have reduced the need for such an approach.

In typical clinical settings, many of the children who undergo audiometric assessment have normal hearing sensitivity. They are usually referred for assessment due to some risk factor or concerns about speech and language development. As audiologists,

we are interested in identifying these normal-hearing children quickly and getting them out of the system prior to the need for sedated AEP testing. That is, we are interested in concentrating the resources required to carry out pediatric AEP measures only on children with hearing impairment and not on normal-hearing children who cannot otherwise be tested. OAE measures have had a positive impact on our ability to identify normal-hearing children in a more cost- and time-efficient manner, which has led, in turn, to more efficient clinical application of AEP measures. With OAE testing, behavioral and immittance results can be cross-checked in a very efficient and effective way to identify normal hearing (e.g. Stach et al., 1993). If such measures show the presence of a hearing loss, then AEP testing can be implemented to confirm degree of impairment. On the other hand, if these measures show normal cochlear function, the need for additional testing is eliminated. Many audiologists have modified their pediatric protocols to initiate testing with OAEs followed by immittance and then by traditional speech and pure-tone audiometry. In many cases, the objective information about the peripheral auditory mechanism gained from OAEs and immittance measures, when results are normal, is sufficient to preclude additional testing.

Cochlear Function Monitoring

Otoacoustic emission measures have also been used effectively to monitor cochlear function, particularly in patients undergoing treatment that is potentially **ototoxic**. Many drugs used as chemotherapy for certain types of cancer are ototoxic, as are some antibiotics used to control infections. Given in large enough doses, these drugs destroy outer hair cell function, resulting in permanent sensorineural hearing loss. Often, drug dosage can be adjusted during treatment to minimize these ototoxic effects. Thus, it is not unusual for patients undergoing chemotherapy or other drug treatment to have their hearing monitored before, during, and after the treatment regimen. High-frequency pure-tone audiometry is useful for this purpose. In addition, DPOAE testing is now being used as an early indicator of outer hair cell damage in these patients. The combination of pure-tone audiometry and DPOAE measures is quite accurate in determining when drugs are causing ototoxicity.

Ototoxic means it is poisonous to the ear.

Diagnostic Applications

Otoacoustic emission can also be useful diagnostically. Some patients have hearing impairment that is caused by retrocochlear disorder, such as tumors impinging on VIIIth nerve or brainstem lesions affecting the central auditory nervous system pathways. Sometimes these patients will have measurable sensorineural hearing loss but normal OAEs (Kileny et al., 1998; Stach et al., 1998). In such cases, outer hair cell function is considered normal, and the hearing loss can be attributable to the neurologic diseases process.

Otoacoustic emissions are also useful for evaluating patients with functional or nonorganic hearing loss. In a short period of time, the audiologist can determine whether the peripheral auditory system is functioning normally without voluntary responses from the patient. If OAEs are normal in such cases, their use can reduce the time and frustration often experienced with other measures in the functional test battery. Remember, however, that most functional hearing loss has some organicity as its basis, and OAEs are likely to simply reveal that fact.

One other aspect of otoacoustic emissions that is quite interesting from a diagnostic perspective is that the amplitude of a TEOAE is suppressed to a certain extent by stimulation of the contralateral ear (Berlin et al., 1993). This *contralateral suppression* is a small but consistent effect that occurs when broad spectrum noise is presented to one ear and transient emissions are recorded in the other. The effect is mediated by the medial olivocochlear system, which is part of the auditory system's complex efferent mechanism. In some cases of peripheral and central auditory disorder, contralateral suppression is absent, so that the TEOAE is unaffected by stimulation of the contralateral ear. Thus, use of contralateral suppression can be useful for assessing auditory nervous system function.

Summary

- One by-product of the active processes of the cochlear outer hair cells is the generation of a replication of a stimulating sound, which travels back out of the cochlea, through the middle ear, and into the ear canal. This response is a low-intensity sound referred to as an otoacoustic emission or OAE.

- Evoked OAEs occur during and after the presentation of a stimulus. Two classes of evoked OAEs have proven to be useful clinically, transiently-evoked otoacoustic emissions (TEOAE) and distortion-product otoacoustic emissions (DPOAE).
- OAEs are useful in at least four clinical areas: infant screening, pediatric assessment, cochlear function monitoring, and certain diagnostic cases.
- OAEs are used most effectively as a screening measure.
- One of the most important applications of OAEs is as an additional part of the pediatric audiologic assessment battery.
- Otoacoustic emission measures have been used effectively to monitor cochlear function, particularly in patients undergoing treatment that is potentially ototoxic.
- Otoacoustic emission can also be useful diagnostically.

Short Answer Questions

1. Electrical events evoked in the brain by acoustic stimulation are known as _____ _____ _____.
2. Recording ongoing electrical potentials throughout the brain by placing sensing electrodes on scalp is called _____ (EEG).
3. Recording EEG activity requires at least three electrodes: a _____ electrode, a _____ electrode, and an _____ electrode.
4. To extract activity related to the auditory signal from all recorded electrical activity, the _____ -to- _____ ratio must be enhanced.
5. The use of a _____ amplifier helps to increase the signal-to-noise ratio of the evoked auditory potential by eliminating some of the background noise in the signal.
6. The electrical signal is _____ to increase the overall intensity of the recorded signal.
7. The recorded electrical signal is _____ to eliminate some background electrical noise, because the signal representing auditory evoked potentials exists only in a narrow band of frequencies.

8. The use of _____ _____ is designed to enhance the auditory response through the averaging of repeated samples of electrical activity that are time-locked to signal presentation.
9. The _____ _____ _____ is the synchronous change in electrical potential of distal portion of the VIIIth cranial nerve elicited by click stimulus.
10. The _____ _____ is a direct current response that reflects the envelope of the input stimulus.
11. The _____ _____ is a response from cochlea that mimics the input stimulus.
12. A _____-_____ response is recorded with the electrode close to the origin of the response. A _____-_____ response is recorded with the electrode far from the origin of the response, typically with scalp electrodes.
13. The _____ _____ _____ _____ is a short latency auditory evoked response, occurring within approximately the first 10 ms following the stimulus onset.
14. The ABR consists of a series of _____ positive waves that are generated by the auditory nerve and structures of the auditory brainstem.
15. Wave I of the ABR is generated at the _____ portion of the _____ _____ _____. Wave II is generated at the _____ portion of the same nerve. Wave III is generated by the proximal portion of the auditory nerve and the _____ _____. Waves IV and V are generated by the cochlear nucleus, _____ _____ _____, and lateral lemniscus.
16. The _____ _____ _____ occurs during the first 50 ms following the stimulus. It consists of two positive peaks: _____, which occurs around 25–35 ms, and _____, which occurs around 40–60 ms.
17. The _____ _____ _____ is the auditory evoked potential with the longest latency. It is composed of two major responses: a negative peak, _____, that occurs around 90 ms following the stimulus, and a positive peak, _____, occurring around 180 ms. The response is _____ affected by subject state.

18. The _____ _____-_____ _____ occurs when the brain potential closely follows the time course of modulation of the carrier signal. This evoked potential is useful for prediction of hearing sensitivity.
19. The two tests that are most useful for prediction of hearing sensitivity are the _____ _____-_____ _____ and the _____ _____-_____ _____ _____ tests.
20. The _____ _____-_____ _____ is a sensitive diagnostic tool for identifying VIIIth nerve tumors.
21. Otoacoustic emissions are the by-product of active processing by the _____ _____ _____.
22. Otoacoustic emissions are _____ when outer hair cells are healthy. They are _____ when outer hair cells are damaged.
23. Otoacoustic emissions can be _____, occurring without acoustic stimulation, or _____, occurring in response to acoustic stimulation.
24. Otoacoustic emissions that are evoked using a transient stimulus, such as a _____, are called _____ otoacoustic emissions.
25. Otoacoustic emissions that are evoked in response to two tones presented to the cochlea are known as _____ _____ otoacoustic emissions.
26. Evoked otoacoustic emissions are often used for cochlear monitoring in cases where _____ medications or drugs are used.

Discussion Questions

1. Describe the technique of signal averaging for extracting evoked responses from ongoing EEG.
2. Discuss the role of evoked potential testing in surgical monitoring.
3. Explain why evoked potentials are typically chosen as the best available method for screening of hearing in newborns.

4. Given the availability of modern imaging techniques, why is the auditory brainstem response test still used for screening of acoustic tumors?
5. Why are evoked otoacoustic emissions so valuable for pediatric assessment of hearing?
6. Discuss the role of evoked otoacoustic emissions testing in monitoring of cochlear function.

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10

DIFFERENT ASSESSMENT APPROACHES FOR DIFFERENT POPULATIONS

Learning Objectives

Otologic Referrals
- Outer- or Middle-Ear Disorders
- Cochlear Disorder
- Retrocochlear Disorder

Adult Audiologic Referrals
- Younger Adults
- Older Adults

Pediatric Audiologic Referrals
- Infant Screening
- Pediatric Evaluation
- Auditory Processing Assessment

Functional Hearing Loss
- Indicators of Functional Hearing Loss
- Assessment of Functional Hearing Loss

Summary

Short Answer Questions

Discussion Questions

Resources

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- Identify the goals of an audiologic evaluation and explain how goals may vary across patient populations.
- Identify strategies used for audiologic evaluation and explain how they are used to achieve the goals of the audiology evaluation.
- Describe the goals for audiologic evaluation and the assessment strategies used for patients whose referral is based on otologic concerns.
- Describe the differences in goals for audiologic evaluation and the strategies for assessment of younger and older adult populations.
- Describe the goals for audiologic evaluation and the assessment strategies used for pediatric patients.
- Describe the goals for audiologic evaluation and the assessment strategies used for patients with suspected functional hearing loss.

ALTHOUGH the overall goal of an audiological evaluation is to characterize hearing ability, the approach used to reach that goal can vary considerably across patients. The approach chosen to evaluate a patient's hearing is sometimes related to patient factors such as age and sometimes related to the reason that the patient has sought services or has been referred for services. For example, the strategy used for a patient who is seeking otologic care is different in some ways from the strategy used for a patient who is seeking audiologic care. In the former, emphasis is on determination of degree and site of disorder; in the latter, emphasis is on degree of impairment and prognosis for successful hearing aid use. Within these broad categories, the approach may also vary depending on a patient's age. Quantification of degree of hearing loss in a 2-week-old requires a different strategy than that in a 20-year-old. Similarly, testing an 80-year-old patient can require different techniques and an expanded approach from the testing of a 40-year-old. Finally, there are patients who exaggerate or feign hearing loss, requiring an entirely different approach to assessment.

Although assessment must be adapted to the needs and expectations of individual patients, there are several broad categories of patients that present common challenges and can be approached in a similar clinical manner, including pediatric patients, those

being assessed for otologic reasons, those being assessed for audiologic reasons, and patients with functional hearing loss.

OTOLOGIC REFERRALS

An otologist's evaluation of a patient, aimed at diagnosing and treating ear disease, often includes ancillary testing, such as imaging studies, laboratory tests, and audiologic evaluations. Audiologic assessment in this context serves to provide additional information to the physician to aid in diagnosis. In addition, because hearing loss is often a quantifiable consequence of auditory disorder, results can serve as a metric for the success or failure of treatment approaches.

In general, otologists are faced with three main categories of patients: those with outer- or middle-ear disorders, those with cochlear disorders, and those with neurologic disorders affecting the peripheral or central auditory nervous system.

Outer- or Middle-Ear Disorders

Evaluative Goals

Physicians who note the presence of an outer- or middle-ear disorder are likely to refer the patient for an audiologic consultation. For the audiologist, there are two primary goals in the assessment of outer- and middle-ear disorders:

1. investigation of the nature of the disorder and
2. assessment of the impact of that disorder on hearing sensitivity

Tympanosclerosis is the formation of whitish plaques on the tympanic membrane, which can result in membrane stiffness.

Audiologic determination of the nature of the disorder relates to the consequence that a disorder has on the *function* of the outer- and middle-ear structures. For example, excessive cerumen in the ear canal may or may not impede the transduction of sound to the tympanic membrane. Similarly, **tympanosclerosis** may or may not reduce the functioning of the tympanic membrane. The first goal is to determine whether these structural changes result in a disorder in function.

The second goal of the evaluation is to determine whether and how much this disorder in function is causing a hearing loss.

In some circumstances, a structural change in the outer and middle ear can result in outer- or middle-ear disorder without causing a measurable loss of hearing. For example, a tympanic membrane can be perforated, resulting in a disorder of eardrum function, without causing a meaningful conductive hearing loss. On the other hand, a similar perforation in the right location on the tympanic membrane can result in a substantial conductive hearing loss. Similarly, blockage of the Eustachian tube can result in significant negative pressure in the middle-ear space that may result in hearing loss in one case but not in another.

In some cases, the referring physician may not be able to detect a structural change in the middle-ear mechanism and will be referring the patient to rule out middle-ear disorder as the cause of the patient's complaint. The approach in such cases is the same. First, you must assess the normalcy of middle-ear function and then the degree to which any disorder is influencing hearing ability.

The importance of your assessment of hearing sensitivity in these cases cannot be overstated. If the patient has an outer- or middle-ear disorder, the degree of hearing loss that it is causing will serve as an important metric of the success or failure of the medical treatment regimen. If the physician prescribes medication to treat otitis media or performs surgery to mitigate the effects of **otosclerosis**, the pure-tone audiogram will often be the metric by which the outcome of the treatment is judged. That is, the pretreatment audiogram will be compared to the post-treatment audiogram to evaluate the success of the treatment.

Otosclerosis is the formation of new bone around the stapes and oval window, resulting in stapes fixation and conductive hearing loss.

Test Strategies

Immittance audiometry is used to evaluate outer- and middle-ear function, and pure-tone audiometry is used to evaluate the degree of conductive component caused by the presence of middle-ear disorder. In most cases, rudimentary speech audiometry will be carried out as a cross-check of pure-tone thresholds and as a gross assessment of suprathreshold word recognition ability.

Immittance Audiometry. The first step in the evaluation process is immittance audiometry. Because it is the most sensitive indicator of middle-ear function, a full battery of tympanometry, static

immittance, and acoustic reflex thresholds should be carried out. Results will provide information indicating whether a disorder is due to:

- an increase in the mass of the middle-ear mechanism,
- an increase or decrease in the stiffness of the middle-ear system,
- the presence of a perforation of the tympanic membrane, or
- significant negative pressure in the middle-ear space.

If all immittance results are normal, any hearing loss measured by pure-tone audiometry can be attributed to sensorineural hearing loss. If immittance results indicate the presence of a middle-ear disorder, pure-tone audiometry by air- and bone-conduction must be carried out to assess the degree of conductive component of the hearing loss attributable to the middle-ear disorder.

Pure-Tone Audiometry. Pure-tone audiometry is used to quantify the degree to which middle-ear disorder is contributing to a hearing sensitivity loss. If immittance audiometry shows any abnormality in outer- or middle-ear function, then complete air- and bone-conduction audiometry must be carried out on both ears to determine the degree of conductive hearing loss.

It is important to carry out both air and bone conduction in order to quantify the extent of the conductive component. It is important to test both ears because the presence of conductive hearing loss requires the use of masking in the nontest ear and that ear cannot be properly masked without knowing its air- and bone-conduction thresholds.

Speech Audiometry. In cases of outer- and middle-ear disorder, the most important component of speech audiometry is determination of the speech-recognition threshold as a cross-check of the accuracy of pure-tone thresholds. Many audiologists prefer to establish the SRT before carrying out pure-tone audiometry so that they have a benchmark for the level at which pure-tone thresholds should occur. Although this is good practice in general, it is particularly useful in the assessment of young children. SRTs can also be established by bone conduction, permitting the quantification of an air-bone gap to speech signals.

Assessment of word recognition is also often carried out, though more as a matter of routine than importance. Conductive hearing loss has a predictable influence on word-recognition scores, and if such testing is of value, it is usually only to confirm this expectation.

Illustrative Cases

Illustrative Case 10-1. Case 1 is a patient with bilateral, acute otitis media with effusion. The patient is a 4-year-old boy with a history of recurring upper-respiratory infections, often accompanied by otitis media. The upper-respiratory infection often interferes with Eustachian-tube functioning, thereby limiting pressure equalization of the middle-ear space. The patient had been experiencing symptoms of a cold for the past 2 weeks and complained to his parents of difficulty hearing.

Immittance audiometry, shown in Figure 10-1A, is consistent with middle-ear disorder, characterized by flat, Type B tympanograms, low static immittance, and absent crossed and uncrossed reflexes bilaterally. These results are consistent with an increase in the mass of the middle-ear mechanism, a result that often indicates the presence of effusion in the middle-ear space.

Results of pure-tone audiometry are shown in Figure 10-1B. Results show a mild conductive hearing loss bilaterally, with slightly more loss in the left ear. Bone-conduction thresholds indicate normal cochlear function bilaterally.

Speech audiometric results indicate speech thresholds that are consistent with pure-tone thresholds. In addition, suprathreshold understanding of words (PSI-W) and sentences (PSI-S) is excellent, as expected.

This child's ear problems have not responded well in the past to antibiotic treatment. The child's physician is considering the placement of pressure-equalization tubes into the eardrums to help overcome the effects of the Eustachian-tube problems.

Illustrative Case 10-2. Case 2 is a patient with bilateral otosclerosis, a bone disorder that often results in fixation of the stapes

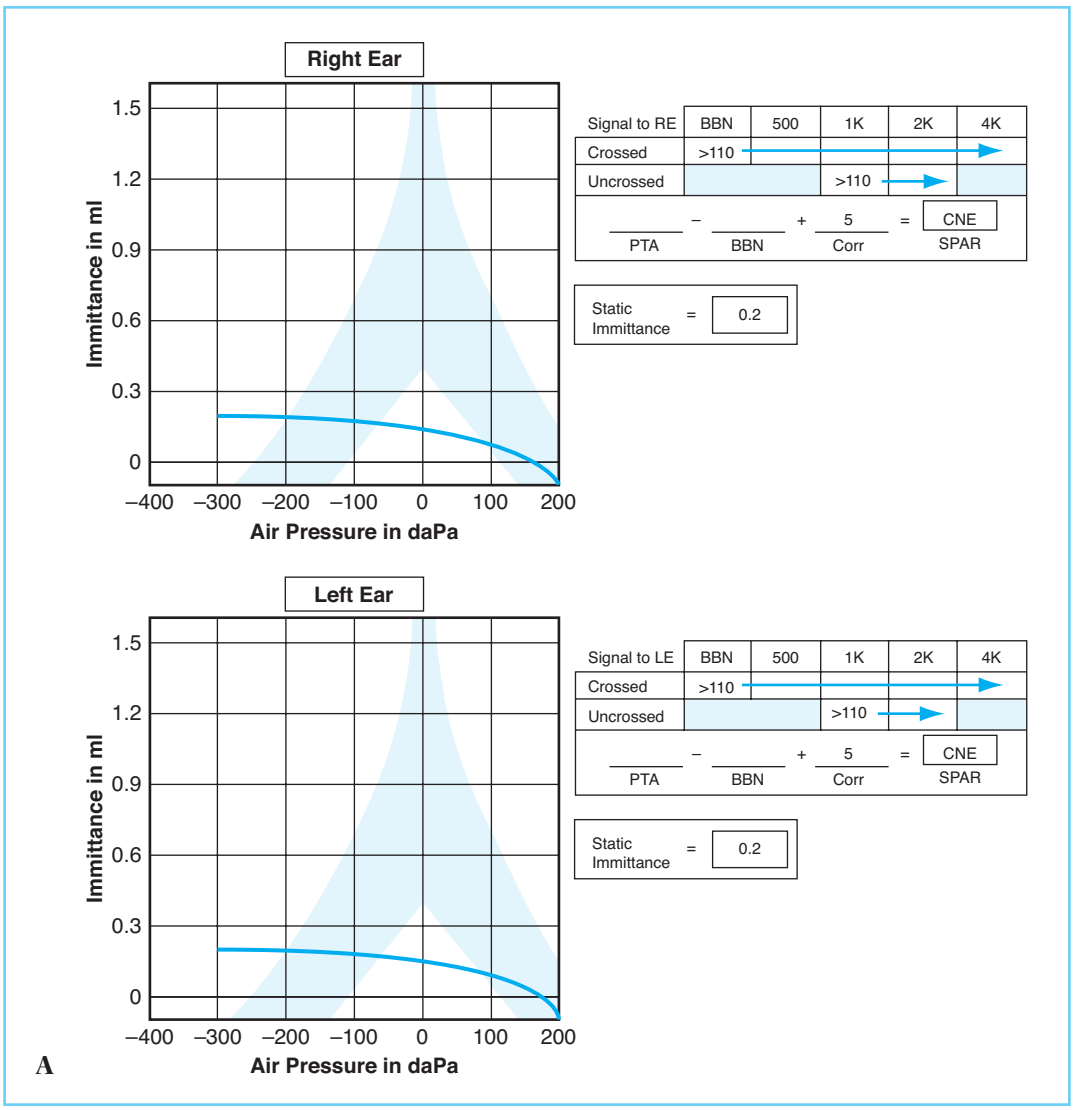
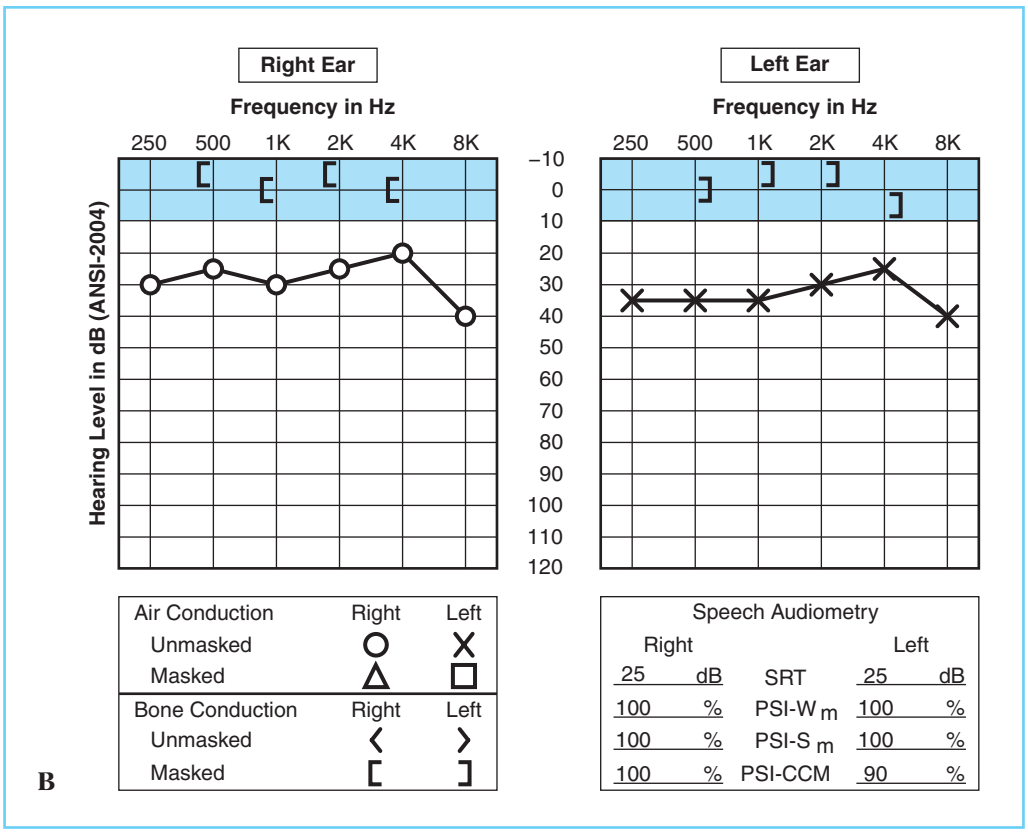


FIGURE 10-1 Hearing consultation results in a 4-year-old boy with a history of otitis media. Immittance measures (A) are consistent with an increase in the mass of the middle-ear mechanism, secondary to otitis media with effusion. Pure-tone audiometric results (B) show a mild conductive hearing loss bilaterally, with slightly more loss in the left ear. Speech audiometric results show excellent suprathreshold recognition of words and sentences once intensity level is sufficient to overcome the conductive hearing loss. (PSI-W_m = Pediatric Speech Intelligibility test maximum word score; PSI-S_m = PSI maximum sentence score; PSI-CCM = PSI with contralateral competing message.)



B

into the oval window. The patient is a 33-year-old woman who developed hearing problems during pregnancy. She describes her problem as a muffling of other people's voices. She also reports tinnitus in both ears that bothers her at night. There is a family history of otosclerosis on her mother's side.

Results of immittance audiometry, as shown in Figure 10-2A, are consistent with middle-ear disorder, characterized by a Type A tympanogram, low static immittance, and absent crossed and uncrossed acoustic reflexes bilaterally. This pattern of results suggests an increase in the stiffness of the middle-ear mechanism and is often associated with fixation of the ossicular chain.

Pure-tone audiometric results are shown in Figure 10-2B. The patient has a moderate, bilateral, symmetric, conductive hearing loss.

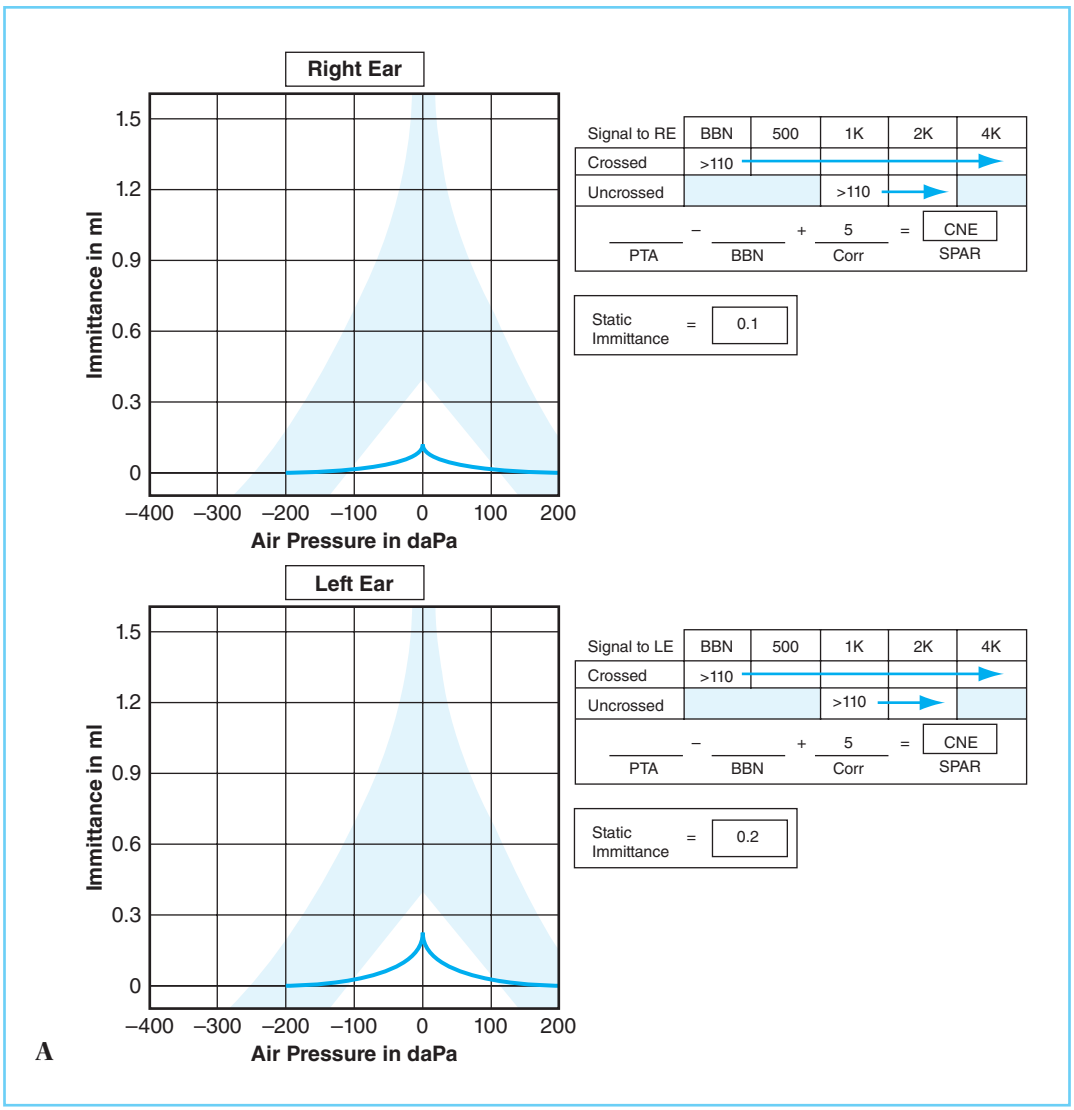
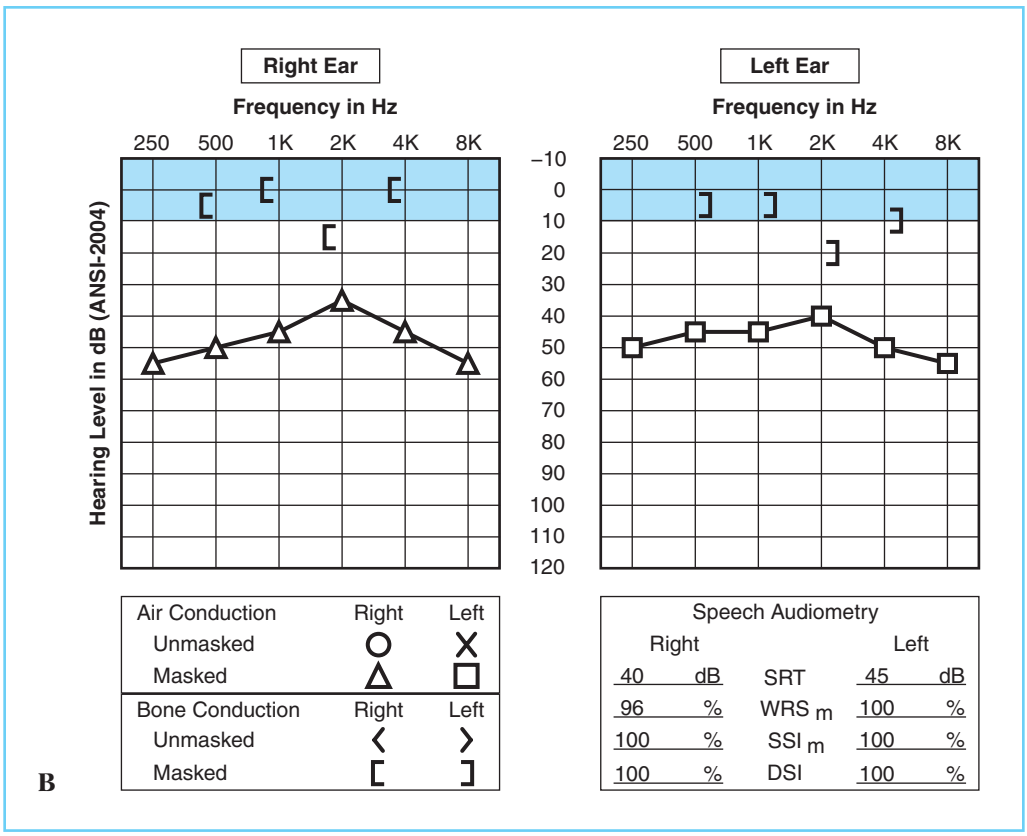


FIGURE 10-2 Hearing consultation results in a 33-year-old woman with otosclerosis. Immittance measures (A) are consistent with an increase in the stiffness of the middle-ear mechanism, consistent with fixation of the ossicular chain. Pure-tone audiometric results (B) show a moderate conductive hearing loss with a 2000-Hz notch in bone-conduction thresholds bilaterally. Speech audiometric results show excellent suprathreshold speech recognition once intensity level is sufficient to overcome the conductive hearing loss. (WRS_m = maximum word recognition score; SSI_m = Synthetic Sentence Identification maximum score; DSI = Dichotic Sentence Identification.)



B

As is typical in otosclerosis, the patient also has an apparent hearing loss by bone conduction at around 2000 Hz in both ears. This so-called Carhart's notch is actually the result of an elimination of the middle-ear contribution to bone-conducted hearing rather than a loss in cochlear sensitivity.

Speech audiometric results show speech thresholds consistent with pure-tone thresholds. Suprathreshold speech recognition ability is normal once the effect of the hearing loss is overcome by presenting speech at higher intensity levels.

The patient is scheduled for surgery on her right ear. The surgeon will likely remove the stapes and replace it with a prosthesis. The result should be restoration of nearly normal hearing sensitivity.

Cochlear Disorder

Evaluative Goals

When an otologist refers a patient with a suspected cochlear disorder, the physician is interested in the answers to several questions, including:

- Is there a hearing loss and what is the extent of it?
- Is the loss truly of a cochlear nature or is there also a conductive component?
- Is the loss truly of a cochlear nature or is it retrocochlear?
- Is the loss fluctuating or stable?
- Could the loss be due to a treatable condition such as endolymphatic hydrops or autoimmune disorder?

The goals of the audiologic evaluation, then, pertain to these questions. The first goal is to determine whether a middle-ear disorder is contributing to the problem. The second goal is to determine the degree and type of hearing loss. The third goal is to scrutinize the audiologic findings for any evidence of retrocochlear disorder.

Test Strategies

Immittance audiometry is used to evaluate outer- and middle-ear function, to indicate the presence of cochlear hearing loss, and to assess the integrity of VIIIth nerve and lower auditory brainstem function. Pure-tone audiometry is used to evaluate the degree and type of hearing loss. Speech audiometry is used as a cross-check of pure-tone thresholds and as an estimate of suprathreshold word recognition ability.

Immittance Audiometry. A complete immittance battery will provide valuable information about the cochlear hearing loss. If a loss is truly cochlear in origin, then the tympanograms will be normal, static immittance will be normal, and acoustic reflex thresholds will be consistent with the degree of sensorineural hearing loss. For example, if a cochlear hearing loss is less than approximately 50 dB HL, then acoustic reflex thresholds to pure tones should be at normal levels. If the loss is greater than 50 dB, reflex thresholds will be elevated accordingly. In either case, a cochlear hearing loss will cause an elevation of the acoustic reflex

thresholds to noise stimuli relative to pure-tone stimuli, resulting in a reduced **SPAR** value.

The **SPAR** test is designed to predict the presence or absence of cochlear hearing loss by comparing the difference between acoustic reflex thresholds elicited by pure tones and by broadband noise.

If immittance audiometry suggests the presence of middle-ear disorder, then any cochlear loss is likely to have a superimposed conductive component that must be quantified by pure-tone audiometry. If immittance audiometry is consistent with normal middle-ear function, but acoustic reflexes are elevated beyond that which might be expected from the degree of sensorineural hearing loss, then suspicion is raised about the possibility of retrocochlear disorder.

Pure-Tone Audiometry. Pure-tone audiometry is used to quantify the degree of sensorineural hearing loss caused by the cochlear disorder. If all immittance measures are normal, then air-conduction testing must be completed on both ears. Bone conduction will not be necessary because outer- and middle-ear function are normal, and air-conducted signals will properly evaluate the sensitivity of the cochlea. If all immittance measures are not normal, then air- and bone-conduction thresholds must be obtained for both ears to assess the possibility of the presence of a mixed hearing loss. In either case, both ears must be tested, because the use of masking is likely to be necessary and cannot be properly carried out without knowledge of the air- and bone-conduction thresholds of the nontest ear.

Pure-tone audiometry is also an important measure for assessing symmetry of hearing loss. If a sensorineural hearing loss is asymmetric, in the absence of other explanations, suspicion is raised about the possibility of the presence of retrocochlear disorder.

There are other ways in which pure-tone audiometry can be useful in the otologic diagnosis of cochlear disorder. Some types of cochlear disorder are dynamic and may be treatable at various stages. One example is endolymphatic hydrops, a cochlear disorder caused by excessive accumulation of endolymph in the cochlea. In its active stage, otologists will attempt to treat it in various ways and will often use the results of pure-tone audiometry as both partial evidence of the presence of hydrops and as a means for assessing benefit from the treatment regimen.

Speech Audiometry. Speech audiometry is used in two ways in the assessment of cochlear disorder. First, speech recognition thresholds are used as a cross-check of the validity of pure-tone thresholds in an effort to ensure the organicity of the disorder. Second, word-recognition and other suprathreshold measures are used to assess whether the cochlear hearing loss has an expected influence on speech recognition. That is, in most cases, suprathreshold speech-recognition ability is predictable from the degree and configuration of a sensorineural hearing loss if the loss is cochlear in origin. Therefore, if word-recognition scores are appropriate for the degree of hearing loss, then the results are consistent with a cochlear site of disorder. If scores are poorer than would be expected from the degree of hearing loss, then suspicion is aroused that the disorder may be retrocochlear in nature.

Otoacoustic Emissions. Otoacoustic emissions can be used in the assessment of sensorineural hearing loss as a means of verifying that there is a cochlear component to the disorder. For example, if the cochlea is disordered, OAEs are expected to be abnormal or absent. Although this does not preclude the presence of retrocochlear disorder, it does implicate the cochlea. Conversely, if OAEs are normal in the presence of a sensorineural hearing loss, a retrocochlear site of disorder is implicated.

Auditory Evoked Potentials. Auditory evoked potentials can be used for two purposes in the assessment of cochlear disorder. First, if there is suspicion that the hearing loss is exaggerated, evoked potentials can be used to predict the degree of organic hearing loss. Second, if there is suspicion that the disorder might be retrocochlear in nature, the auditory brainstem response can be used in an effort to differentiate a cochlear from a retrocochlear site.

Illustrative Cases

Illustrative Case 10-3. Case 3 is a patient with bilateral sensorineural hearing loss of cochlear origin, secondary to ototoxicity. The patient is a 56-year-old man with cancer who recently finished a round of chemotherapy with a drug regimen that included cisplatin.

Immittance audiometry, as shown in Figure 10-3A, is consistent with normal middle-ear function bilaterally, characterized

by Type A tympanograms, normal static immittance, and normal crossed and uncrossed acoustic reflex thresholds. You will note that the SPARs, or sensitivity prediction by acoustic reflexes, predict the presence of a sensorineural hearing loss, as they are

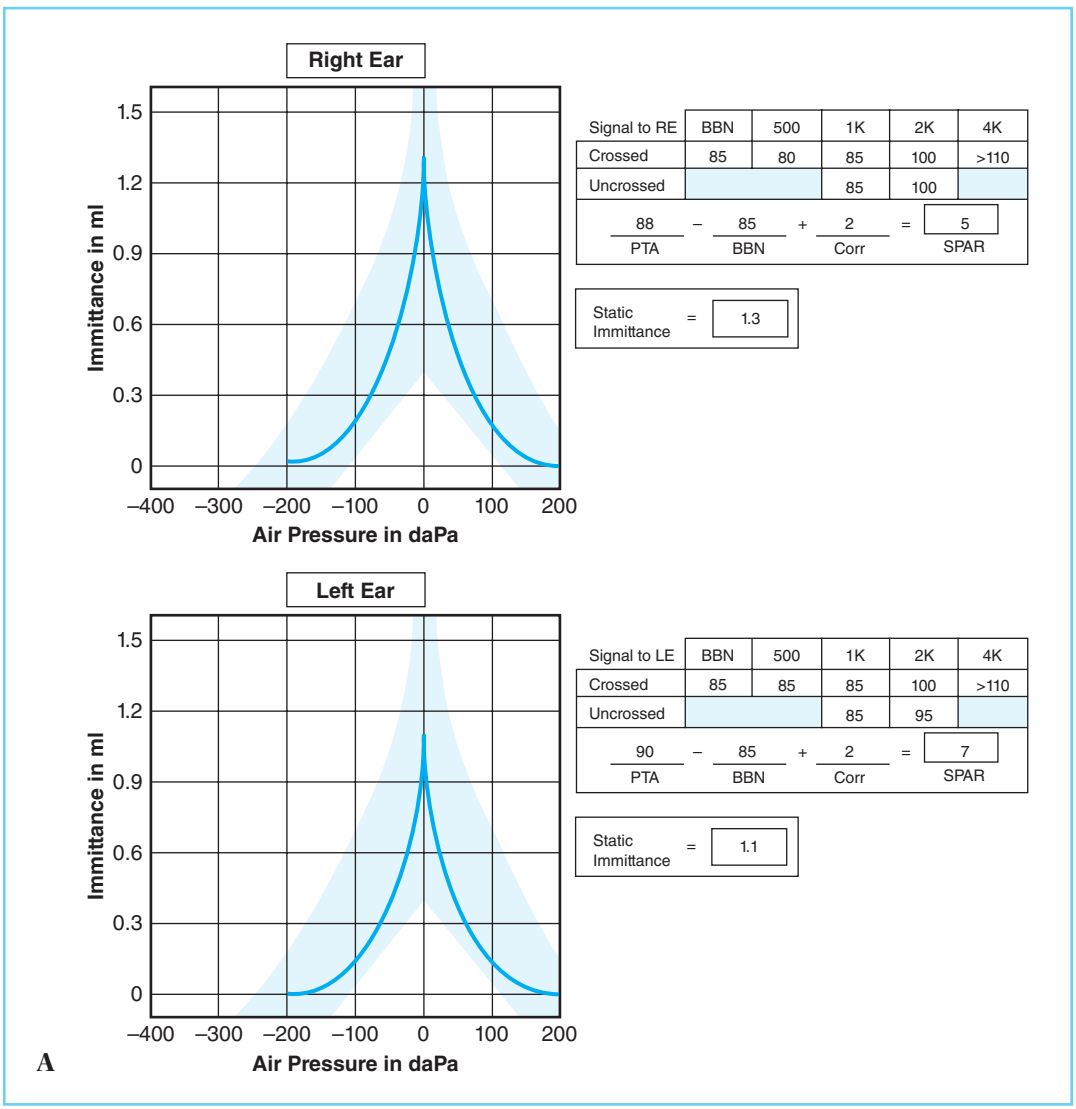
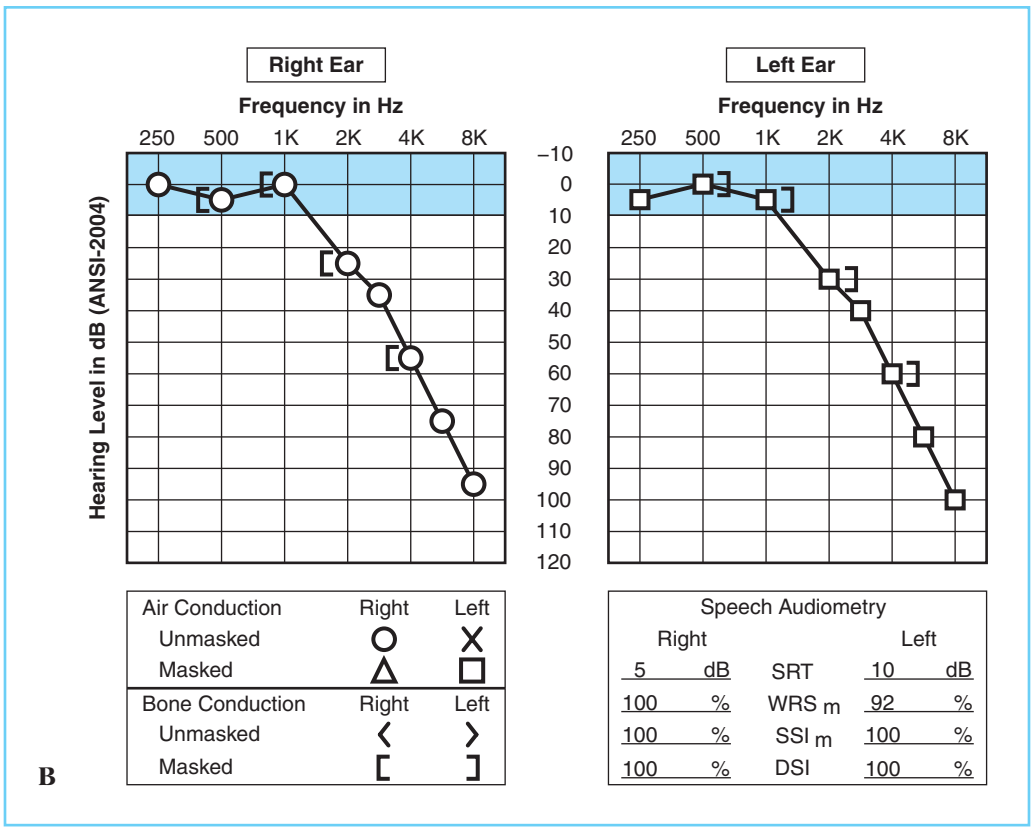


FIGURE 10-3 Hearing consultation results in a 56-year-old man with hearing loss resulting from ototoxicity. Immittance measures (A) are consistent with normal middle-ear function. SPARs predict the presence of hearing loss. Pure-tone audiometric results (B) show a high-frequency sensorineural hearing loss bilaterally. Speech audiometric results are consistent with the degree and configuration of the hearing loss.



B

below the score of 15, which is the lower limit for normal cochlear function.

Pure-tone audiometry is shown in Figure 10-3B. Results show bilaterally symmetric, high-frequency sensorineural hearing loss, progressing from mild levels at 2000 Hz to profound at 8000 Hz.

Further doses of chemotherapy would be expected to begin to affect the remaining high-frequency hearing and progress downward toward the low frequencies.

Speech audiometric results are consistent with the degree and configuration of cochlear hearing loss. First, the speech thresholds match the pure-tone thresholds. Second, the word-recognition scores are consistent with this degree of hearing loss. You can compare these results with those that would be expected from the

degree of loss or by calculating the audibility index and predicting the score from that calculation as described in Chapter 7.

This patient may well be a candidate for high-frequency amplification, if the hearing loss is causing a communication disorder for him. Caution should also be taken to monitor hearing sensitivity if the patient undergoes additional chemotherapy. He is at risk for additional hearing loss, and the physician may be able to alter the dosage of cisplatin to reduce the potential for further cochlear damage.

Illustrative Case 10-4. Case 4 is a patient with unilateral sensorineural hearing loss secondary to endolymphatic hydrops. The patient is a 45-year-old woman who, 2 weeks prior to the evaluation, experienced episodes of hearing loss, ear fullness, tinnitus, and severe vertigo. After several episodic attacks, hearing loss persisted. A diagnosis of Ménière's disease was made by her otolaryngologist.

Immittance audiometry, as shown in Figure 10-4A is consistent with normal middle-ear function bilaterally, characterized by Type A tympanograms, normal static immittance, and normal crossed and uncrossed reflex thresholds.

Pure-tone audiometry is shown in Figure 10-4B. Results show a moderate, rising, sensorineural hearing loss on the left ear and normal hearing sensitivity on the right.

Speech audiometric results were normal for the right ear. On the left, although speech thresholds agree with the pure-tone thresholds, suprathreshold speech-recognition scores are very poor. This performance is significantly reduced from what would normally be expected from a cochlear hearing loss. These results are unusual for cochlear hearing loss, except in cases of Méniére's disease, where they are characteristic.

Because of the unilateral nature of the disorder, the physician was interested in ruling out an VIIIth nerve tumor as the causative factor. Results of an auditory brainstem response assessment are shown in Figure 10-4C. Both the absolute and interpeak latencies are normal and symmetric, supporting the diagnosis of cochlear disorder.

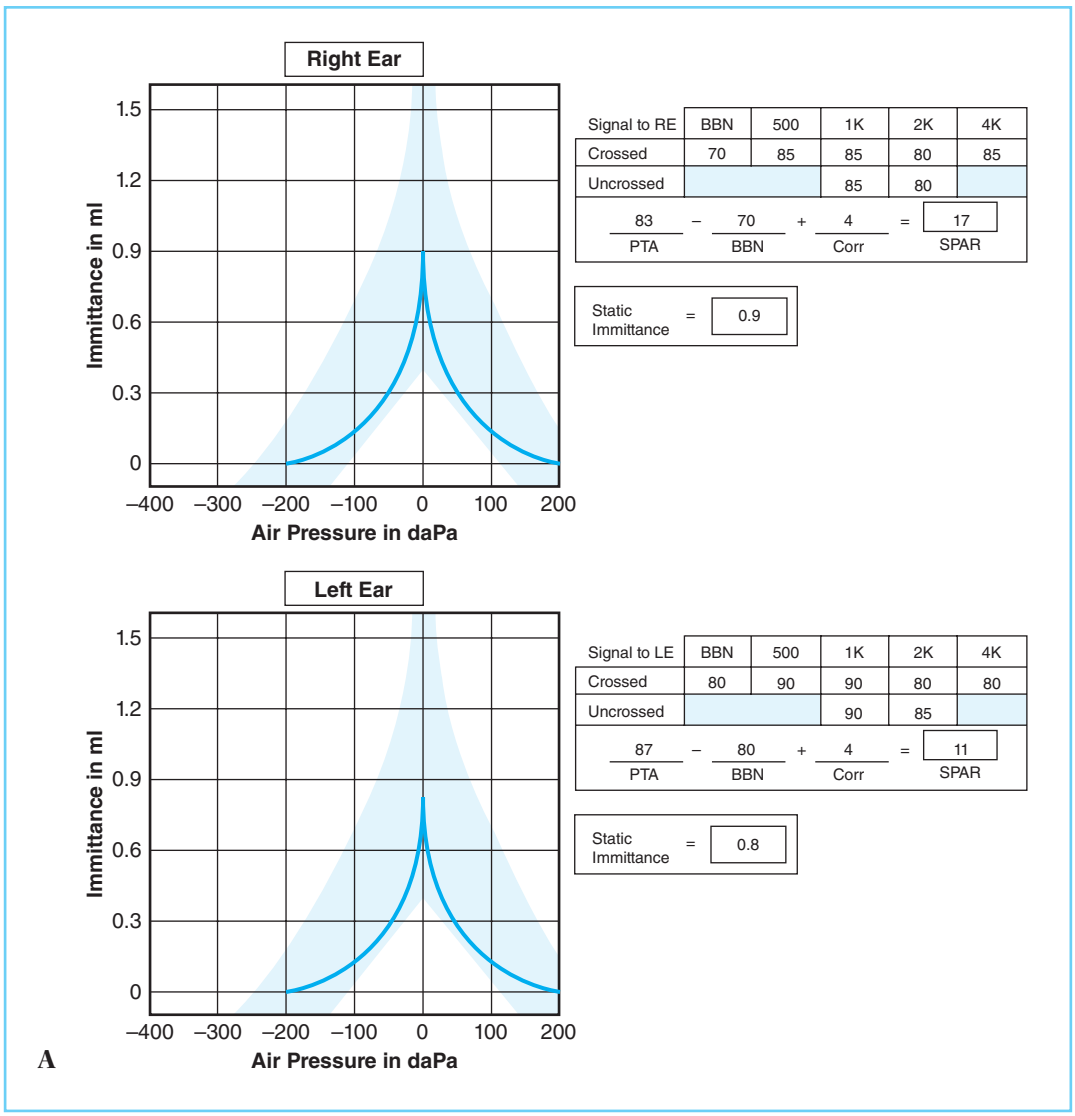
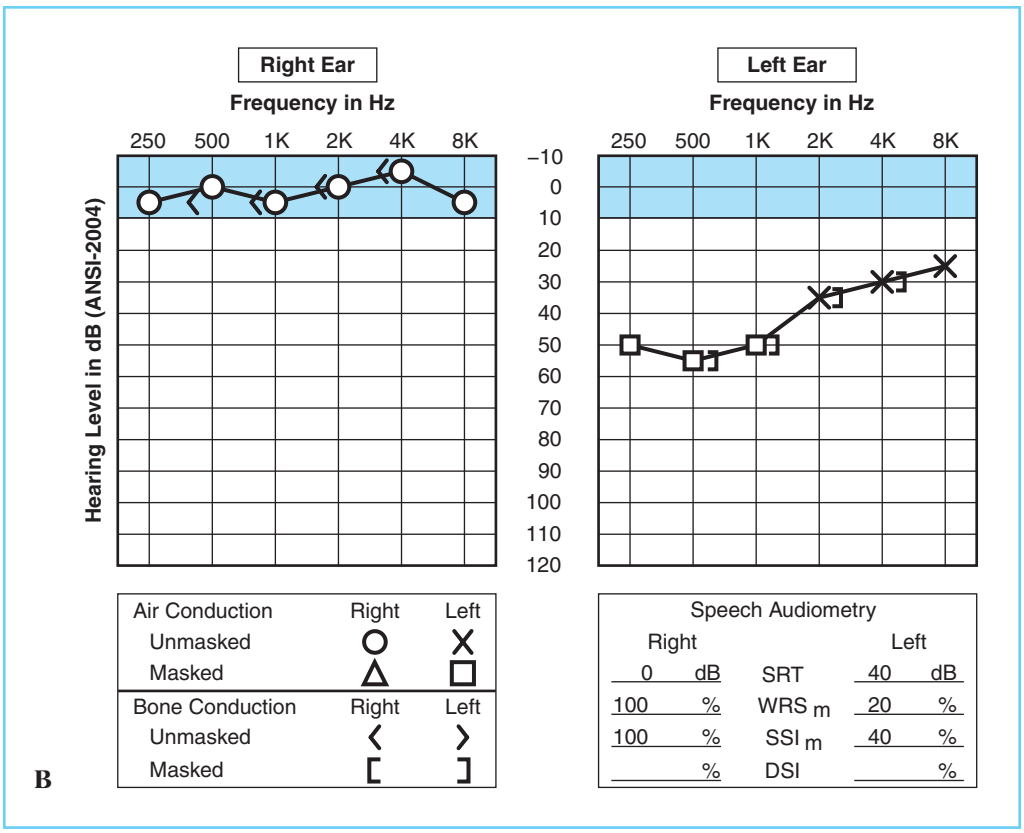


FIGURE 10-4 Hearing consultation results in a 45-year-old woman with hearing loss secondary to endolymphatic hydrops. Immittance measures (A) are consistent with normal middle-ear function. SPARs predict the presence of hearing loss in the left ear. Pure-tone audiometric results (B) show normal hearing sensitivity on the right and a moderate, rising sensorineural hearing loss on the left. Speech audiometric results show that speech-recognition ability on the left ear is poorer than would be predicted from the degree and configuration of hearing loss. Auditory brainstem response results (C) show that both the absolute and interpeak latencies are normal and symmetric, consistent with normal VIIIth nerve and auditory brainstem function.

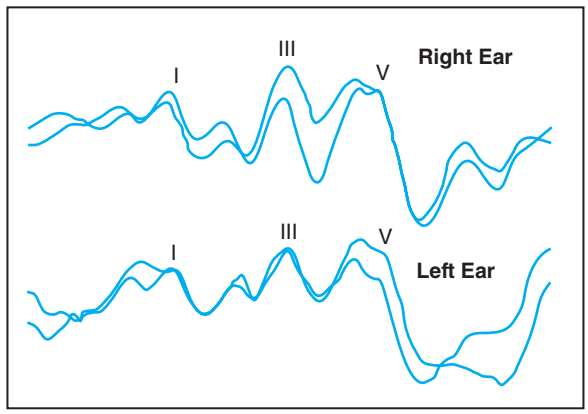


The physician may recommend a course of diuretics or steroids and may recommend a change in diet and stress level for the patient. From an audiologic perspective, the patient is not a good candidate for amplification because of the normal hearing in the right ear and because of the exceptionally poor speech recognition ability in the left. Presenting amplified sound to an ear that distorts this badly is unlikely to result in a favorable reaction. Monitoring of hearing is indicated to assess any changes that might occur in the left ear.

Retrocochlear Disorder

Evaluative Goals

Sometimes the patient history or physical examination will lead the otologist to suspect that a patient might have a retrocochlear disorder. In most cases, the physician will be concerned about the presence of a space-occupying lesion on the VIIIth nerve. This often



	Latency Wave V	Interwave Intervals		
		I-III	III-V	I-V
RE	5.8	2.0	2.0	4.0
LE	5.8	2.0	2.0	4.0

C Click Level: 90 dB nHL

occurs when a patient reports the presence of unilateral hearing loss, unilateral tinnitus, unexplained dizziness, or other neurologic symptoms. In such cases, the physician is interested in several aspects of the audiologic evaluation, including:

- Is there a hearing loss, and what is the extent of it?
- Is the loss **unilateral** or **asymmetric**?
- Is speech understanding asymmetric or poorer than predicted from the hearing loss?
- Are acoustic reflexes normal or elevated?
- Is there other evidence of retrocochlear disorder?

Unilateral pertains to one side only; bilateral pertains to both sides.

Symmetric means there is a similarity between two parts; **asymmetric** means there is a dissimilarity between two parts.

One goal of the audiologic evaluation is to determine the degree and type of hearing loss. Another goal is to scrutinize the audiologic findings for any evidence of retrocochlear disorder. Often a third goal is to assess the integrity of the VIIIth nerve and auditory brainstem with electrophysiologic measures.

Test Strategies

Immittance audiometry is used to evaluate outer- and middle-ear function and to assess the integrity of the VIIth and VIIIth cranial nerves and lower auditory brainstem function. Pure-tone audiometry is used to evaluate the extent of any hearing asymmetry. Speech audiometry is used as a cross-check of pure-tone thresholds, as an estimate of suprathreshold speech recognition ability, as a measure of hearing symmetry, and as an assessment of any abnormality of hearing under adverse listening conditions. Electroacoustic and electrophysiologic measures are used in an effort to assess integrity of the cochlea, VIIIth nerve, and auditory brainstem.

Immittance Measures. A complete immittance battery may provide valuable information about the nature of a retrocochlear hearing disorder. Assuming normal middle-ear function, the absence of crossed and uncrossed reflexes measured from the same ear may be indicative of facial nerve disorder on that side. The absence of crossed and uncrossed reflexes when the eliciting signal is presented to one ear may be indicative of VIIIth nerve disorder on that side.

If the disorder is truly cochlear in origin, the tympanograms will be normal, static immittance will be normal, and acoustic reflex thresholds will be consistent with the degree of sensorineural hearing loss. Immittance audiometry is also important in assessing middle-ear function in cases of suspected retrocochlear disorder, because middle-ear disorder and any resultant conductive hearing loss can affect interpretation of other audiometric measures.

Pure-Tone Audiometry. Pure-tone audiometry is used to quantify the degree of sensorineural hearing loss caused by a retrocochlear disorder. If all immittance measures are normal, only air-conduction testing need be completed on both ears. Bone conduction will not be necessary because outer- and middle-ear function is normal, and air-conducted signals will properly evaluate the sensitivity of the cochlea. If all immittance measures are not normal, air- and bone-conduction thresholds must be obtained for both ears to assess the possibility of the presence of a mixed hearing loss. In either case, both ears must be tested, because the use of masking

is likely to be necessary and cannot be properly carried out without knowledge of the air- and bone-conduction thresholds of the nontest ear.

Pure-tone audiometry is also an important measure for assessing symmetry of hearing loss. If a sensorineural hearing loss is asymmetric in the absence of other explanations, suspicion is raised about the possibility of the presence of retrocochlear disorder.

Speech Audiometry. Speech audiometry is used in two ways in the assessment of retrocochlear disorder. First, as usual, speech-recognition thresholds are used as a cross-check of the validity of pure-tone thresholds in an effort to ensure the organicity of the disorder. Second, word-recognition and other suprathreshold measures are used to assess whether speech-recognition is poorer than would be expected from the amount of hearing loss. That is, in most cases of cochlear disorder, suprathreshold speech-recognition ability is predictable from the degree and configuration of a sensorineural hearing loss. However, if speech-recognition ability is poorer than would be expected from the degree of hearing loss, suspicion is aroused that the disorder may be retrocochlear in nature.

Suprathreshold speech audiometric measures are very important in the assessment of patients suspected of retrocochlear disorder.

One useful technique is to obtain performance-intensity functions by testing word-recognition ability at several intensity levels and looking for the presence of rollover of the function. Rollover, as you will recall, is the unexpectedly poorer performance as intensity level is increased, a phenomenon associated with retrocochlear disorder. Often, however, such a disorder will escape detection of simple measures of word-recognition presented in quiet. Another technique is to evaluate speech recognition in background competition. Although those with normal neurologic systems will perform well on such measures, those with retrocochlear disorder are likely to perform more poorly than would be predicted from their hearing sensitivity loss.

Otoacoustic Emissions. Otoacoustic emissions can be used in the assessment of retrocochlear disorder, although the results

are often equivocal. If a hearing loss is caused by a retrocochlear disorder due to the disorder's primary effect on function of the VIIIth nerve, otoacoustic emissions may be normal despite the hearing loss. That is, the loss is caused by neural disorder, and the cochlea is functioning normally. However, in some cases a retrocochlear disorder can affect function of the cochlea, secondarily resulting in a hearing loss and abnormality of otoacoustic emissions. Thus, in the presence of a hearing loss and normal middle-ear function, the absence of OAEs indicates either cochlear or retrocochlear disorder. On the other hand, in the presence of a hearing loss, the preservation of OAEs suggests that the disorder is retrocochlear in nature.

Auditory Evoked Potentials. If suspicion of a retrocochlear disorder exists and if that suspicion is enhanced by the presence of audiometric indicators, it is quite common to assess the integrity of the auditory nervous system directly with the auditory brainstem response. The ABR is a sensitive indicator of the integrity of VIIIth nerve and auditory brainstem function. If it is abnormal, there is a very high likelihood of retrocochlear disorder.

In recent years, imaging techniques have improved to the point that structural changes in the nervous system can sometimes be identified before those changes have a functional influence. Thus, the presence of a normal ABR does not rule out the presence of a neurologic disease process. It simply indicates that the process is not having a measurable functional consequence. The presence of an abnormal ABR, however, remains a strong indicator of neurologic disorder and can be very helpful to the physician in the diagnosis of retrocochlear disease.

Illustrative Cases

Illustrative Case 10-5. Case 5 is a patient with an VIIIth nerve tumor on the left ear. The tumor is diagnosed as a cochleovestibular schwannoma. The patient is a 42-year-old man with a 6-month history of left-ear tinnitus. His health and hearing histories are otherwise unremarkable.

Immittance audiometry, as shown in Figure 10-5A is consistent with normal middle-ear function bilaterally, characterized by Type A

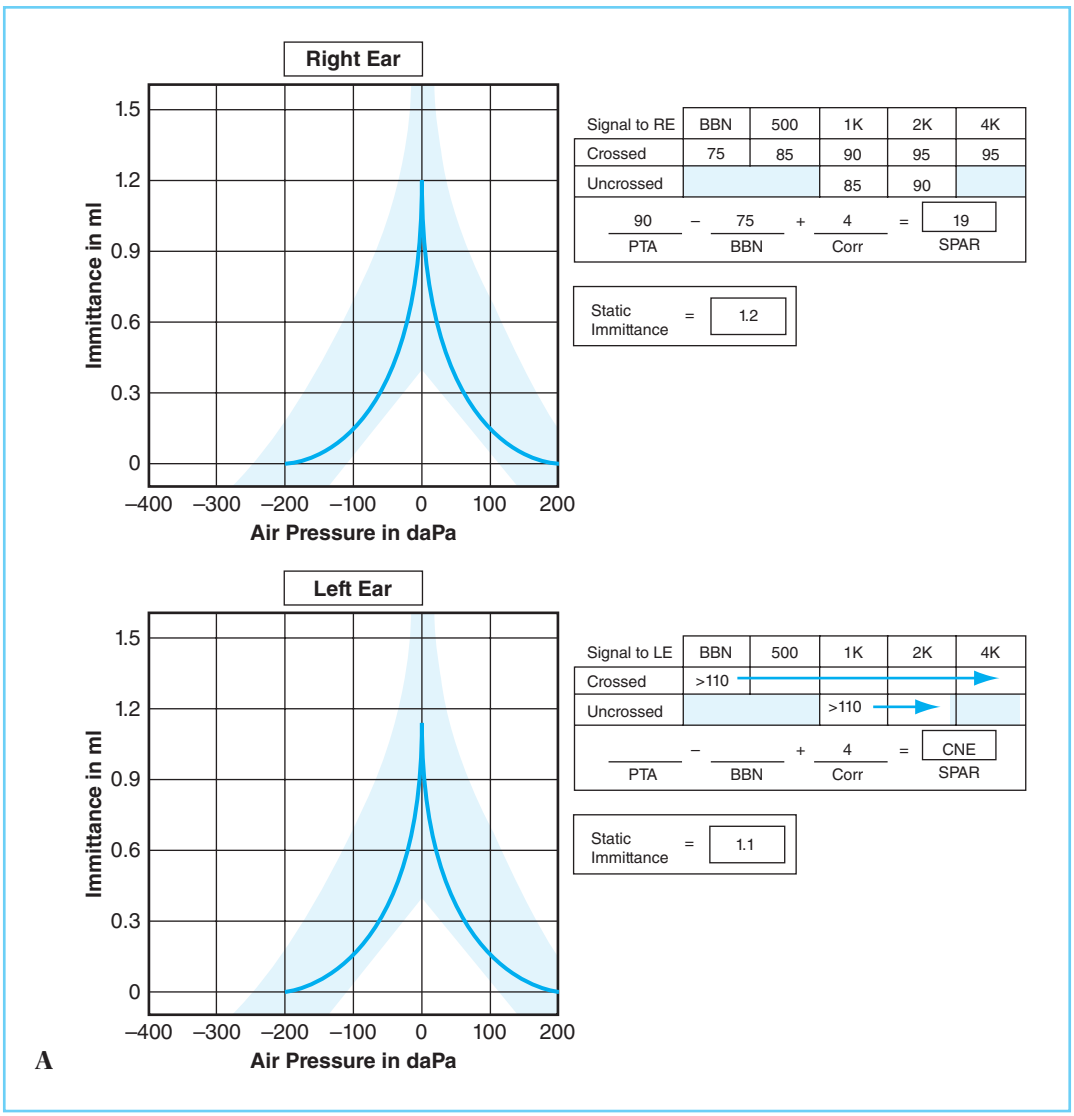
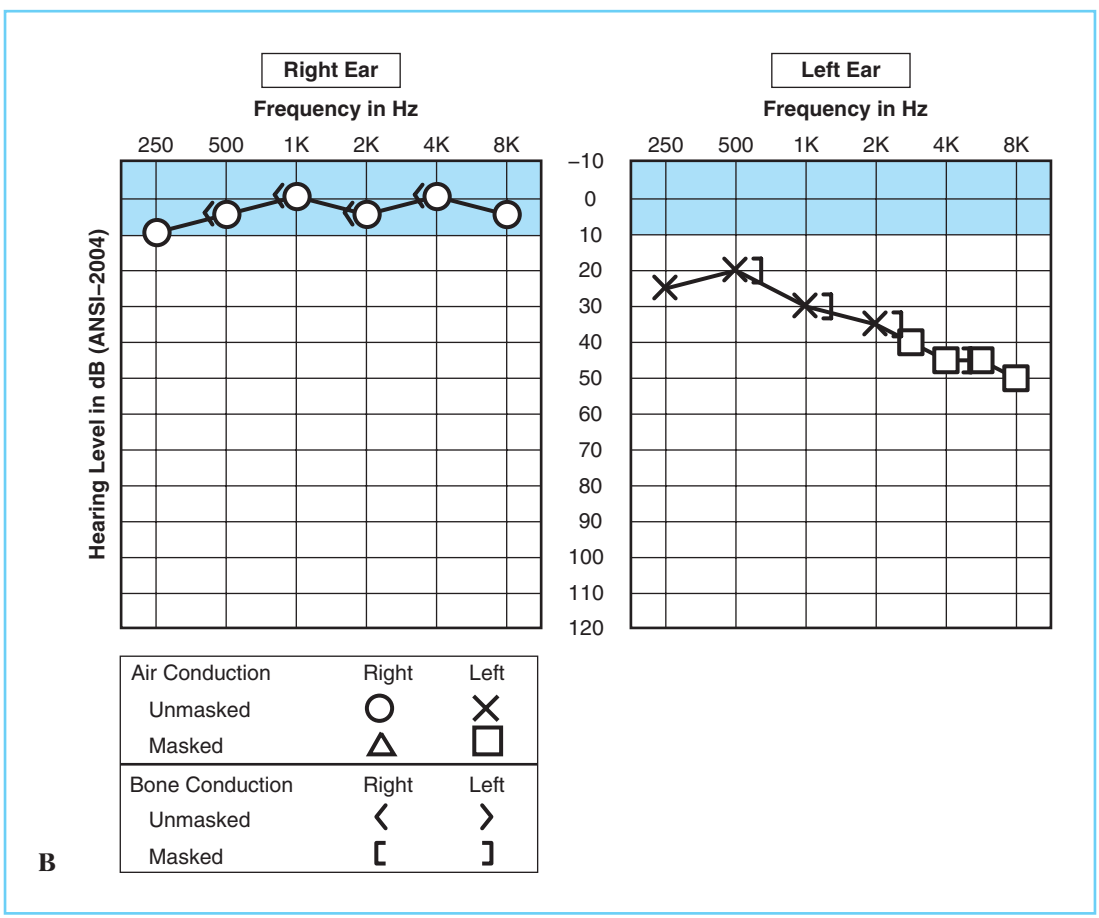


FIGURE 10-5 Hearing consultation results in a 42-year-old man with a left VIIIth nerve tumor. Immittance measures (A) are consistent with normal middle-ear function. Left crossed and left uncrossed reflexes are absent, consistent with left afferent disorder. Pure-tone audiometric results (B) show normal hearing sensitivity on the right and a mild, relatively flat sensorineural hearing loss on the left. Speech audiometric results (C) show rollover of the performance-intensity functions on the left ear. Auditory brainstem response results (D) show delayed latencies and prolonged interpeak intervals on the left ear, consistent with retrocochlear site of disorder.

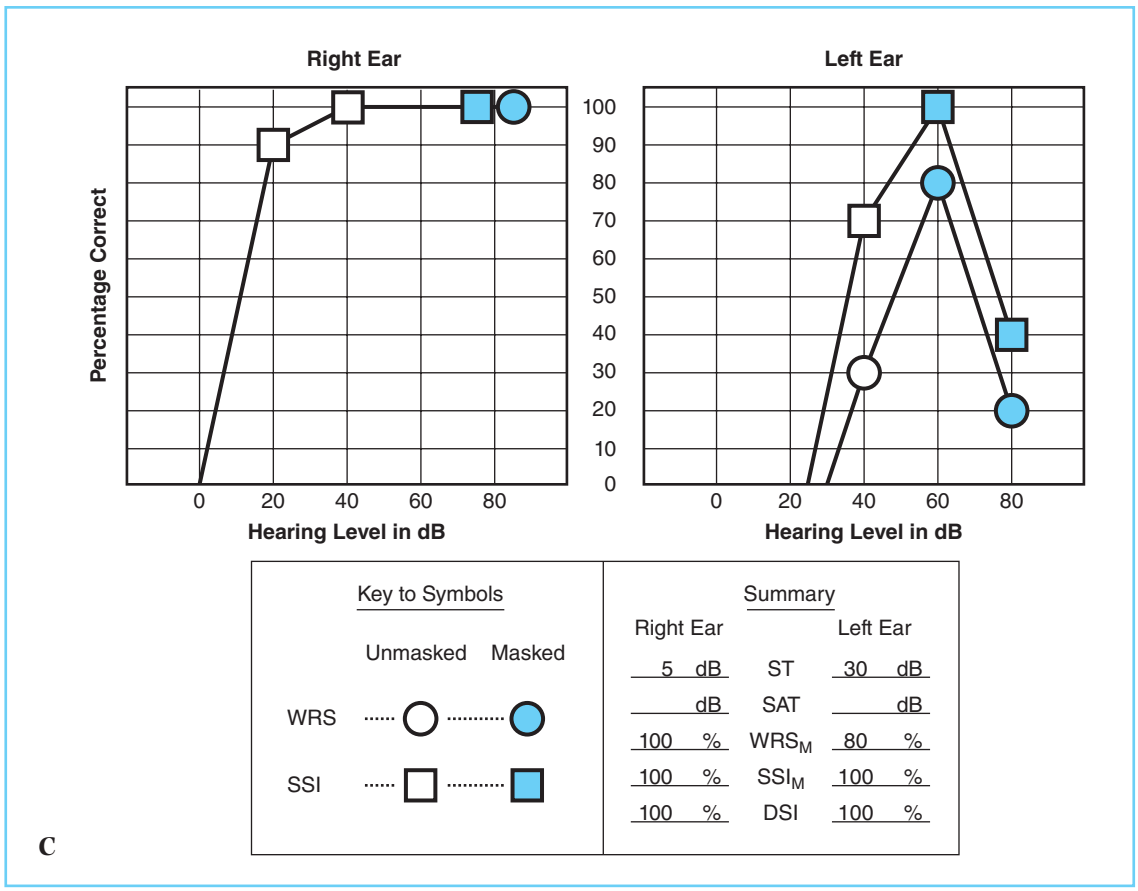
tympanograms, normal static immittance, and normal right crossed and right uncrossed reflex thresholds. Left crossed and left uncrossed reflexes are absent, consistent with some form of afferent abnormality on the left, in this case an VIIIth-nerve tumor.

Pure-tone audiometric results are shown in Figure 10-5B. The patient has normal hearing sensitivity on the right ear and a mild, relatively flat sensorineural hearing loss on the left.

Speech audiometric results, shown in Figure 10-5C, are normal on the right ear but abnormal on the left. Although maximum speech-recognition scores are normal at lower intensity levels, the performance-intensity function demonstrates significant rollover,



B

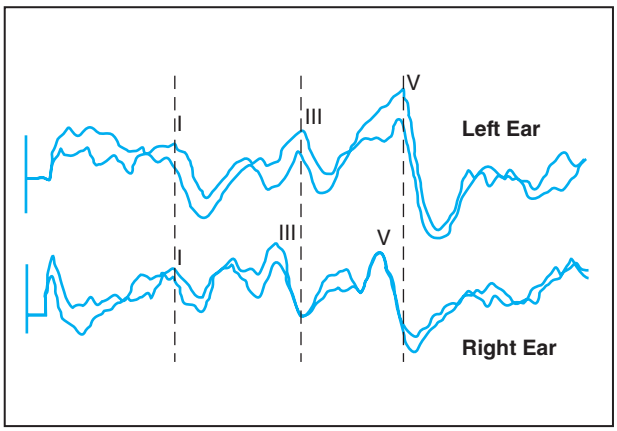


C

or poorer performance at higher intensity levels. This rollover is consistent with retrocochlear site of disorder.

Results of an auditory brainstem response assessment are shown in Figure 10-5D. Right ear results are normal. Left ear results show delayed latencies and prolonged interpeak intervals. These results are also consistent with retrocochlear site of disorder.

This patient had surgery to remove the tumor. Because the tumor was relatively small and the hearing relatively good, the surgeon opted to try a surgical approach to remove the tumor *and* preserve hearing. Hearing was monitored throughout the surgery, and postsurgical audiometric results showed that hearing was effectively preserved.



	Latency Wave V	Interwave Intervals		
		I-III	III-V	I-V
RE	5.9	1.9	2.0	3.9
LE	6.5	2.5	2.0	4.5

D Click Level: 90 dB nHL

Illustrative Case 10-6. Case 6 is a patient with auditory complaints secondary to multiple sclerosis. The patient is a 34-year-old woman. Two years prior to her evaluation, she experienced an episode of diplopia, or double vision, accompanied by a tingling sensation and weakness in her left leg. These symptoms gradually subsided and reappeared in slightly more severe form a year later. Ultimately, she was diagnosed with multiple sclerosis. Among various other symptoms, she had vague hearing complaints, particularly in the presence of background noise.

Immittance audiometry, as shown in Figure 10-6A is consistent with normal middle-ear function, characterized by a Type A tympanogram, normal static immittance, and normal right and left uncrossed reflex thresholds. However, crossed reflexes are absent bilaterally. This unusual pattern of results is consistent with a central pathway disorder of the lower brainstem.

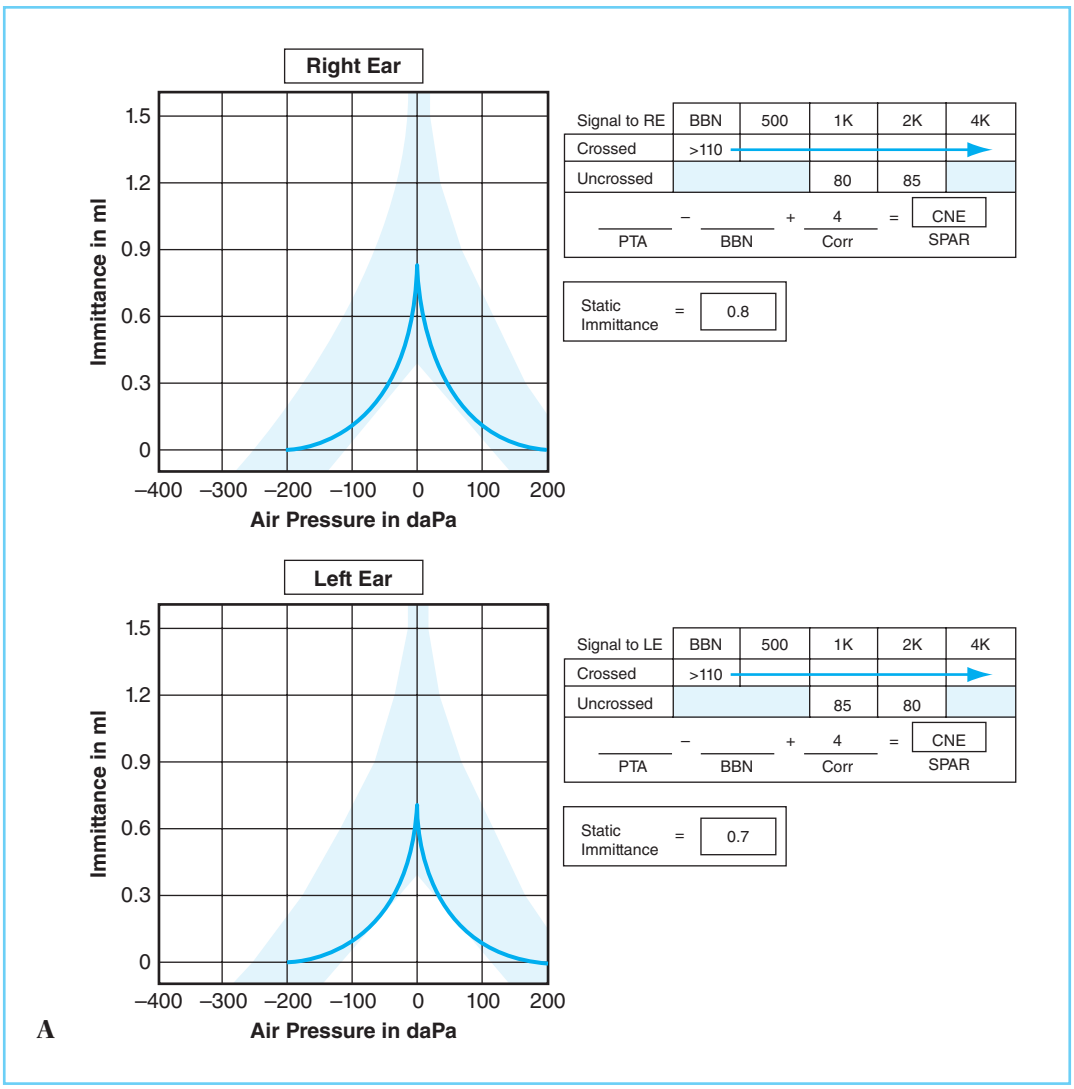
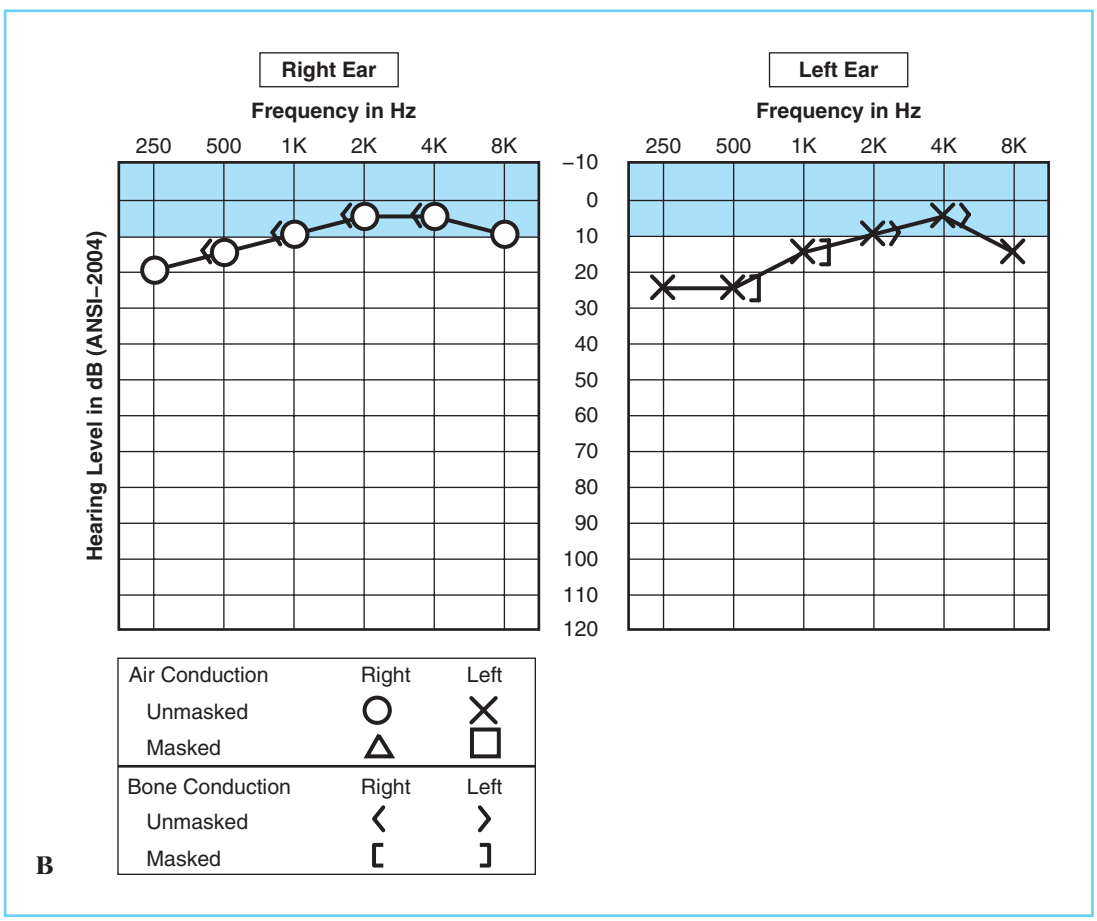


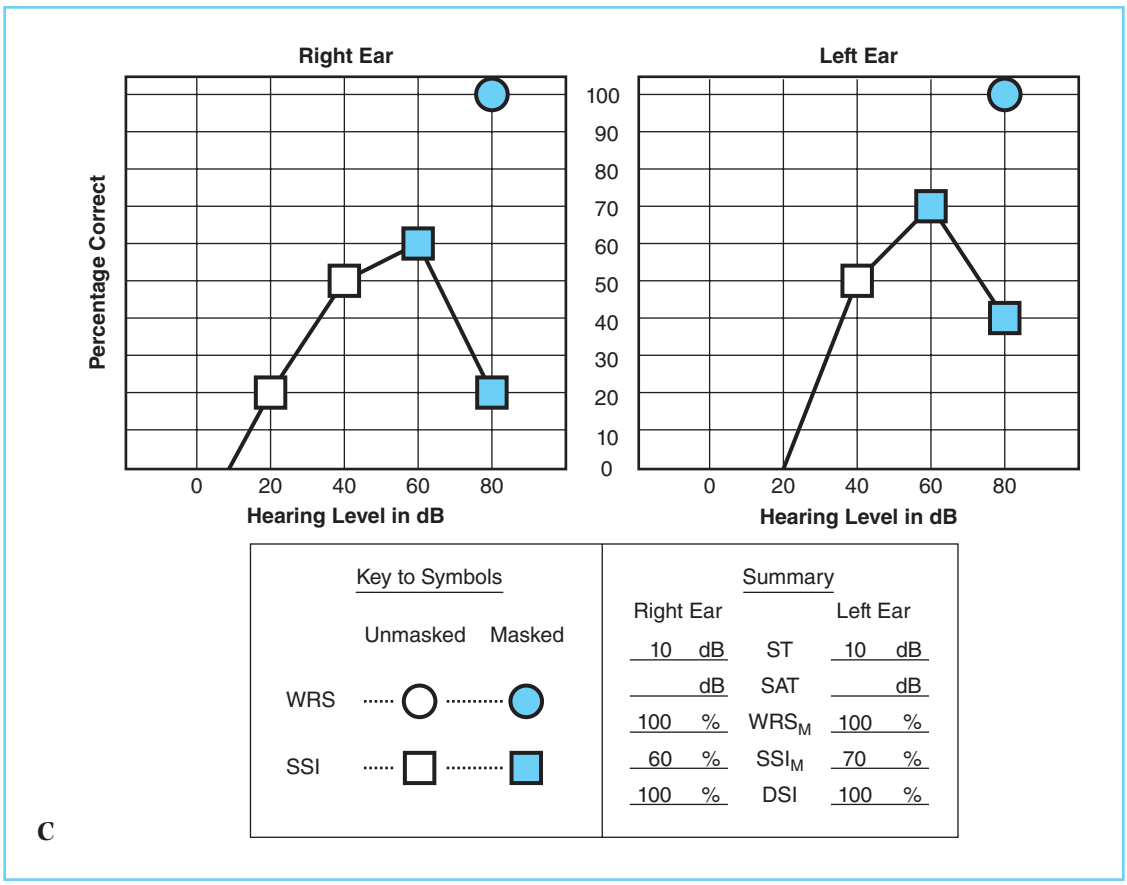
FIGURE 10-6 Hearing consultation results in a 34-year-old woman with multiple sclerosis. Immittance measures (A) are consistent with normal middle-ear function. However, left crossed and right crossed reflexes are absent, consistent with brainstem disorder. Pure-tone audiometric results (B) show mild low-frequency sensorineural hearing loss bilaterally. Speech audiometric results (C) show that word recognition in quiet is normal, but sentence recognition in competition is abnormal. Auditory brainstem response results (D) show no identifiable waves beyond Wave I on the left and significant prolongation of the Wave I-V interpeak interval on the right.

Pure-tone audiometric results are shown in Figure 10-6B. The patient has a mild low-frequency sensorineural hearing loss bilaterally.

Speech thresholds match pure-tone thresholds in both ears. However, suprathreshold speech-recognition performance is abnormal in both ears. Although speech-recognition scores are normal when words are presented in quiet, they are abnormal when sentences are presented in the presence of competition, as shown in Figure 10-6C. These results are consistent with retrocochlear disorder.



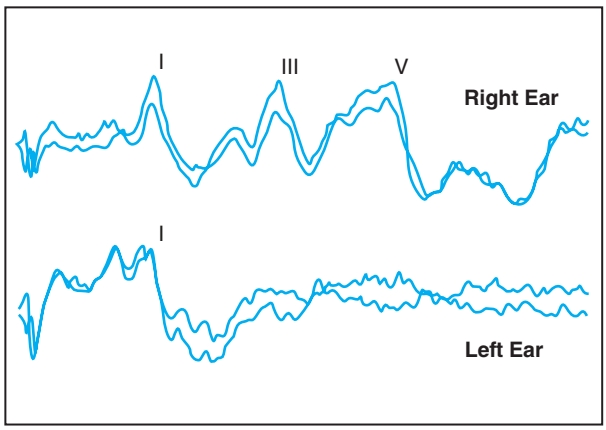
B



C

Auditory evoked potentials are also consistent with abnormality of brainstem function. Figure 10-6D shows auditory brainstem responses for both ears. On the left, no waves were identifiable beyond component Wave I, and on the right, absolute latencies and interpeak intervals were significantly prolonged.

Multiple sclerosis is commonly treated with chemotherapy in an attempt to keep it in its remission stage. Although the patient's auditory complaints were vague and subtle, she was informed of the availability of certain assistive listening devices that could be used if she was experiencing substantive difficulty during periods of exacerbation of the multiple sclerosis.



	Latency Wave V	Interwave Intervals		
		I-III	III-V	I-V
RE	6.6	2.3	2.3	4.6
LE	CNE	CNE	CNE	CNE

D Click Level: 80 dB nHL

ADULT AUDIOLOGIC REFERRALS

An audiologist's evaluation of a patient is aimed at diagnosing and treating hearing impairments that are caused by a disordered auditory system. The purpose of the evaluation is to quantify the degree and nature of the hearing impairment, assess its impact on a patient's communication ability, and plan and provide prosthetic and rehabilitative treatment for the impairment.

In some patients referred for audiologic purposes, the absence of active disease process has been determined. For example, some referrals for audiologic assessment are from otolaryngologists or other physicians who have ruled out the presence of active or medically treatable conditions. In other cases, the referral is a self-referral or emanates from some source other than the medical

community. In both cases, the audiologic assessment is carried out with vigilance for indicators of medically treatable conditions. The focus, however, is on the impact of the hearing loss on the individual's communication ability.

In general, audiologists are faced with two main categories of adult patients, those who are younger and have significant vocational communication demands and those who are older and have more complex auditory problems. Of course, age is not necessarily a factor, so that some of the older adults may fit into the younger category and vice versa. However, often the approach that is appropriate for patients who are elderly is different from that necessary for those who are younger, and the distinction seems worth making.

Younger Adults

Evaluative Goals

The main goals of the audiologic evaluation of adult patients are to assess the degree and type of hearing loss and to assess the impact that the hearing loss has on their communicative function. An important subgoal is to maintain vigilance for indicators of underlying conditions that might require medical attention.

Test Strategies

Immittance audiometry is used to evaluate outer- and middle-ear function, to indicate the presence of cochlear hearing loss, and to assess the integrity of VIIIth nerve and lower auditory brainstem function. Pure-tone audiometry is used to evaluate the degree and type of hearing loss. Speech audiometry is used as a cross-check of pure-tone thresholds and as an estimate of suprathreshold word-recognition ability. Both pure-tone and speech audiometric measures are used as prognostic indicators for the successful use of hearing aid amplification. Self-assessment measures are used to quantify the impact that the hearing impairment is having on communication ability.

Immittance Measures. A complete immittance battery is an important first step in the audiologic evaluation. It is important to assess the integrity of middle-ear function for several reasons. If it is abnormal, proper medical referrals may need to be made,

depending on the initial referral source. Also, results will direct the audiologist as to the need for bone-conduction testing. Should a middle-ear disorder cause a conductive hearing loss, the degree of the conductive component is likely to influence hearing aid fitting.

Immittance audiometry also provides valuable information about the cochlear hearing loss. If a loss is truly cochlear in origin, the tympanograms will be normal, static immittance will be normal, and acoustic reflex thresholds will be consistent with the degree of sensorineural hearing loss. A cochlear hearing loss will also cause an elevation of the acoustic reflex thresholds to noise stimuli relative to pure-tone stimuli, resulting in a reduced SPAR value. This information serves as an important cross-check of the organicity of the hearing loss.

Finally, immittance audiometry allows an assessment of the integrity of the auditory nervous system. If immittance audiometry is consistent with normal middle-ear function, but acoustic reflexes are elevated beyond a level that might be expected from the degree of sensorineural hearing loss, suspicion is raised about the possibility of retrocochlear disorder.

Pure-Tone Audiometry. Pure-tone audiometry is used to quantify the degree of conductive, sensorineural, or mixed hearing loss caused by the auditory disorder. If all immittance measures are normal, only air-conduction testing is necessary. Bone-conduction testing will not be necessary because outer- and middle-ear function are normal, and air-conducted signals will properly evaluate the sensitivity of the cochlea. If all immittance measures are not normal, air- and bone-conduction thresholds must be obtained for both ears to assess the possibility of the presence of a conductive or mixed hearing loss.

Correctly or incorrectly the audiogram itself has become the single most important metric in an audiologic evaluation. Nearly all estimates of hearing impairment, activity limitations and participation restrictions begin with this measure of hearing sensitivity as their basis. Gain, frequency response, and sometimes output limitations of hearing aids are also estimated based on the result of pure-tone audiometry.

Pure-tone audiometry is also an important measure for assessing symmetry of hearing loss. If a sensorineural hearing loss is asymmetric, in the absence of other explanations, then suspicion is raised about the possibility of the presence of retrocochlear disorder.

Speech Audiometry. Speech audiometry is used in several ways in the audiologic assessment of hearing disorder. First, speech-recognition thresholds are used as a cross-check of the validity of pure-tone thresholds in an effort to ensure the organicity of the disorder.

Second, word-recognition and other suprathreshold measures are used to assess whether the hearing loss has an expected influence on speech recognition. That is, in most cases, suprathreshold speech-recognition ability is predictable from the degree and configuration of a hearing loss if the loss is due to conductive or cochlear disorders. If not, then suspicion is aroused that the disorder may be retrocochlear in nature.

Third, speech-recognition measures are used for assessing the amount of impairment caused by a hearing loss and for assessing prognosis for successful hearing aid use. If a patient's speech-recognition ability is significantly reduced, he or she is likely to have greater impairment and reduced success with conventional hearing aid amplification.

Communication Needs Assessment. One final important aspect of the audiologic evaluation is an assessment of the impact that a hearing loss has on self-perception of communication ability (Ventry & Weinstein, 1982; Newman et al., 1991; Gate house, 1999). If the hearing loss is perceived to be limiting or restrictive, motivation for treatment and rehabilitation will be significantly higher than if the hearing loss is perceived to have little influence on communication. Thus, hearing self-assessment tools can be useful as prognostic indicators of hearing aid success. In addition, they can be used before and after intervention as a way of quantifying benefit received from the treatment.

Illustrative Case

Illustrative Case 10-7. Illustrative Case 7 is a patient with a history of exposure to excessive noise. The patient is a 54-year-old

man with bilateral sensorineural hearing loss that has progressed slowly over the last 20 years. He has a positive history of noise exposure, first during military service and then at his workplace. In addition, he is an avid hunter. The patient reports that he has used hearing protection on occasion in the past, but has not done so on a consistent basis. He was having his hearing tested at the urging of family members who were having increasing difficulty communicating with him.

Immittance audiometry, as shown in Figure 10-7A, is consistent with normal middle-ear function, characterized by a Type A tympanogram, normal static immittance, and normal crossed and uncrossed reflex thresholds bilaterally.

Pure-tone audiometric results are shown in Figure 10-7B. The patient has a bilateral, fairly symmetric, high-frequency sensorineural hearing loss. The loss is greatest at 4000 Hz.

Speech audiometric results are consistent with the degree and configuration of cochlear hearing loss. First, the speech thresholds match the pure-tone thresholds. Second, the word-recognition scores, although reduced, are consistent with this degree of hearing loss.

The patient also completed a communication needs assessment. Results showed that he has communication problems a significant proportion of the time that he spends in certain listening environments, especially those involving background noise.

The hearing loss is sensorineural in nature, resulting from exposure to excessive noise over long periods of time. It is not amenable to surgical or medical intervention. Because the patient is experiencing significant communication problems due to the hearing loss, he is a candidate for hearing aid amplification. A hearing aid consultation was recommended.

Older Adults

Evaluative Goals

The goals in evaluating older adults are similar to those in younger adults. However, the complexity of auditory disorders experienced

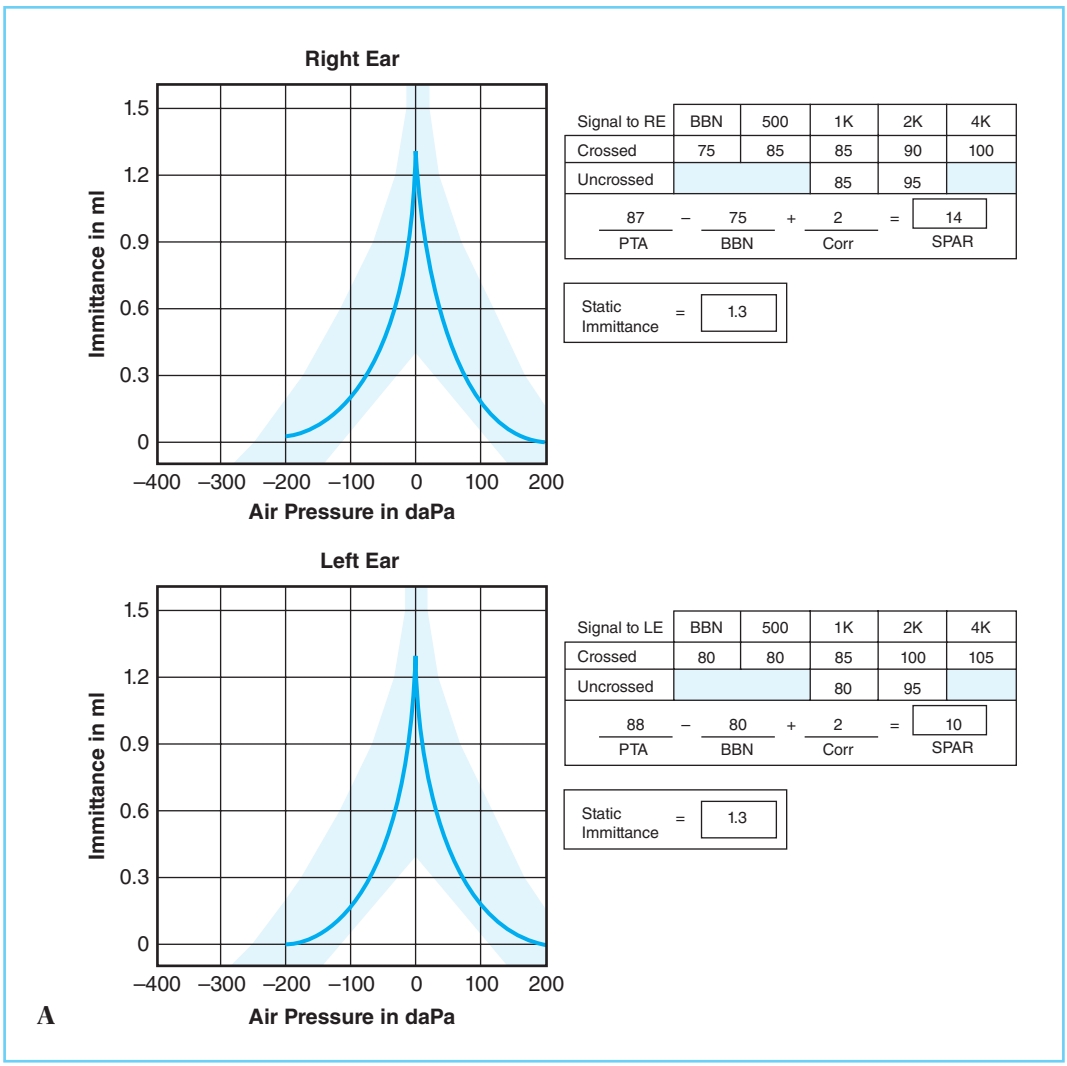
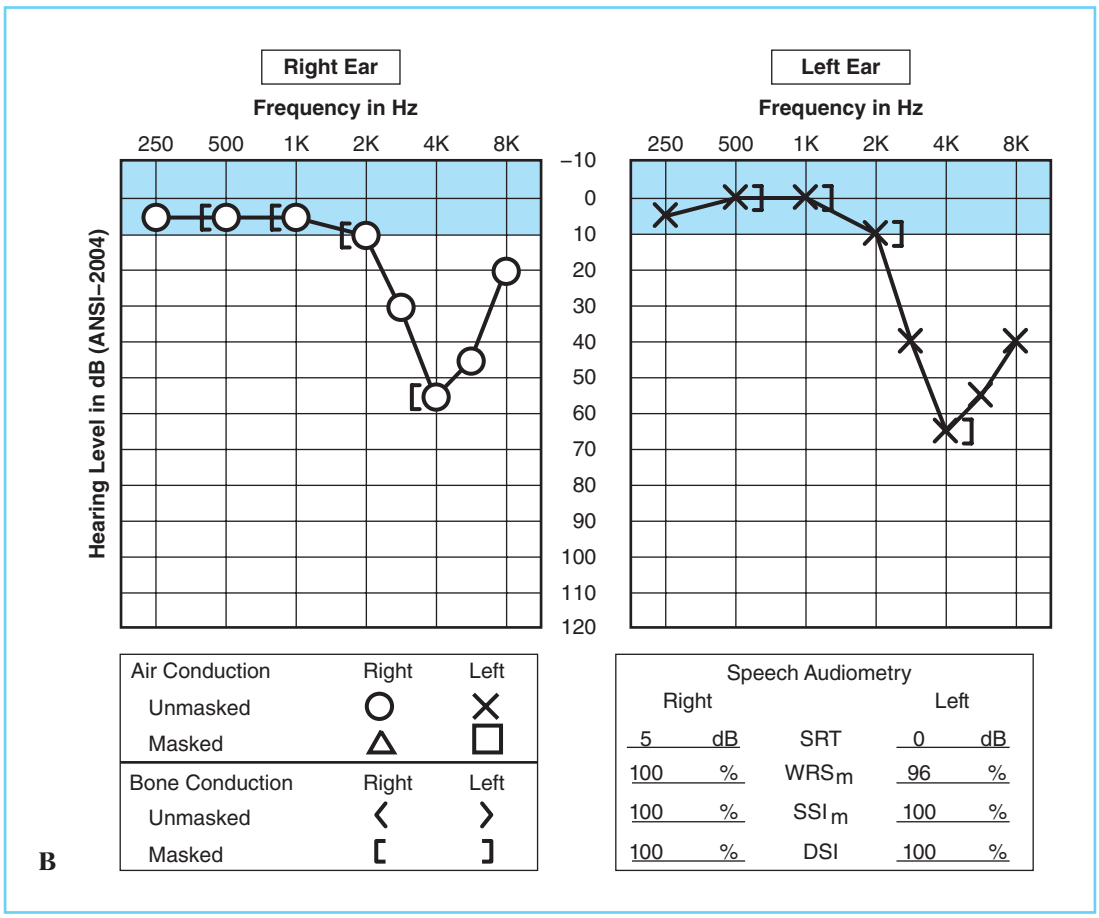


FIGURE 10-7 Hearing consultation results in a 54-year-old man with noise-induced hearing loss. Immittance measures (A) are consistent with normal middle-ear function. Pure-tone audiometric results (B) show high-frequency sensorineural hearing loss bilaterally, greatest at 4000 Hz. Speech audiometric results are consistent with the degree and configuration of cochlear hearing loss.

by many older people suggests the need for more rigor in the assessment of their communication function (Stach, 2007).

Test Strategies

Strategies used for immittance audiometry, pure-tone audiometry, and communication needs assessment are similar to those used



B

for younger adults. The major difference in assessment strategy is in speech audiometry.

Speech Audiometry. The aging of the auditory mechanism results in complex changes in function of the cochlea and central auditory nervous system (Willott, 1996). These changes appear to have an important negative influence on hearing of older individuals, particularly in their ability to hear rapid speech (Fitzgibbons & Gordon-Salant, 1996) and to hear speech in the presence of background competition (Jerger et al., 1989). Assessment of older people should include quantification of such changes.

In addition to routine speech audiometric measures, speech recognition in background competition should be assessed. If a patient

has difficulty identifying speech under fairly easy listening conditions, the prognosis for successful use of conventional hearing aids is likely to be reduced. Older individuals may also have reduced ability in using both ears (Jerger et al., 1993). Assessment of dichotic speech recognition provides an estimate of their ability to use two ears to separate different signals. Patients with dichotic deficits may find it difficult to wear binaural hearing aids (Jerger et al., 1995). Finally, older people seem to have greater difficulty processing rapid speech. Assessment of this ability may help to understand the influence that their hearing disorder has on communication ability.

Illustrative Case

Illustrative Case 10-8. Illustrative Case 8 is an elderly patient with a long-standing sensorineural hearing loss. The patient is a 78-year-old woman with bilateral sensorineural hearing loss that has progressed slowly over the last 15 years. She has worn hearing aids for the last 10 years, and has an annual audiologic re-evaluation each year. Her major complaints are in communicating with her grandchildren and trying to hear in noisy cafeterias and restaurants. Although her hearing aids worked well for her at the beginning, she is not receiving the benefit from them that she did 10 years ago.

Immittance audiometry, as shown in Figure 10-8A, is consistent with normal middle-ear function, characterized by a Type A tympanogram, normal static immittance, and normal crossed and uncrossed reflex thresholds bilaterally.

Pure-tone audiometric results are shown in Figure 10-8B. The patient has a bilateral, symmetric, moderate, sensorineural hearing loss. Hearing sensitivity is slightly better in the low frequencies than in the high frequencies.

Speech audiometric results are consistent with those found in older patients. Speech thresholds match pure-tone thresholds. Word-recognition scores are reduced, but not below a level predictable from the degree of hearing sensitivity loss. However, speech recognition in the presence of competition is substantially reduced, as shown in Figure 10-8C, consistent with the patient's age.

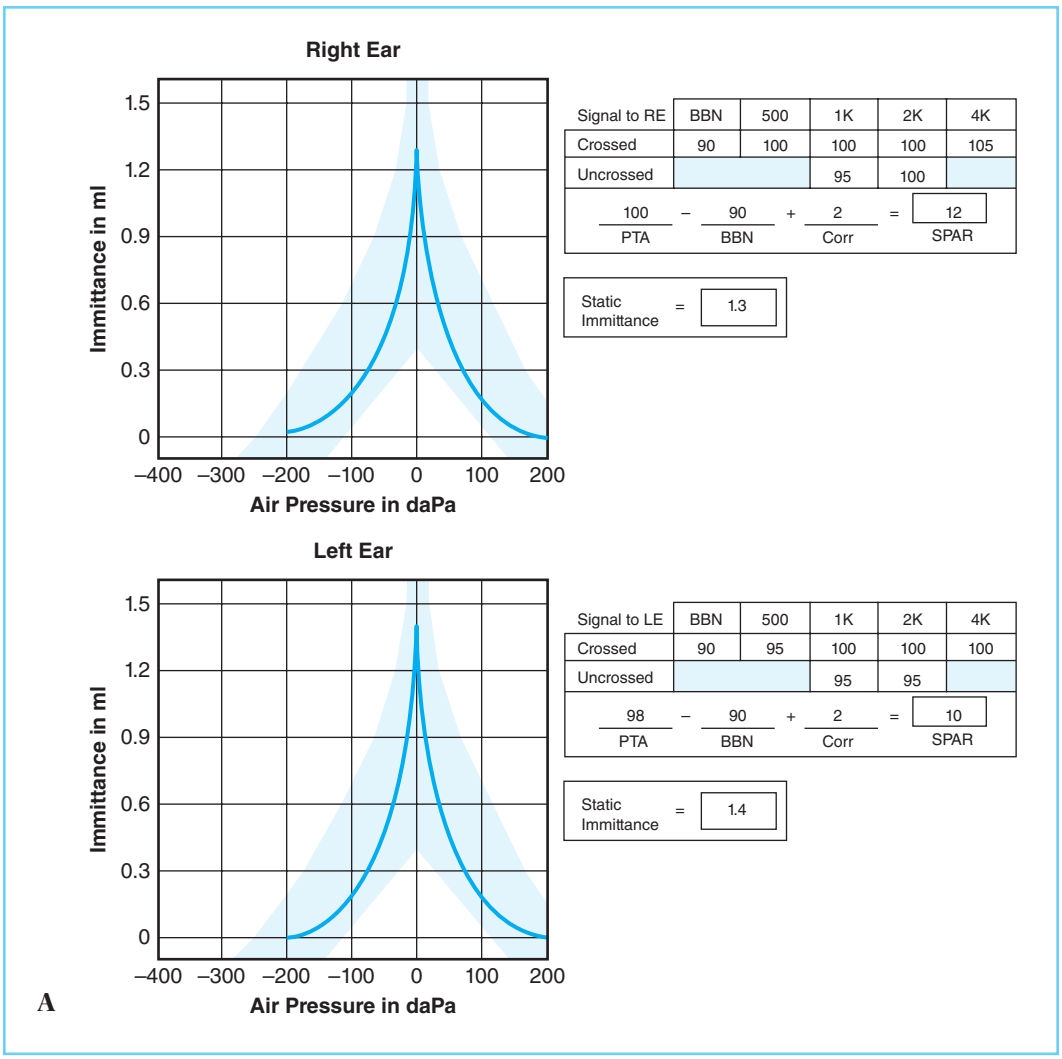
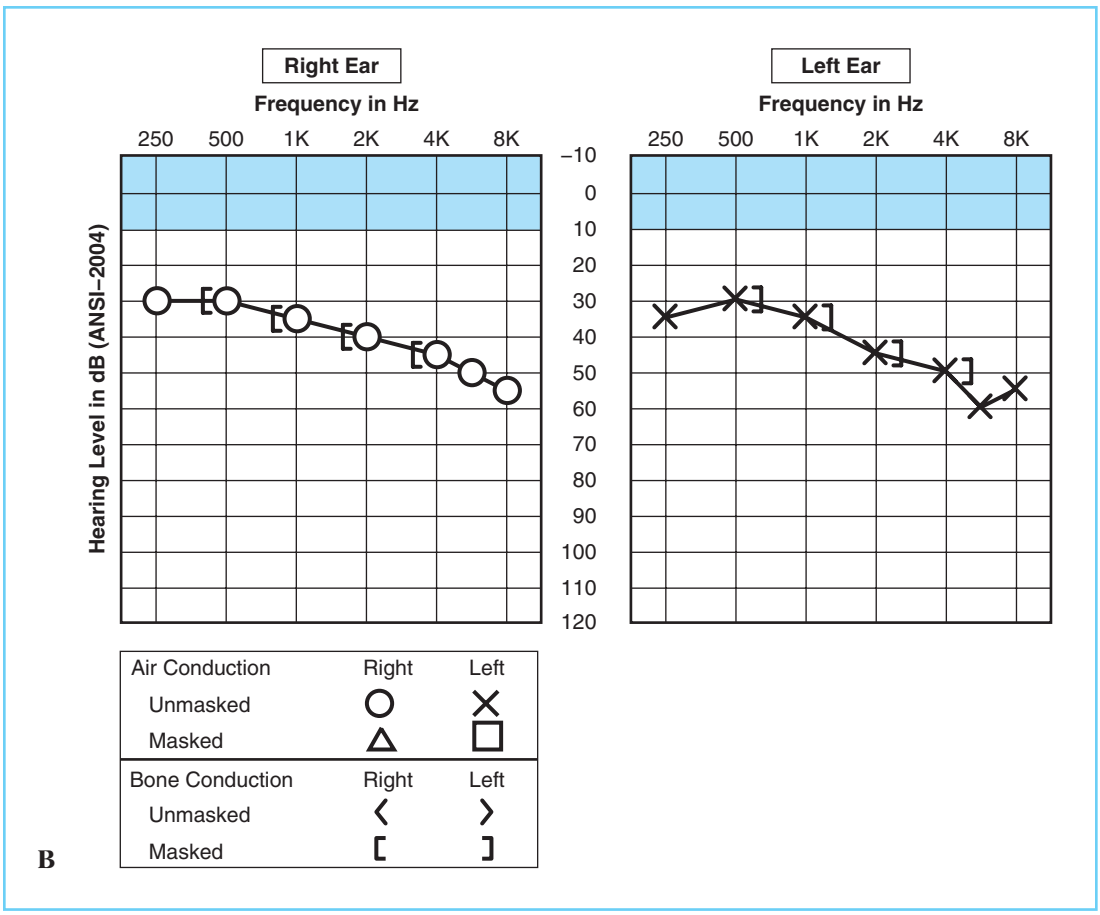


FIGURE 10-8 Hearing consultation results in a 78-year-old woman with long-standing, progressive hearing loss. Immittance measures (A) are consistent with normal middle-ear function. Pure-tone audiometric results (B) show bilateral, symmetric, moderate, sensorineural hearing loss. Speech audiometric results (C) show reduced word recognition in quiet, consistent with the degree and configuration of cochlear hearing loss. Sentence recognition in competition is substantially reduced, as is dichotic performance.

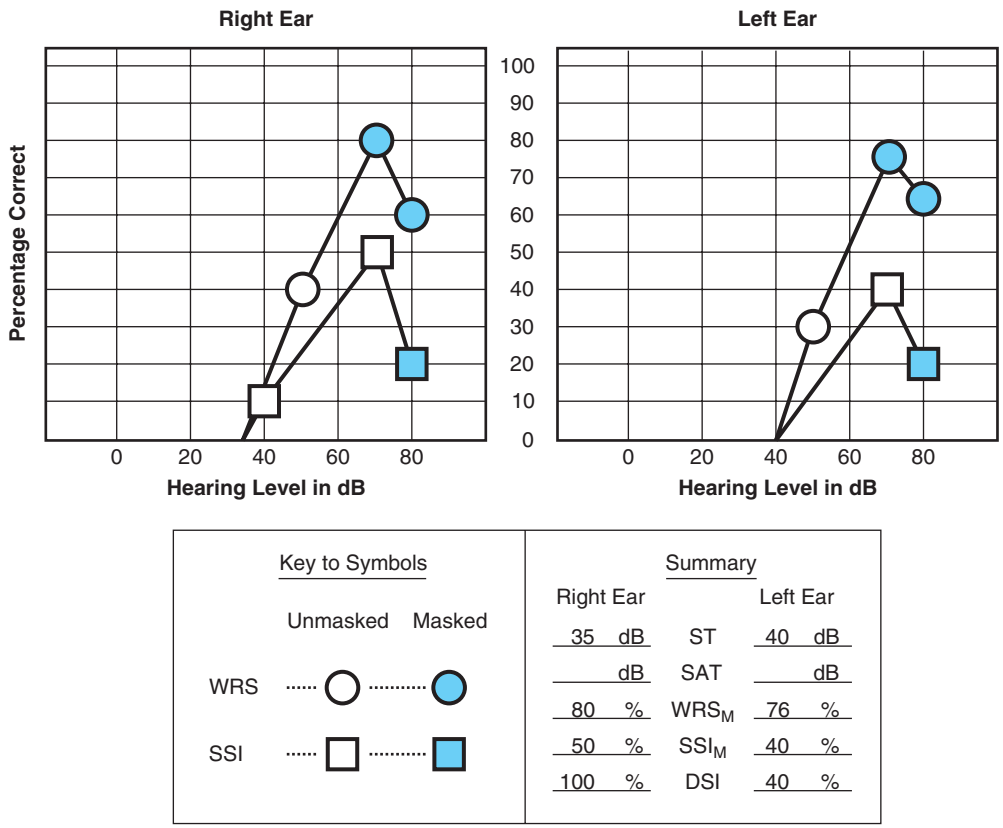


B

She also shows evidence of a dichotic deficit, with reduced performance in the left ear.

Results of the communication needs assessment show that she has communication problems a significant proportion of the time in most listening environments, especially those involving background noise.

The patient currently uses hearing aid amplification with some success, especially in quiet environments. Output of the hearing aids showed them to be functioning as expected. This patient may benefit from the use of assistive listening devices, and a consultation to discuss these alternatives was recommended.



C

PEDIATRIC AUDIOLOGIC REFERRALS

An audiologist's evaluation of an infant or child is aimed first at identifying the existence of an auditory disorder and then quantifying the degree of impairment resulting from the disorder. Once the degree and nature of the hearing impairment have been quantified, the goal is to assess its impact on the child's communication ability and plan and provide prosthetic and rehabilitative treatment for the impairment.

In general, the audiologist is faced with three main challenges in the assessment of infants and children. The first challenge is to identify children who are at risk for hearing loss and need

further evaluation. Infant hearing screening takes place shortly after birth, and pediatric hearing screening usually occurs at the time of enrollment in school. The goal here is to identify, as early as possible, children with hearing loss of a magnitude sufficient to interfere with speech and language development or academic achievement.

The second challenge is to determine if the children identified as being at risk for auditory disorder actually have a hearing loss and, if so, to determine the nature and degree of the loss. The goal here is to differentiate outer- and middle-ear disorder from cochlear disorder and to quantify the resultant conductive and sensorineural hearing loss.

The third challenge is to assess the hearing ability of preschool and early school-age children suspected of having auditory processing disorders. The goal here is to try to identify the nature and quantify the extent of suprathreshold hearing deficits in children who generally have normal hearing sensitivity but exhibit hearing difficulties.

Infant Screening

Evaluative Goals

The goal of an infant hearing screening program is to identify infants who are at risk for significant permanent hearing loss and require further audiologic testing. The challenge of any screening program is to both capture all children who are at risk and, with similar accuracy, identify those children who are normal or not at risk. Several methods have been employed in an effort to meet this challenge, some with more success than others.

Test Strategies

Prenatal pertains to the time period before birth.

Perinatal pertains to the period around the time of birth, from the 28th week of gestation through the 7th day following delivery.

Two approaches are taken to screening: (1) to identify those children who have significant sensorineural, permanent conductive, or neural hearing loss at birth; and (2) to identify those children who are at risk for delayed-onset or progressive hearing loss. Efforts to identify children who are at risk involve mainly an evaluation of **prenatal**, **perinatal**, and parental factors that place a child at greater risk for having delayed-onset or progressive sensorineural hearing loss. To identify those with hearing loss at birth, current

practice in the United States is to screen the hearing of all babies before they are discharged from the hospital or birthing center. Those who pass the screening and have no risk factors are generally not re-screened but are monitored for communication development during childhood evaluations in their medical home. Those who pass the initial screening but have risk factors are tested periodically throughout early childhood to ensure that hearing loss has not developed. Those who do not pass the initial screening are re-screened or scheduled to return for re-screening. A failed re-screening leads to a more thorough audiological evaluation. The goal of the initial screening, then, is to identify those infants who need additional testing, some percentage of whom will have permanent, sensorineural, conductive, or neural hearing loss.

Another perspective on the screening strategy is to view it as a way, not of identifying those who might have significant hearing loss, but of identifying those who have normal hearing. That is, most newborns have normal hearing. Hearing loss occurs in 1 to 3 of 1,000 births annually (Finitzo et al., 1998). Thus, if you were attempting to screen the hearing of all newborns, you might want to develop strategies that focus on identifying those who are normal, leaving the remainder to be evaluated with a full audiologic assessment.

Initial hearing screening is now accomplished most successfully with automated ABR testing (Sininger, 2007). A description of the screening techniques can be found in Chapter 9. A summary of the benefits and challenges of these techniques as they relate specifically to the screening process follows.

Risk Factors. Several factors have been identified as placing a newborn at risk for sensorineural hearing loss. A list of those factors was delineated previously in Table 5-1. For many years, such factors were used as a way of reducing the number of children whose hearing needed to be screened or to be monitored carefully over time. Applying risk factors was successful in at least one important way. The percentage of the general population of newborns who have risk factors is reasonably low, and the relative proportion of those who actually have hearing loss is fairly high. Conversely, the number of infants in the general population who do not have risk factors is high, and the proportion with hearing

loss is relatively much lower. So if you were to concentrate your efforts on one population, it makes sense to focus on the smaller, at-risk population, because your return on investment of time and resources would be much higher.

The major problem with using risk factors alone is that there are probably as many children with significant sensorineural hearing loss who fall into the at-risk category as there are children who do not appear to have any risk factors. Thus, although the prevalence of hearing loss in the at-risk population is significantly higher than in the nonrisk population, the numbers of children are the same. Thus, limiting your screening approach to this population would identify only about half of those with significant sensorineural hearing loss.

The current practice in the United States is to screen hearing of all newborns. Infants who fail are considered necessarily at risk for hearing loss and are referred for re-screening. Those who have risk factors for progressive hearing loss are also referred for re-screening and periodic follow-up testing. Risk factors for progressive hearing loss are delineated in Table 5-1 and include:

- family history,
- cytomegalovirus (CMV) infection, and
- syndromes associated with progressive loss.

Behavioral Screening. Early efforts to screen hearing involved the presentation of relatively high-level acoustic signals and the observation, in one manner or another, of outward changes in an infant's behaviors. Typical behaviors that can be observed include alerting movements, cessation of sucking, changes in breathing, and so on.

Although successful in identifying some babies with significant sensorineural hearing loss, the approach proved to be less than adequate when viewed on the basis of its test characteristics. From that perspective, too many infants with significant hearing loss passed the screening, and too many infants with normal hearing sensitivity failed the screening. Applied to a specific high-risk population and carried out with sufficient care, the approach was useful in its time. Applied generally to the newborn population, this approach no longer meets current screening standards.

Auditory Brainstem Response Screening. For a number of years, measurement of the auditory brainstem response has been used successfully in the screening of newborns. Initial application of this technology was limited mainly to the intensive care nursery, where risk factors were greatest. The cost of the procedure and the skill level of the audiologist needed to carry out such testing simply precluded its application to wider populations. Nevertheless, its accuracy in identifying children with significant sensorineural hearing loss made it an excellent tool for screening hearing.

Limitations to using the ABR for screening purposes are few. One is the cost of widespread application as described above. Another is the occasional problem of electrical interference with other equipment, which is especially challenging in an environment such as an intensive care unit. One other limitation is that, due to neuromaturational delays, especially in infants who are at risk, the auditory brainstem response may not be fully formed at birth, despite normal cochlear hearing function. Thus an infant might fail an ABR screening and still have normal hearing sensitivity. The other side of that coin is that the ABR is quite good at not missing children who have significant hearing loss.

Automated ABR (AABR) strategies have now been implemented which address the issue of widespread application of the technology for infant screening. These automated approaches are designed to be easy to administer and result in a "Pass" or "No-Pass" decision (for a review, see Sininger, 2007). Automation allows the procedure to be administered by technical and support staff in a routine manner that can be applied to all newborns.

Otoacoustic Emissions Screening. In general, otoacoustic emissions are present in ears with normally functioning cochleas and absent in ears with more than mild sensorineural hearing losses. In this way, OAE measurement initially appeared to be an excellent strategy for infant hearing screening. When OAEs are absent, a hearing disorder is present, making it useful in identifying those who need additional assessment. When OAEs are present, it generally means that the outer, middle, and inner ears are functioning properly and that hearing sensitivity should be normal or nearly so.

When something is open or unobstructed, it is **patent.**

Limitations to using OAEs for screening purposes are few, but important. One is that they are more easily recorded in quieter environments. This can be challenging in a noisy nursery. Another is that the technique is susceptible to obstruction in sound transmission of the outer and middle ears. Thus, an ear canal of a newborn that is not **patent** or contains fluid, as many do, will result in the absence of an OAE, even if cochlear function is normal. The result is similar for middle-ear disorder. This susceptibility to these peripheral influences can make OAE screening challenging, resulting in too many normal children failing the screen.

A more important limitation to OAE use in screening is that some infants with significant auditory disorder have quite normal and healthy OAEs. Recall from the discussion in Chapter 4, that there is a group of disorders termed *auditory neuropathy* that share the common clinical signs of absent ABR, present OAE, and significant hearing sensitivity loss. Perhaps as many as one in four infants with significant hearing loss, presumably of inner hair cell origin, has preserved outer hair cell function and measurable OAEs. These children would be missed if screened exclusively with OAE measure.

Combined Approaches. There are advantages and disadvantages to all screening techniques. Most of the disadvantages can be overcome by combining techniques in a careful and systematic way. Current practice relies on automated ABR as the initial screening technique in regular care nurseries and regular, nonautomated ABR in intensive care nurseries. If there is evidence of neural synchrony in an infant during the initial screening, for example, a response recorded in one ear or at higher intensity levels, then follow-up screening can be safely accomplished with OAE measures. This type of combined strategy can help to reduce the problems of overreferral for additional testing.

Illustrative Case

Illustrative Case 10-9. Illustrative Case 9 is an infant born in a regular-care nursery. She was the product of a normal pregnancy and delivery. There is no reported family history of hearing loss, and the infant does not fall into any of the risk-factor categories for hearing loss. She was tested within the first 24 hours after

birth as part of a program that provides infant hearing screening for all newborns at her local hospital.

The child was screened with automated ABR. The automated instrument delivered what was judged to be a valid test and could not detect the presence of an ABR to clicks presented at 35 dB HL.

Results of an ABR threshold assessment are shown in Figure 10-9. ABRs were recorded in both ears down to 60 dB by air conduction. No responses could be recorded by bone conduction at equipment limits of 40 dB. These results predict the presence of a moderate, primarily sensorineural hearing loss bilaterally.

This child is not likely to develop speech and language normally without hearing aid intervention. Ear impressions were made, and a hearing aid evaluation was scheduled.

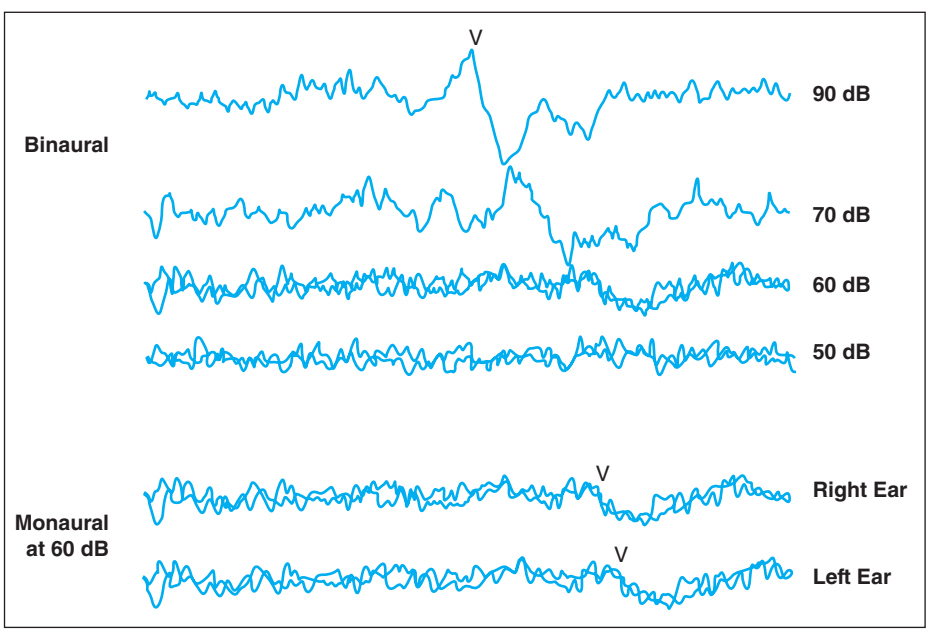


FIGURE 10-9 Results of ABR thereshold assessment in a newborn who failed an AABR screening. ABRs were recorded down to 60 dB in both ears, consistent with a moderate sensorineural hearing loss.

Pediatric Evaluation

Evaluative Goals

The goals of a pediatric evaluation are to (1) identify the existence of an auditory disorder, (2) identify the nature of the disorder, and (3) identify the nature and extent of the hearing impairment caused by the disorder. Although these goals are not unlike those of the adult evaluation, infants and young children present special challenges in reaching them.

A child who has been referred for an audiologic consultation has usually been screened and determined to be at risk for hearing impairment. Infants are usually referred because they have failed a hearing screening or have some other known risk factor for hearing loss. Young children are usually referred either because their speech and language are not developing normally or because they have otologic disease, and a physician is interested in understanding its effect on hearing. Older children are usually referred because of an otologic problem, because they have failed a school screening, or because they are suspected of having auditory processing disorder.

The goals of the evaluation for each of these groups will vary depending on the reason for referral and the nature of the referral source. The approach can vary depending on the nature of the goal. For example, in young infants, the question is often an audiologic one, not an otologic one. In young children, it can be either. In older children, it might not even be related to hearing sensitivity, but rather to suprathreshold auditory ability.

Test Strategies

The following are guidelines for test strategies based on chronologic age. Because the relationship of chronologic age to functional age varies from child to child, there may be considerable overlap in these age categories.

In most clinical settings, despite whatever screening might have led to a referral, many if not most children who are evaluated end up having normal hearing sensitivity. As unusual as it may seem, much of a pediatric audiologist's time is spent evaluating children with normal hearing. As such, test strategies tend to be designed

around quickly identifying normal-hearing children so that resources can be committed to evaluating children who truly have hearing impairment. So the process of pediatric assessment may begin with more of a screening approach, again aimed at eliminating from further testing those individuals who do not require it.

Infants 0 to 6 Months. Infants are usually referred for audiologic consultation because they failed a hearing screening or because they have been identified as being at risk for hearing loss. Many of these patients have normal hearing. Thus, the approach to their assessment is usually one of re-screening, followed by assessment and confirmation of hearing loss in those who fail the re-screening. A diagram of the approach is shown in Figure 10-10.

A productive approach to the initial re-screening is to combine tympanometry, ABR screening, and/or OAE measurement

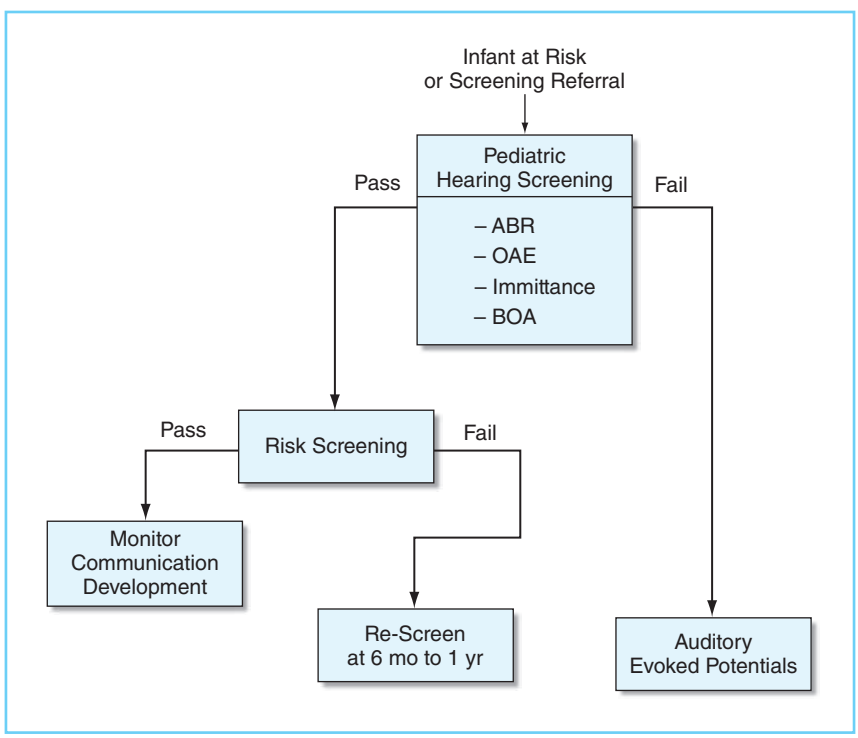


FIGURE 10-10 Hearing consultation model for infants age 0 to 6 months. The model begins with screening, followed by re-screening, and then by assessment of hearing sensitivity in those who do not pass the screening.

in combination with behavioral observation audiometry in an effort to identify those with normal hearing. With proper preparation, infants are likely to sleep through ABR re-screenings. In cases when they will not sleep, OAEs can be used as an alternative. Precautions must be taken, however, to ensure that the child has the requisite neural synchrony to have normal hearing sensitivity. OAE measurement alone will not suffice. In these cases, the wise audiologist will insist on some other evidence of adequate hearing such as behavioral observation audiometry.

Otoacoustic emissions can be carried out routinely in this population. Tympanometry is a bit more challenging, however, due mostly to ear canal size. Results of tympanometry are more valid with use of a higher frequency probe tone than is customary for older children and adults (Baldwin, 2006). Nevertheless, tympanometry can give a general impression of the integrity of middle ear function at this age, especially if it is abnormal.

Sound field is an area or room into which sound is introduced via a loudspeaker.

Behavioral observation audiometry involves the controlled presentation of signals in a **sound field** and careful observation of the infant's response to those signals (Madell, 1998). Minimal response levels to signals across a frequency range can be determined with a fair degree of accuracy and reliability, even in young infants.

The combination of OAEs, tympanometry, ABR screening, and behavioral audiometry should determine the need for additional audiologic testing. If an infant is found to have normal cochlear and middle-ear function, the child passes the hearing screening, and no further testing is required. If the child does not pass the screening, then a hearing loss may exist, and the child should be evaluated further with auditory evoked potentials.

Auditory brainstem response audiometry is used to verify the existence of a hearing loss, help determine the nature of the hearing loss, and quantify the degree of loss. Judicious use of ABR measures will provide an estimate of the type, degree, and slope of the hearing loss. In addition, auditory steady-state responses can be used effectively at this age to predict an audiogram with adequate precision.

Children 6 Months to 2 Years. Young children are usually referred to an audiologist (1) because they have risk factors for progressive hearing loss, (2) as part of an otologic evaluation of middle-ear disorder, (3) for audiologic consultation because the parents or caregivers are concerned about hearing loss, or (4) the child has failed to develop speech and language as expected. Many of these patients have middle-ear disorder, and many have normal hearing. Thus, the first step in their assessment is again almost a screening approach, followed by assessment and confirmation of middle-ear disorder and hearing loss in those who fail the screening. A diagram of the approach is shown in Figure 10-11.

A useful way to begin the assessment is by measuring otoacoustic emissions. If emissions are normal, the middle-ear mechanism is normal. If a sensorineural hearing loss exists, it is no more than a

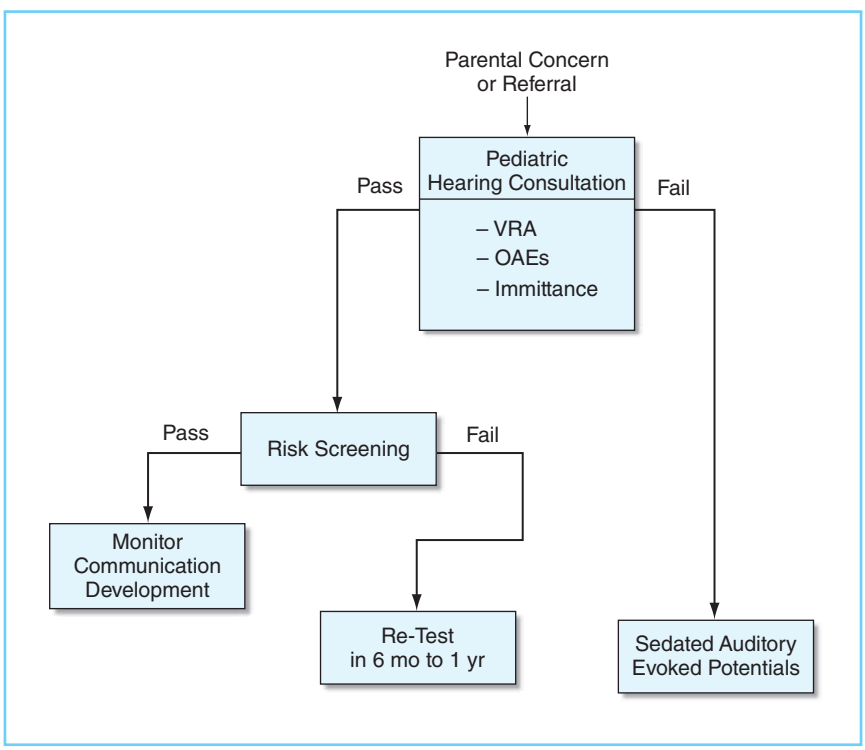


FIGURE 10-11 A pediatric hearing consultation model for assessing children age 6 months to 2 years. The model begins with screening, followed by assessment of middle-ear function and hearing sensitivity in those who do not pass the screening.

mild one and, in general, should not preclude speech and language development. If otoacoustic emissions are absent, the cause of that absence must be explored because the culprit could be anything from mild middle-ear disorder to profound sensorineural hearing loss.

Immittance audiometry is an important next step in the evaluation process. If otoacoustic emissions are normal, prediction of hearing loss by acoustic reflexes can be used as a cross-check for normal hearing sensitivity. If emissions are abnormal, immittance audiometry can shed light as to whether their absence is due to middle-ear disorder. If immittance measures indicate middle-ear disorder, the absence of otoacoustic emissions is equivocal in terms of predicting hearing loss.

In the absence of otoacoustic emissions information, immittance audiometry is a good beginning. Normal immittance measures suggest that any hearing problem that might be detected is due to sensorineural rather than conductive impairment. Normal immittance measures also allow assessment of acoustic reflex thresholds as a means of screening hearing sensitivity. If prediction of hearing level by acoustic reflexes suggests normal hearing sensitivity, the audiologist has a head start in knowing what might be expected from behavioral audiometry. Similarly, if the prediction is that a hearing loss might be present, the audiologist is so alerted. Abnormal immittance measures indicating middle-ear disorder suggest that any hearing problem that might be detected has at least some conductive component. The conductive component may be the entire hearing loss or it may be superimposed on a sensorineural hearing loss. Immittance audiometry provides no insight into this issue. If immittance measures are abnormal, little or no information can be gleaned about hearing sensitivity.

Visual reinforcement audiometry (VRA) is an audiometric technique used in pediatric assessment in which an appropriate response to a signal presentation, such as a head turn toward the speaker, is rewarded by the activation of a light or lighted toy.

Depending on a child's functional level, behavioral thresholds can often be obtained by **visual reinforcement audiometry (VRA)** (Moore et al., 1975; Madell, 1998; Gravel & Hood, 1999). VRA is a technique in which the child's behavioral response to a sound, usually a head turn toward the sound source, is conditioned by reinforcement with some type of visual stimulus. Careful conditioning and a cooperative child may permit the establishment of threshold or near-threshold levels to speech and tonal signals. A typical approach is to obtain speech thresholds in a sound field, followed by thresholds to as many **warble-tone** stimuli as possible.

A **warble tone** is a frequency-modulated pure tone used in sound field testing.

If a young child will wear earphones, and many *will* tolerate insert earphones, ear-specific information can be obtained to assess hearing symmetry. If a child will tolerate wearing a bone vibrator, a speech threshold by bone is often a very valuable result to obtain.

As in any testing of children, the assessment becomes somewhat of a race against time, as attention is not a strong point at this age. Although the goal of behavioral audiometry is to obtain hearing threshold levels across the audiometric frequency range in both ears, this can be a fairly lofty goal for some children. The approach and the speed at which information can be gathered is the art of testing this age group. It is probably far better to understand hearing in the sound field, which in general reflects hearing in the better ear, and have an estimate of hearing symmetry than to have a complete audiogram in one ear only.

In many children of this age group, a definitive assessment can be made of hearing ability by the combined use of OAEs, immittance measures, and behavioral audiometry, especially if hearing is normal. However, in some cases, due to the need to confirm a hearing loss or because the child was not cooperative with such testing, auditory evoked potentials are used to predict hearing sensitivity. Specifically, the auditory brainstem response is measured to verify the existence of a hearing loss, help determine the nature of the hearing loss, and quantify the degree of loss. Judicious use of ABR and ASSR measures will provide an estimate of the type, degree, and slope of hearing loss in both ears and may be the only reliable measure attainable in some children of this age group.

You will recall that ABR and ASSR measures require that a patient be still or sleeping throughout the evaluation. Children in this younger age group, and, indeed, some children up to 4 or 5 years of age, can seldom be efficiently tested in natural sleep. Therefore, pediatric ABR assessment is often carried out while the child is under sedation or general anesthesia. Sedation techniques vary, and all pose an additional challenge to evoked potential measurement. However, once the child is properly sedated, the AEP measures provide the best confirmation available of the results of behavioral audiometry.

Children Older than 2 Years. Not unlike their younger counterparts, children in this age group are usually referred to an audiologist either as part of an otologic evaluation of middle-ear disorder or

for audiologic consultation because the parents or caregivers are concerned about hearing loss or the child has failed to develop speech and language as expected. Many of these patients have middle-ear disorder, and many have some degree of hearing impairment.

Otoacoustic emissions can be used very effectively as an initial screening tool in this population. Normal emissions indicate a middle-ear mechanism that is functioning properly and suggest that any sensorineural hearing impairment that might exist would be mild in nature. Absent otoacoustic emissions are consistent with either middle-ear disorder or some degree of sensorineural hearing loss.

Immittance audiometry in this age group, as in all children, can provide a large amount of useful information. If tympanograms, static immittance, and acoustic reflexes are normal, middle-ear disorder can be ruled out, and a prediction can be made about the presence or absence of sensorineural hearing loss. Combined with the results of OAE testing, the audiologist will begin to have an accurate picture of hearing ability, especially if all results are normal. If immittance audiometry is abnormal, the nature of the middle-ear disorder will be apparent, but no predictions can be made about hearing sensitivity.

Conditioned play audiometry is an audiometric technique used in pediatric assessment in which a child is conditioned to respond to a stimulus by engaging in some game, such as dropping a block in a bucket, when a tone is heard.

Closed-set means the choice is from a limited set; multiple choice.

A **spondee** is a two-syllable word spoken with equal emphasis on each syllable.

At this age, children can often be tested with **conditioned play audiometry**, in which the reinforcer is some type of play activity, such as tossing blocks in a box or putting pegs in a board (Madell, 1998; Gravel & Hood, 1999). Usually under earphones, the typical first step is to establish speech-recognition or speech awareness thresholds, depending on language skills, in both ears. Speech awareness thresholds can be obtained by conditioning the child to respond to the presence of the examiner's voice. Speech-recognition thresholds are obtained in the youngest children by, for example, pointing to body parts; in young children, by pointing to pictures presented in a **closed-set** format; and in older children by having them repeat familiar **spondaic words**. The next step is to try to establish pure-tone thresholds at as many frequencies as possible. Behavioral bone-conduction thresholds are also attainable in this age group. Again, a successful strategy is to begin with speech thresholds and move to pure-tone thresholds.

If reliable behavioral thresholds can be obtained, especially in combination with immittance and OAE measures, results of the audiologic evaluation will provide the necessary information about type and degree of hearing loss. Unfortunately, even in children of this age group, and especially in the 2- to 3-year-old group, cooperation for audiometric testing is not always assured, and reliability of results may not be acceptable. In these cases, auditory evoked potentials can be used either to establish hearing levels or to confirm the results of behavioral testing. Again in children of this age, judicious use of ABR measures will provide an estimate of the type, degree, and slope of the hearing loss. Once again as well, sedation is likely to be needed in order to obtain useful evoked potential results.

The Cross-Check Principle. There is a principle in pediatric testing that is worth learning early and demanding of yourself throughout your professional career known as the cross-check principle of pediatric audiometry (Jerger & Hayes, 1976). The cross-check principle simply states that *no single test result obtained during pediatric assessment should be considered valid until you have obtained an independent cross-check of its validity.* Stated another way, if you rely on one audiometric measure as *the* answer in your assessment of young children, you will probably misdiagnose children during your career. Conversely, if you insist on an independent cross-check of your results, the odds against such an occurrence improve dramatically.

Practically, we do not use the cross-check principle when we are screening hearing. Here we simply assume a certain percentage of risk of being wrong. Such is the nature of screening. However, if a child has been referred to you for an audiologic evaluation because of a suspected hearing loss, then you have a professional obligation to be correct in your assessment. That is not always easy, and it is certainly not always efficient, but if you do not get the answer right, then who does? Perhaps an example will serve to illustrate this point.

The patient was 18 months old and enrolled in a multidisciplinary treatment program for pervasive delays in development. The speech-language pathologist suspected a hearing loss because of the child's behavior. A very experienced audiologist evaluated the child. Immittance measures showed patent pressure-equalization

tubes in both ears, placed recently due to chronic middle-ear disorder. No other information could be obtained from immittance testing because of the tubes. Results of visual-reinforcement audiometry to warble tones presented in a sound field showed thresholds better than 20 dB HL across the frequency range. The audiologist concluded that hearing was normal in at least one ear and dismissed the speech-language pathologist's concern about hearing. Six months later, the speech-language pathologist asked the audiologist to evaluate again, certain that the audiologist was incorrect the first time. On re-evaluation, immittance testing showed normal tympanograms, normal static immittance, and no measurable acoustic reflexes. OAEs were absent. Behavioral measures continued to suggest no more than a mild hearing loss. ABR testing revealed a profound sensorineural hearing loss. Behavioral testing in this case was misleading, due probably to undetectable parental cueing of the child in the sound field.

This is just one of many examples of misdiagnosis that could have been prevented by insisting on a cross-check. In this case, results of behavioral audiometry were incorrect. There are also examples of cases in which ABR measures were absent due to brainstem disorder even though hearing sensitivity was normal or cases in which OAEs were normal but hearing was not. Although test results usually agree, these cases happen often enough that the best clinicians take heed. The solution is really rather simple. If you always demand from yourself a cross-check, then you can be confident in your results.

Illustrative Case

Illustrative Case 10-10. Illustrative Case 10 is a young child with a fluctuating, mild-to-severe sensorineural hearing loss bilaterally. The patient is a 4-year-old girl. The hearing loss appears to be caused by CMV or cytomegalic inclusion disease, a viral infection usually transmitted in utero. There is no family history of hearing loss and no other significant medical history.

Immittance audiometry, as shown in Figure 10-12A, is consistent with normal middle-ear function, characterized by a Type A tympanogram, normal static immittance, and normal crossed and uncrossed reflex thresholds bilaterally. SPAR predicts sensorineural hearing loss bilaterally.

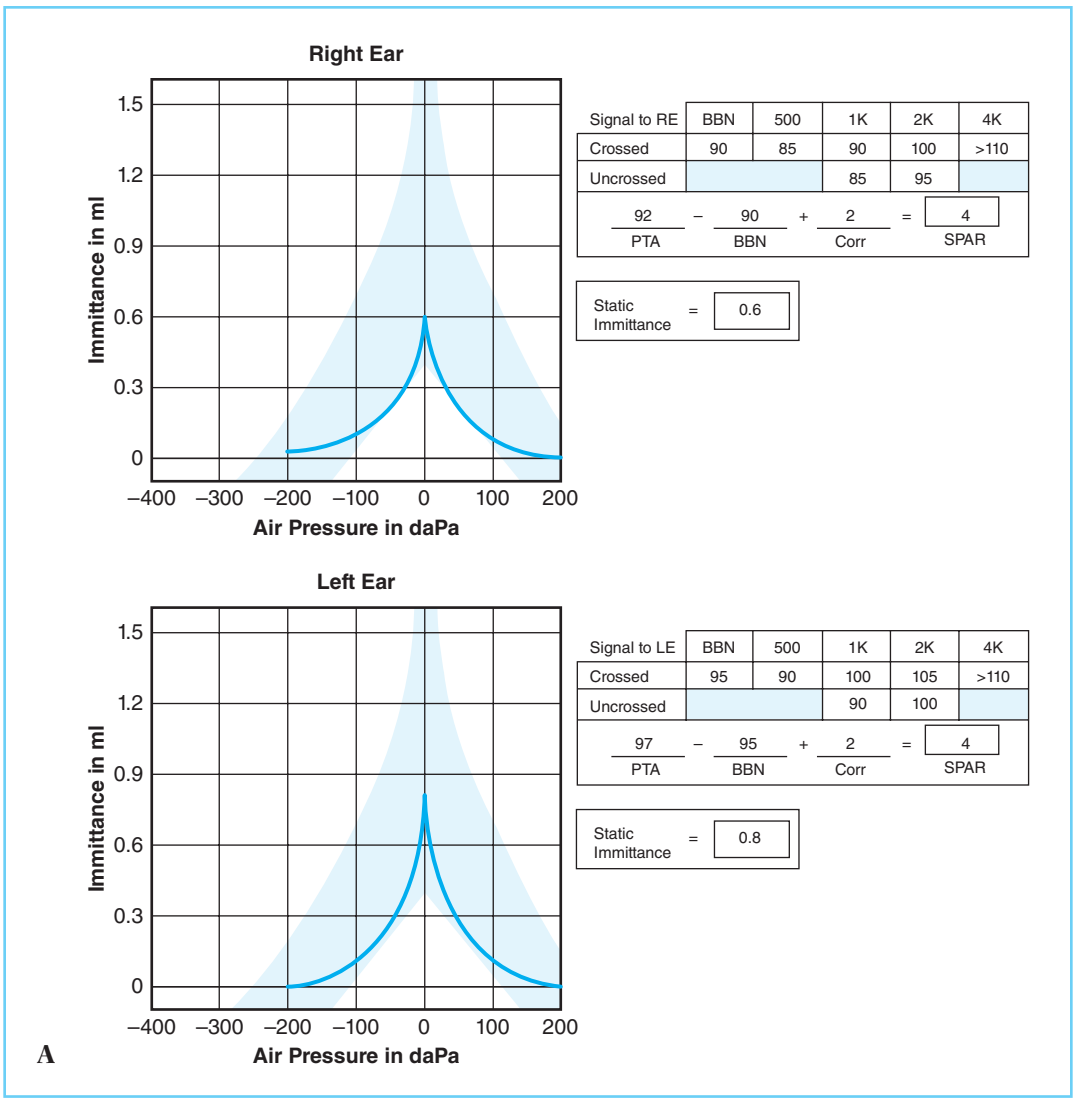


FIGURE 10-12 Hearing consultation results in a 4-year-old child with hearing loss secondary to CMV infection. Immittance measures (A) are consistent with normal middle-ear function. SPARs predict sensorineural hearing loss bilaterally. Distortion-product otoacoustic emissions results (B) show that OAEs are present in the lower frequencies on the right ear, but absent at higher frequencies. OAEs are absent on the left. Pure-tone audiometric results (C) show bilateral sensorineural hearing loss.

Otoacoustic emissions are present in the right ear in the 1000 Hz frequency region, but absent at higher frequencies. OAEs are absent in the left ear, as shown in Figure 10-12B.

Air-conduction pure-tone thresholds were obtained via play audiometry and are shown in Figure 10-12C. The patient responded consistently by placing pegs in a pegboard.

Bone-conduction thresholds could not be obtained conventionally because the child had difficulty responding to tones presented to the bone vibrator in the presence of masking noise presented to an earphone. However, the SAL technique was used to estimate the amount of air-bone gap. Bone-conduction thresholds estimated by the SAL test showed the loss to be sensorineural in nature.

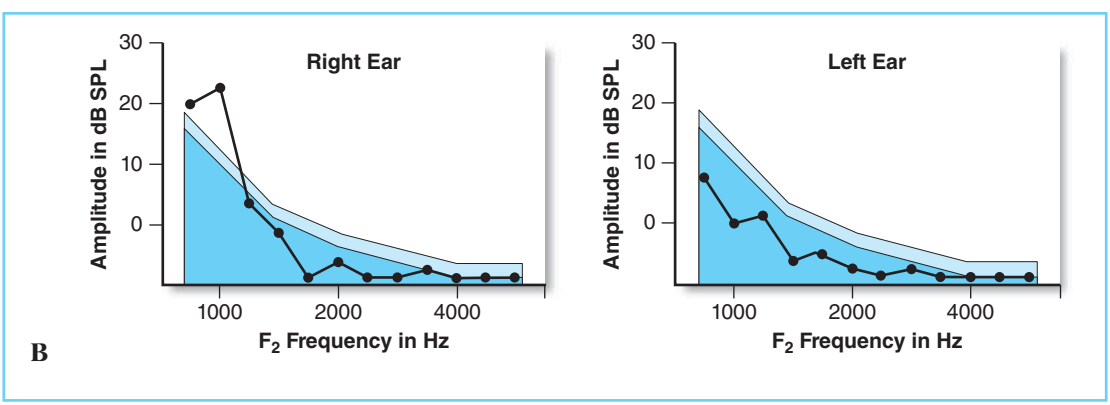
Speech audiometric results were consistent with the hearing loss. Speech thresholds matched pure-tone thresholds. Word-recognition scores were good, despite the degree of hearing loss.

This child is a candidate for hearing aid amplification and will likely benefit substantially from hearing aid use. A hearing aid consultation was recommended.

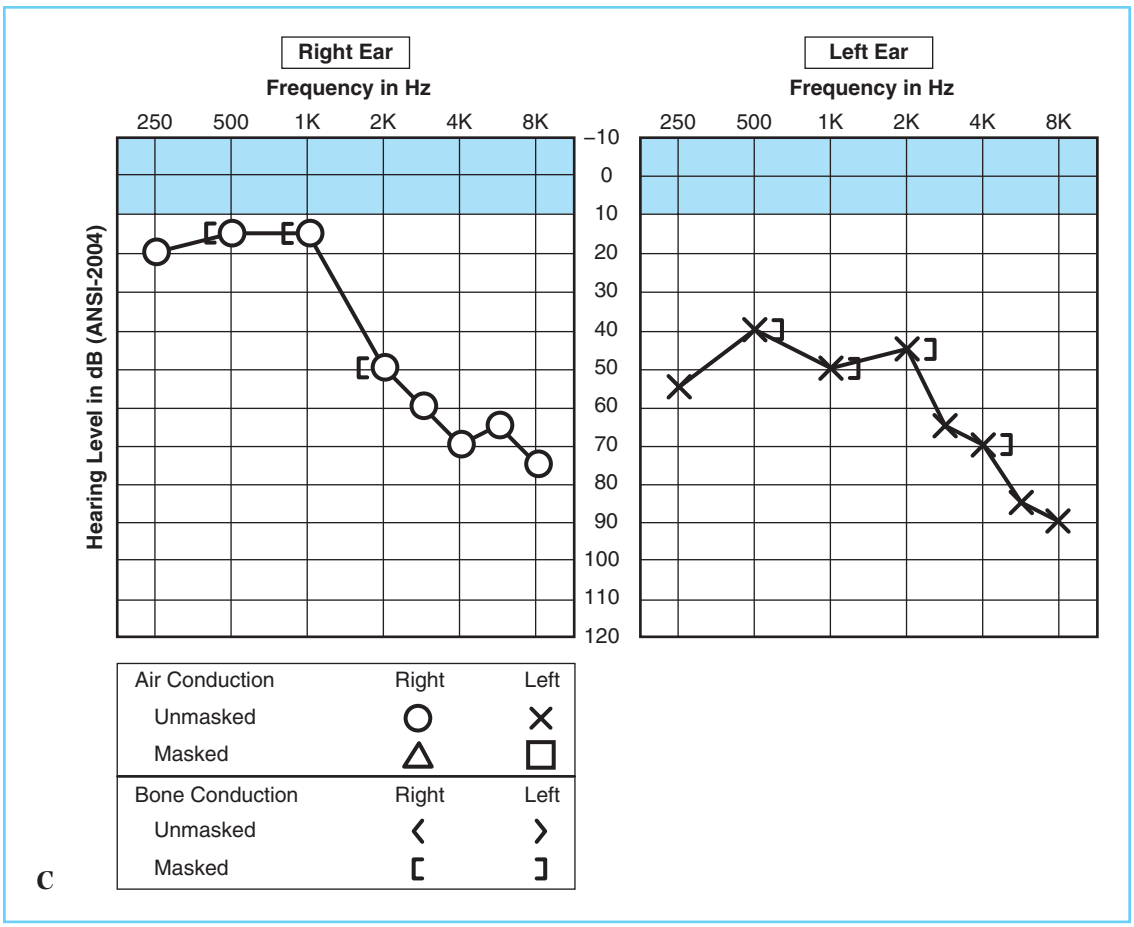
Auditory Processing Assessment

Evaluative Goals

Diagnosis of APD is challenging because there is no biologic marker. That is, it cannot be identified "objectively" with MRI scans or blood



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tests. Instead, its diagnosis relies on operational definitions, based mostly on results of speech audiometry. Basing the diagnosis solely on behavioral measures such as these can be difficult because interpretation of the test results can be influenced by nonauditory factors such as language delays, attentional deficits, and impaired cognitive functioning (Cocace & McFarland, 1998). Thus, one important evaluative goal is to separate APD from these other disorders.

The importance of this evaluative goal cannot be overstated. One of the main problems with APD measures is that too many children who do not have APD fail some of the tests. This results in a large number of false-positive test results, which not only burdens

the health-care system with children who do not need further testing, but also muddles the issue of APD and its contribution to a child's problems. The reason that so many children who do not have APD fail these tests is that nonauditory factors influence the interpretation of results.

This problem has been illustrated clearly in a number of studies. For example, in one study (Gascon et al., 1986) children who were considered to be hyperactive and have attention deficit disorders were evaluated with several speech audiometric tests of auditory processing ability and a battery of tests aimed at measuring attention ability.

Both the APD test battery and the attention test battery were administered before and after the children were medicated with stimulants to control hyperactivity. Results showed that most of the children improved on the APD test battery following stimulant administration. What these results showed is that the APD tests are very sensitive to the effects of attention. Stated another way, children who have attention disorders often perform poorly on these APD measures even if they do not have APD, because they cannot attend to the task thoroughly enough for the auditory system to be evaluated. As a result, the effects of auditory processing disorder cannot be separated from the effects that attention deficits have on a child's ability to complete these particular test measures.

What this study and others suggest is that, if our clinical goal is to test exclusively for APD, then the influences of attention, cognition, and language skills must be controlled during the evaluation process.

Test Strategies

Well-controlled speech audiometric measures, in conjunction with auditory evoked potential measures, can be powerful diagnostic tools for assessing APD. Although there is no single gold standard against which to judge the effectiveness of APD testing, it can be operationally defined on the basis of behavioral and electrophysiologic test results.

Speech Audiometry. There are numerous speech audiometric measures of auditory processing ability. Most of them evolved from adult measures that were designed to aid in the diagnosis of neurological disease in the pre-MRI era. The application of many of these adult measures to the pediatric population has not been altogether successful, largely because of a lack of control over linguistic and cognitive complexity in applying them to young children.

Speech audiometric approaches have been developed that have proven to be valid and reliable (Jerger et al., 1988). When they are administered under properly controlled acoustic conditions, with materials of appropriate language age and testing strategies that control for the influences of attention and cognition, these measures permit a diagnosis with reasonable accuracy in most children (Jerger et al., 1980; 1983).

Perhaps an example of a successful testing strategy will illustrate the challenges and some of the ways to solve them. One example of a APD test battery is summarized in Table 10-1. The strategy used with this test battery is to vary several parameters of the speech testing across a continuum in order to "sensitize" the speech materials or to make them more difficult. The parameters include intensity, **signal-to-noise ratio**, **redundancy** of informational content, and **monotic** versus **dichotic** performance.

The difference in dB between a sound of interest and background noise is called the **signal-to-noise ratio**.

Redundancy is the abundance of information available to the listener due to the substantial informational content of a speech signal and the capacity of the central auditory nervous system.

Monotic refers to different signals presented to the same ear.

Dichotic refers to different signals presented simultaneously to each ear.

TABLE 10-1 An example of a APD test battery

Test Parameter	Younger Children	Older Children
Monaural word recognition	PSI-ICM words	PB word lists
Monaural sentence recognition	PSI-ICM sentences	SSI
Dichotic speech recognition	PSI-CCM	DSI
Auditory evoked potentials	MLR/LLR	MLR/LLR

Note: PSI-ICM: Pediatric Speech Intelligibility test with ipsilateral competing message; PSI-CCM: Pediatric Speech Intelligibility test with contralateral competing message; PB: phonetically balanced; SSI: Synthetic Sentence Identification test; DSI: Dichotic Sentence Identification test; MLR: middle latency response; LLR: late latency response.

Suppose we are testing a young child. We might choose to use the *Pediatric Speech Intelligibility* (PSI) test (Jerger et al., 1980). In this test, words are presented with a competing message in the same ear at various signal-to-noise ratios (SNRs) or message-to-competition ratios (MCRs). Testing at a better ratio provides an easier listening condition to ensure that the child knows the vocabulary, is cognitively capable of performing the task, and can attend adequately enough to complete the procedure. Then the ratio is made more difficult to challenge the integrity of the auditory nervous system. At the more difficult MCR, a performance-intensity (PI) function is obtained to evaluate for rollover of the function, or poorer performance at higher intensity levels. This assessment in the intensity domain is also designed to assess auditory nervous system integrity.

Both words and sentences are usually presented with competition in the same ear and the opposite ear. The word-versus-sentence comparison is used to assess the child's ability to process speech signals of different redundancies. The same-ear versus opposite-ear competition comparison is used to assess the difference between monotic and dichotic auditory processing ability.

An illustration of the results of these test procedures and how they serve to control the nonauditory influences is shown in the speech audiometric results in Figure 10-13. The patient is a 4-year 1-month-old child who was diagnosed with APD. Hearing sensitivity is within normal limits in both ears. However, speech audiometric results are strikingly abnormal. In the right ear, the PI functions for both words and sentences show rollover. Rollover of these functions cannot be explained as attention, linguistic, or cognitive disorders because such disorders are not intensity-level dependent. In other words, language, cognition, or attention deficits are not present at one intensity level and absent at another. In addition, in the left ear, there is a substantial discrepancy between understanding of sentences and understanding of words. This is obviously not a language problem, because, at 60 dB HL, the child understands all of the sentences correctly and, at an easier listening condition, the child identifies all of the words correctly. The child is clearly capable of doing the task linguistically and cognitively. Thus, use of PI functions, various SNRs, and word-versus-sentence comparisons

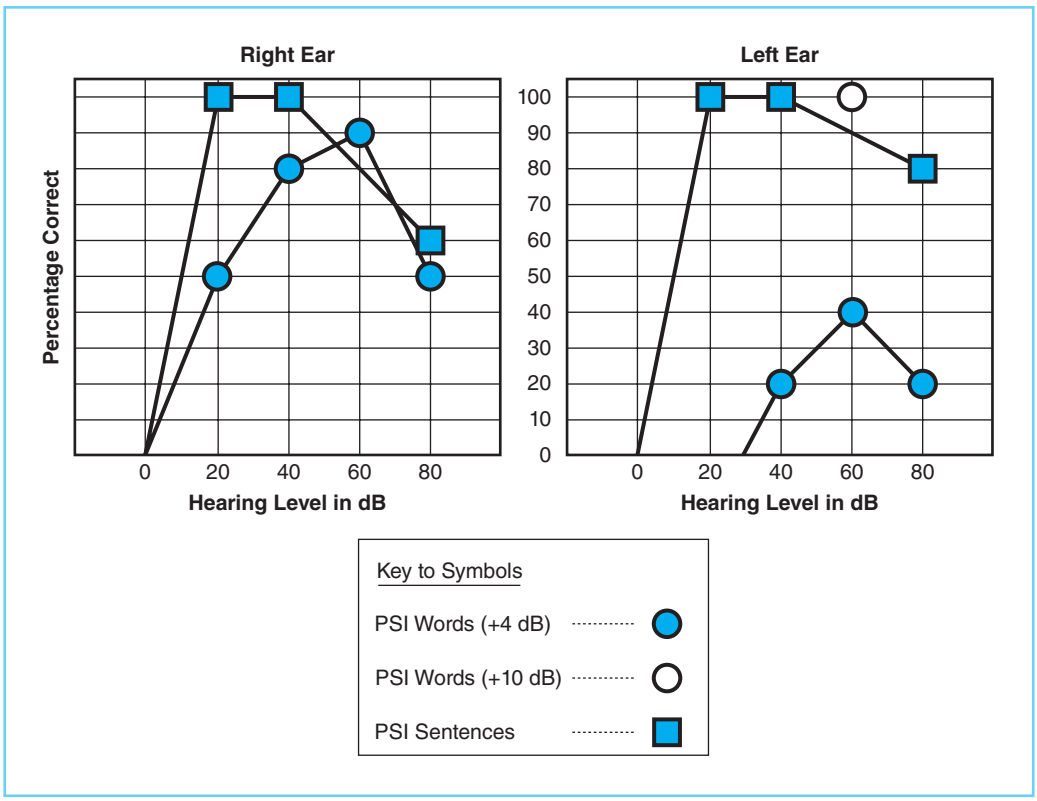


FIGURE 10-13 Speech audiometric results in a young child with auditory processing disorder. Results of the Pediatric Speech Intelligibility (PSI) test illustrate how assessment procedures can be used to control for nonauditory influences on test interpretation.

permits the assessment of auditory processing ability in a manner that reduces the likelihood of nonauditory factors influencing the interpretation of test results.

Auditory Evoked Potentials. Auditory evoked potentials may be used to corroborate speech audiometric testing (e.g. Stach & Loiselle, 1993). Specifically, the auditory middle latency response and late latency response have been found to be abnormal in children who have APD. Although encouraging, a lack of sufficient normative data on young children reduces the ease of interpretation of auditory evoked potentials on an individual basis at this point in time (Martin et al., 2007). Advances in evoked potential technologies are likely to enhance APD diagnosis.

In conjunction with thorough speech, language, and neuropsychological evaluations, the use of well-controlled speech audiometric measures and auditory evoked potentials can be quite powerful in defining the presence or absence of an auditory processing disorder.

Illustrative Case

Illustrative Case 10-11. Illustrative Case 11 is a young child with normal hearing sensitivity but with auditory processing disorder. The patient is a 6-year-old girl with a history of chronic otitis media. Although her parents have always suspected that she had a hearing problem, previous screening results were consistent with normal hearing sensitivity. Previous tympanometric screening results showed either Type B tympanograms during periods of otitis media or normal tympanograms during times of remission from otitis media.

Immittance audiometry, as shown in Figure 10-14A is consistent with normal middle-ear function, characterized by a Type A tympanogram, normal static immittance, and normal crossed and uncrossed reflex thresholds bilaterally.

Pure-tone audiometric results are shown in Figure 10-14B. Hearing sensitivity is normal in both ears.

Speech audiometry reveals a different picture. Results are shown in Figure 10-14C. For both ears, the pattern is one of rollover of the performance-intensity functions for both word recognition and sentence recognition in the presence of competition. In addition, she shows a dichotic deficit, with poor performance in her left ear. These results are consistent with auditory processing disorder.

Auditory evoked potentials provide additional support for the diagnosis. Although ABRs are present and normal bilaterally, middle and late latency responses are not measurable in response to signals presented to either ear.

This child is likely to experience difficulty in noisy and distracting environments. She may be at risk for academic achievement problems if her learning environment is not structured to be a quiet one. The parents were provided with information about the

nature of the disorder and the strategies that can be used to alter listening environments in ways that will be useful to this child. The patient will be re-evaluated periodically, especially during the early academic years.

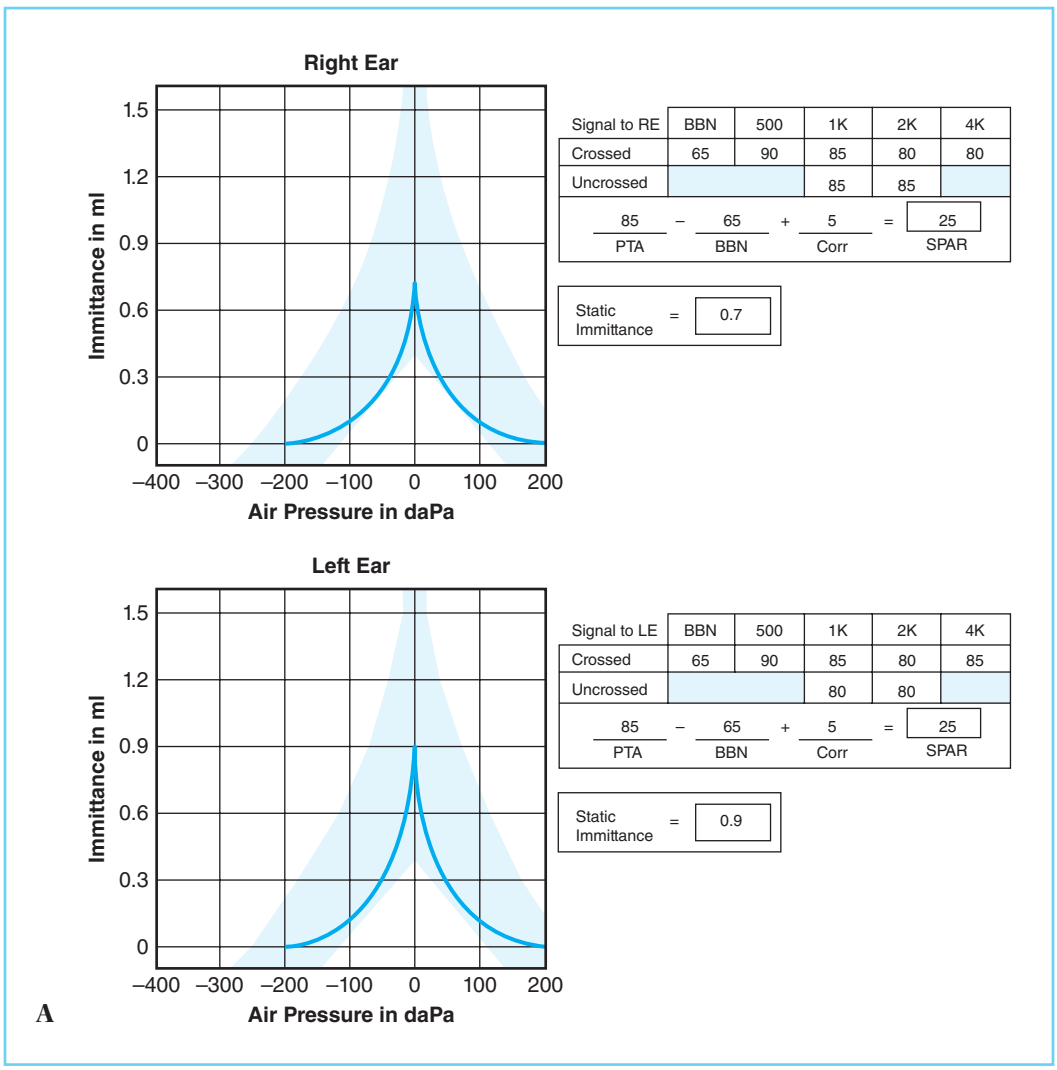


FIGURE 10-14 Hearing consultation results in a 6-year-old girl with auditory processing disorder. Immittance measures (A) are consistent with normal middle-ear function. Pure-tone audiometric results (B) show normal hearing sensitivity in both ears. Speech audiometric results (C) show significant rollover of PI functions for both word and sentence recognition. Results also show a dichotic deficit, with poorer performance on the left ear.

AUDIOLOGIST PROFILE

ANNE E. MURRAY, AU.D.



WHERE I LIVE: San Diego, California

WHERE I WORK: Veterans Administration (VA) San Diego Healthcare System. The Audiology Department has four locations in the San Diego area: one medical center and three outpatient clinics. Our staff is comprised of 13 audiologists, 6 pre-doctoral externs, 3 speech-language pathologists, 4 audiologic technicians, and 5 support staff. Students in their third year of the joint Au.D. program at San Diego State University and University of California-San Diego complete rotations through our facility.

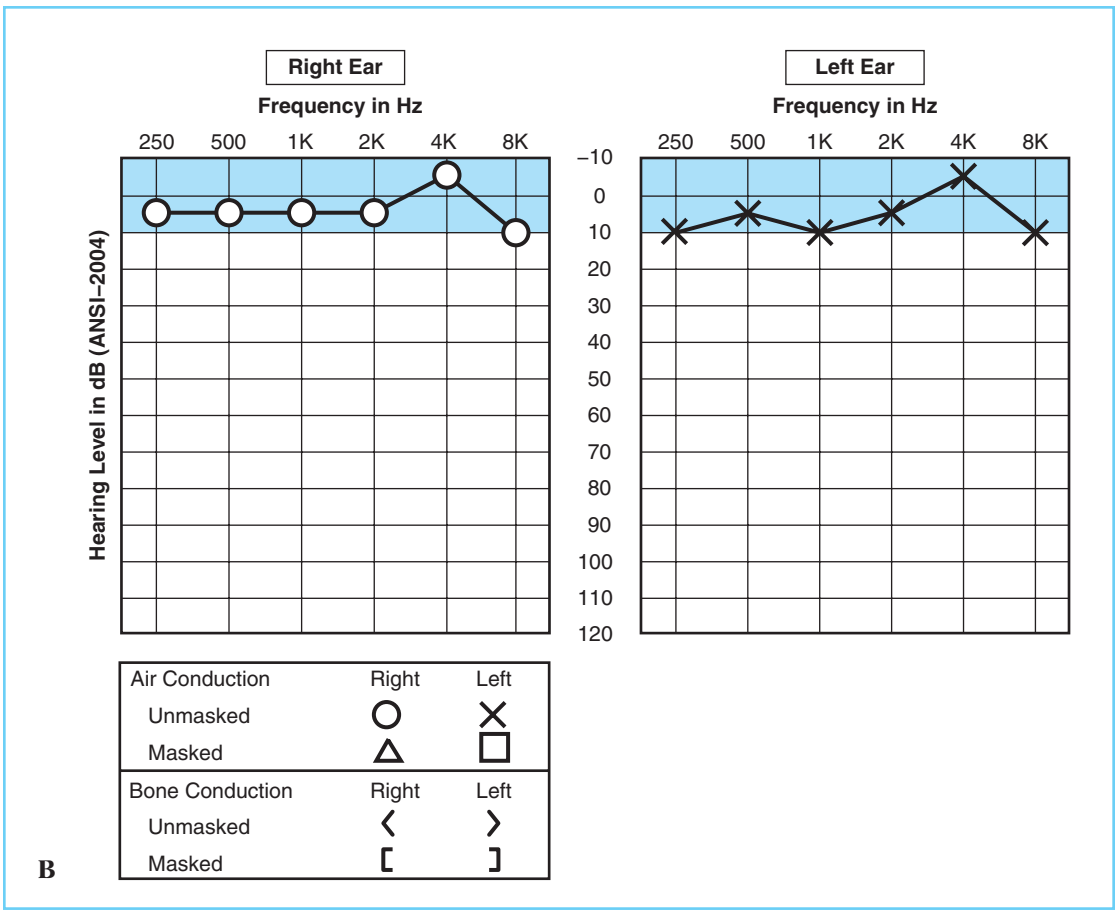
WHAT I DO: As a clinical audiologist, my current responsibilities primarily include comprehensive hearing evaluation, hearing aid evaluation and fitting, aural rehabilitation, electrophysiologic testing, vestibular evaluation, and tinnitus management of the veteran population. I also enjoy supervising students through their VA rotations.

WHY AUDIOLOGY? I like that audiology is a specialized science and profession, yet has a broad scope of practice. As an audiologist, I have the rewarding opportunity to improve patients' communicative abilities, which improves their quality of life.

FUNCTIONAL HEARING LOSS

Exaggerated, functional, or nonorganic hearing loss is a timeless audiologic challenge. Functional hearing loss is the exaggeration or feigning of hearing impairment. In many cases, particularly in adults, an organic hearing loss exists (Gelfand & Silman, 1985) but is willfully exaggerated, usually for compensatory purposes. In other cases, often secondary to trauma of some kind, the entire hearing loss will be willfully feigned. This is commonly referred to as malingering.

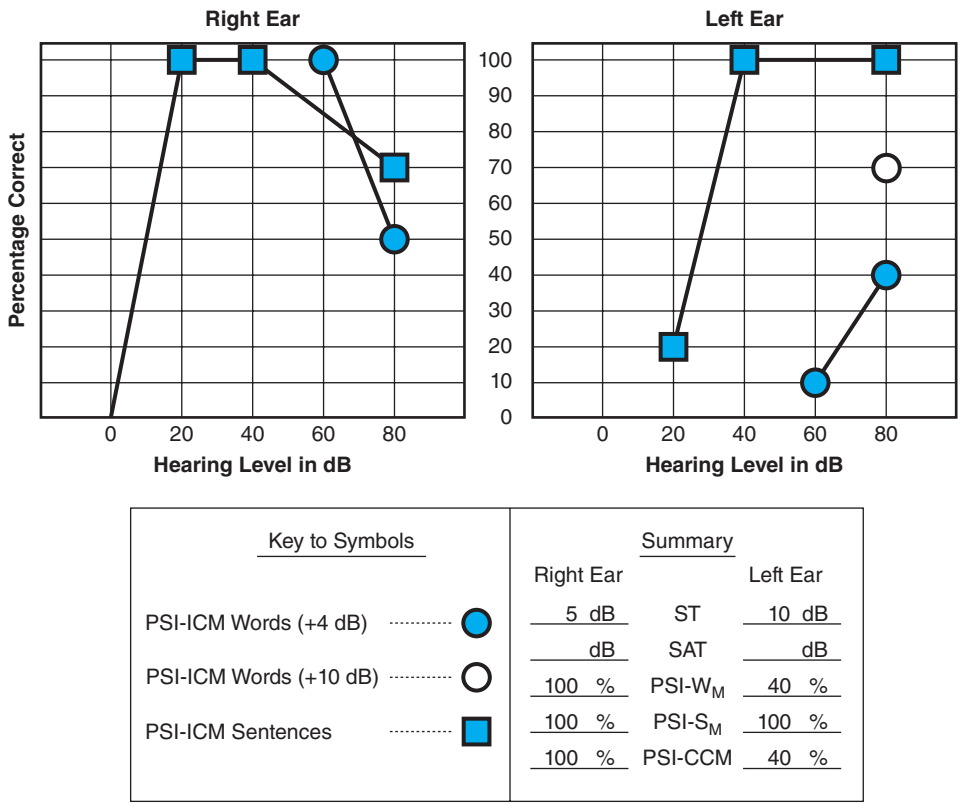
Adults and children feign hearing loss for different reasons. Adults are usually seeking secondary or financial gain. For example, an employee may be applying for worker's compensation for hearing loss secondary to exposure to excessive sound in the workplace. Or someone discharged from the military may be seeking compensation for



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hearing loss from excessive noise exposure. Although most patients have legitimate concerns and provide honest results, a small percentage tries to exaggerate hearing loss in the mistaken notion that it will result in greater compensation. There are also those who have been involved in an accident or altercation and are involved in a lawsuit against an insurance company or someone else. Occasionally such a person will think that feigning a hearing loss will lead to greater monetary award. In either case of malingering, the patient is wasting valuable professional resources in an attempt to reap financial gain. Although these cases are always interesting and challenging to the audiologist, the clinical approach changes from one of caregiving to something a little more direct.

Children with functional hearing loss often are using hearing impairment as an excuse for poor performance in school or to



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gain attention. This is often referred to as factitious hearing loss. The idea may have emerged from watching a classmate or sibling getting special treatment for having a hearing impairment or it may be secondary to a bout of otitis media and the consequent parental attention paid to the episode. The challenge is to identify this functional loss before the child begins to realize the secondary gains inherent in having hearing loss. This is challenging business. Children feigning hearing loss need support. Their parents, on the other hand, may not be overly pleased to learn that they have taken time off of work and spent money to discover that their child was faking a hearing loss. Counseling is an important aspect following the discovery of a factitious hearing loss in a child.

Regardless of the reason for functional hearing loss, the role of the audiologist is (1) to detect that a functional component exists and (2) to resolve the true hearing sensitivity.

Indicators of Functional Hearing Loss

The evaluation of functional hearing loss begins with identification of the existence of the disorder. There are several indicators of the existence of a functional component, some of which are audiometric and some of which are nonaudiometric.

Nonaudiometric Indicators

Careful observation of a patient from the very beginning of the evaluation can often provide indications of the likelihood of a functional component to a hearing loss. For example, as a general rule, patients with functional hearing loss are late for appointments. Perhaps the thought is that the later they are, the more rushed will be the evaluation, and the greater the likelihood that their malingering will not be detected. It seems important to point out that the argument is not transitive. That is, clearly, not everyone who is late has a functional hearing loss. Nevertheless, those who have functional hearing loss are often late.

Other signs of functional hearing loss can also be detected early. Patients with functional hearing loss will often exhibit behaviors that are exaggerated compared to what might be expected from someone with an organic loss. For example, patients with true hearing impairment are usually alert in the waiting room because of concern that they will not hear their appointment being called. Those with functional hearing loss may overexaggerate to the point that they will appear to struggle when they are being identified in the waiting room. This exaggeration may continue throughout the process of greeting the patient and taking a case history. Experienced audiologists understand how individuals with true hearing impairment function in the world. For example, they seldom bring attention to themselves by purposefully raising their voices or by cupping their hands behind their ears. Those feigning hearing loss are likely to not handle this type of communication very subtly. As another example, the case history process is full of context that allows patients with true hearing impairment to answer questions reasonably routinely and graciously. Patients with functional hearing loss will often struggle inappropriately with this task.

Other behaviors that are often attributable to patients with functional hearing loss are excessive impatience, tension, and irritability.

One other nonaudiometric indicator that is not subtle but suprisingly often overlooked is the reason for the referral and evaluation. Is the patient having a hearing evaluation for compensation purposes? This is a question that should be asked. Again, many who are seeking compensation will have legitimate hearing loss and will be forthcoming during the audiologic evaluation. But if compensation or litigation is involved, the audiologist must be alert to the possibility of functional hearing loss.

Audiometric Indicators

There are also several audiometric indicators of the presence of functional hearing loss. First, and perhaps most obvious, the amateur malingerer will display substantial variability in response to pure-tone audiometry. However, the more malingerers are tested, the more consistent their responses become. An experienced malingerer will not demonstrate variability in responding.

One important audiometric indicator is a disparity between the speech-recognition threshold and pure-tone thresholds (Ventry & Chaiklin, 1965). In patients who are feigning or exaggerating hearing loss, the speech recognition threshold is usually significantly better than pure-tone thresholds. Thus, it is important to begin testing with the SRT and then evaluate whether the pure-tone thresholds match up appropriately.

These and other indicators alert the experienced audiologist to the possibility of functional hearing loss:

- variability in response to pure-tone audiometry
- lack of correspondence of SRT to pure-tone thresholds
- bone conduction poorer than air conduction
- very flat audiogram
- lack of a **shadow curve** in unilateral functional loss
- air-conduction pure-tone thresholds poorer than acoustic reflex thresholds
- half-word spondee responses during speech recognition threshold testing
- rhyming word responses on word recognition testing
- unusual pattern of word-recognition scores on performance-intensity functions

A **shadow curve** appears on an audiogram during unmasked testing of an organic, unilateral hearing loss; thresholds for the test ear occur at levels equal to the interaural attenuation.

- normal sensitivity prediction by acoustic reflexes in the presence of an apparent hearing sensitivity loss
- normal otoacoustic emissions measures in the presence of an apparent hearing sensitivity loss

Assessment of Functional Hearing Loss

If functional hearing loss is suspected but not confirmed, audiometric measures should be carried out to confirm the existence of a functional component. Once functional hearing loss is confirmed, several strategies can be used to determine the true nature of hearing sensitivity (for a review, see Durrant et al., 1997; Gelfand, 2001).

Strategies to Detect Exaggeration

Sometimes a patient will feign complete deafness in one or both ears and behavioral audiometric measures will not be available to judge the validity of responding. The most useful tools to detect functional hearing losses in these cases are the sensitivity prediction by acoustic reflexes and the use of otoacoustic emissions. If the results of these measures are normal, then functional loss has been detected and the search for true thresholds can begin. It is just that simple in patients who are truly malingering. The problem is that most feigned hearing loss is actually a functional overlay on an existing hearing loss. In such cases, both reflex predictions and OAEs will indicate the presence of hearing loss, and the functional component will not be detectable.

In cases where a patient is feigning complete bilateral loss, simple clinical strategies can be used to determine that the loss is functional. One is to attempt to elicit a startle response by presenting an unexpected, high-intensity signal into the audiometric sound field. Another is to present some form of an unexpected comment through the earphones and watch for the patient's reaction. There are also some older formalized tests that were championed in the days before electrophysiologic measures. For example, one test, the *Lombard voice intensity test,* made use of the fact that a person's voice increases in intensity when masking noise is presented to both ears. In this case, the patient was asked to read a passage. Vocal level was monitored while white noise was introduced into the earphones. Any change in vocal level would indicate that the

patient was perceiving the white noise and feigning the hearing loss. Another example is the *delayed auditory feedback test.* This test made use of the fact that patients' speech becomes dysfluent if the perception of their own voice is delayed by a certain amount. To test this patients were asked to read a passage. A microphone recorded the speech and delivered it back into the patients' ears with a carefully controlled time delay. Any change in fluency would indicate that the patients were hearing their own voices and feigning a hearing loss.

In cases where the patient is feigning a complete unilateral hearing loss, the best strategy to detect the malingering is the *Stenger test* (Altshuler, 1970). A detailed description of procedures for carrying out the Stenger test is presented in the following box. Briefly, the test is based on the Stenger principle, which states that only the louder of identical sounds presented simultaneously to both ears will be perceived. For example, if you have normal hearing, and I simultaneously present a 1000-Hz tone to your right ear at 30 dB HL and to your left ear at 40 dB HL, you will only perceive the sound in your left ear. In the Stenger test, a tone is presented to the good ear at a level at which the patient responds. The signal in the poorer ear is raised until the patient stops responding. Patients who are feigning a hearing loss will stop responding as soon as they perceive sound in the suspect ear, unaware that sound is also still being presented to the good ear at a perceptible level. The Stenger test is so simple, valid, and reliable that many audiologists use it routinely in any case of unilateral hearing loss just to be sure of its authenticity.

Strategies to Determine "True" Thresholds

Once a functional hearing loss has been detected, the challenge becomes one of determining actual hearing sensitivity levels. Sometimes this is very simply a matter of reinstructing the patient. Thus, the first step is to make patients aware that you have detected their exaggeration, provide them with a reasonable "face-saving" explanation for why they may have been having difficulty with the pure-tone task, reinstruct them, and reestablish pure-tone thresholds. Some patients will immediately recant and begin cooperating. Others will not.

Clinical Note

The Stenger test: A Good Clinical Friend

A good clinical rule to live by: If a patient has a unilateral hearing loss or significant asymmetry, always do a Stenger test.

The Stenger test is a simple and fast technique for verifying the organicity of a hearing loss. If the hearing loss is organic, you will have wasted a minute of your life verifying that fact. If the hearing loss is feigned or exaggerated, you will have rapid verification of the presence of a functional component.

The Stenger test is easy to do. A form is provided in Figure 10-15 to make it even easier.

Either speech or pure-tone stimuli are presented simultaneously to both, ears. Initially, the signal is presented to the good ear at a comfortable, audible level of about 20 dB SL and to the poorer ear at 20 dB below the level of the good ear. The patient will respond, because the patient will hear the signal presented to the good ear. Testing proceeds by increasing the intensity level of the signal presented to the poorer ear. If the loss in the poorer ear is organic, the patient will continue to respond to the signal being presented to the good ear. This is a negative Stenger. If the loss is functional, the patient will stop responding when the loudness of the signal in the feigned ear exceeds that in the other ear, because the signal will only be heard in the feigned ear due to the Stenger principle. Because you are still presenting an audible signal to the good ear, you know that the patient is not cooperating. This is a positive Stenger, indicative of functional hearing loss.

Stenger Test

Recording Form

Name: _____ Age: _____ Date: _____

Pure-Tone

Voluntary Thresholds

Right Ear: _____ Frequency: _____

Left Ear: _____

Presentation Level		Response
Better Ear	Test Ear	+ correct – no response

Stenger is: positive
negative

Speech

Voluntary Thresholds

Right Ear: _____

Left Ear: _____

Presentation Level		Response
Better Ear	Test Ear	+ correct – no response

Stenger is: positive
negative

FIGURE 10-15 Clinical form for recording results of the Stenger test.

For those who continue to exaggerate their hearing levels, there are several behavioral strategies that can be used. Children are the easiest under these circumstances, and some of the approaches to children work remarkably well with some adults. One particularly useful strategy in children is the *yes-no* test. For this test, children are instructed to indicate that they hear a tone by saying "yes" and that they do not hear the tone by saying "no." In most cases, you will be able to track the "no" responses all the way down to the real threshold level. Another useful technique is to have the child "count the beeps" while presenting groups of two or more tones at each intensity level. As threshold approaches, the child will begin counting incorrectly, but will continue to respond.

In adults, one of the more productive approaches is to use a variable *ascending-descending strategy* to try to bracket the threshold. Many audiologists will adhere strictly to an ascending approach so that the patient does not have too many opportunities to judge suprathreshold loudness levels. If a patient is feigning a unilateral hearing loss, the Stenger test can be used to predict threshold levels generally.

In patients who simply will not cooperate, accurate pure-tone threshold levels might not be attainable despite considerable toil on the part of the audiologist. Many audiologists feel that their time is not being well spent by trying to establish a behavioral audiogram in patients who will not cooperate. Those audiologists are likely to stop testing fairly early in the evaluation process and move immediately to assessment by auditory evoked potentials. The strategy is a good one in terms of resource utilization because, most likely, the patient will be undergoing evoked potential testing anyway. The art of audiometric testing in this case is to know quickly when you have reached a point at which additional testing will not yield additional results.

If valid and reliable behavioral thresholds cannot be obtained, current standard of care is to use auditory evoked potentials to predict the audiogram. Three approaches are commonly used. One approach is to establish ABR thresholds to clicks as a means of predicting high-frequency hearing and 500-Hz tone bursts as a means of predicting low-frequency hearing. The advantages to this approach are that testing can be completed quickly and the

patient can be sleeping during the procedure. The disadvantages are that the audiogram is predicted in broad frequency categories, and low-frequency tone-burst ABRs can be difficult to record.

Another approach is to establish late latency response (LLR) thresholds to pure tones across the audiometric frequency range. The advantage of this approach is that an electrophysiologic audiogram can be established with frequency-specific stimuli. The disadvantage is that the procedure is rather time consuming.

A third approach is to use the auditory steady-state response to estimate hearing sensitivity. The advantages of ASSR testing are: (1) better frequency specificity than the ABR; and (2) patients do not need to remain awake as they do for LLR testing.

Regardless of the test strategy, auditory evoked potentials are now commonly used as the method of choice for verifying and documenting hearing thresholds in cases of functional hearing loss.

Illustrative Case

Illustrative Case 10-12. Illustrative Case 12 is a patient who complains of a hearing loss in his right ear following an automobile accident. The patient is a 30-year-old man with an otherwise unremarkable health and hearing history. Two months prior to the evaluation, he was involved in an automobile accident. He reports that he sustained injuries to his neck and head and that a blow to the right side resulted in a significant loss of hearing in that ear.

Immittance audiometry, as shown in Figure 10-16A is consistent with normal middle-ear function bilaterally, as characterized by a Type A tympanogram, normal static immittance, and normal crossed and uncrossed reflex thresholds. SPAR results predict normal hearing sensitivity bilaterally.

Pure-tone audiometry shows normal hearing sensitivity in the left ear. Results from the right ear show responses that were generally inconsistent in the 80 to 100 dB range. Air-conduction thresholds are above or close to acoustic reflex thresholds. Admitted thresholds are shown in Figure 10-16B. Bone-conduction thresholds are also inconsistent and suggest the presence of an air-bone gap in the poorer ear and a bone-air gap in the normal ear.

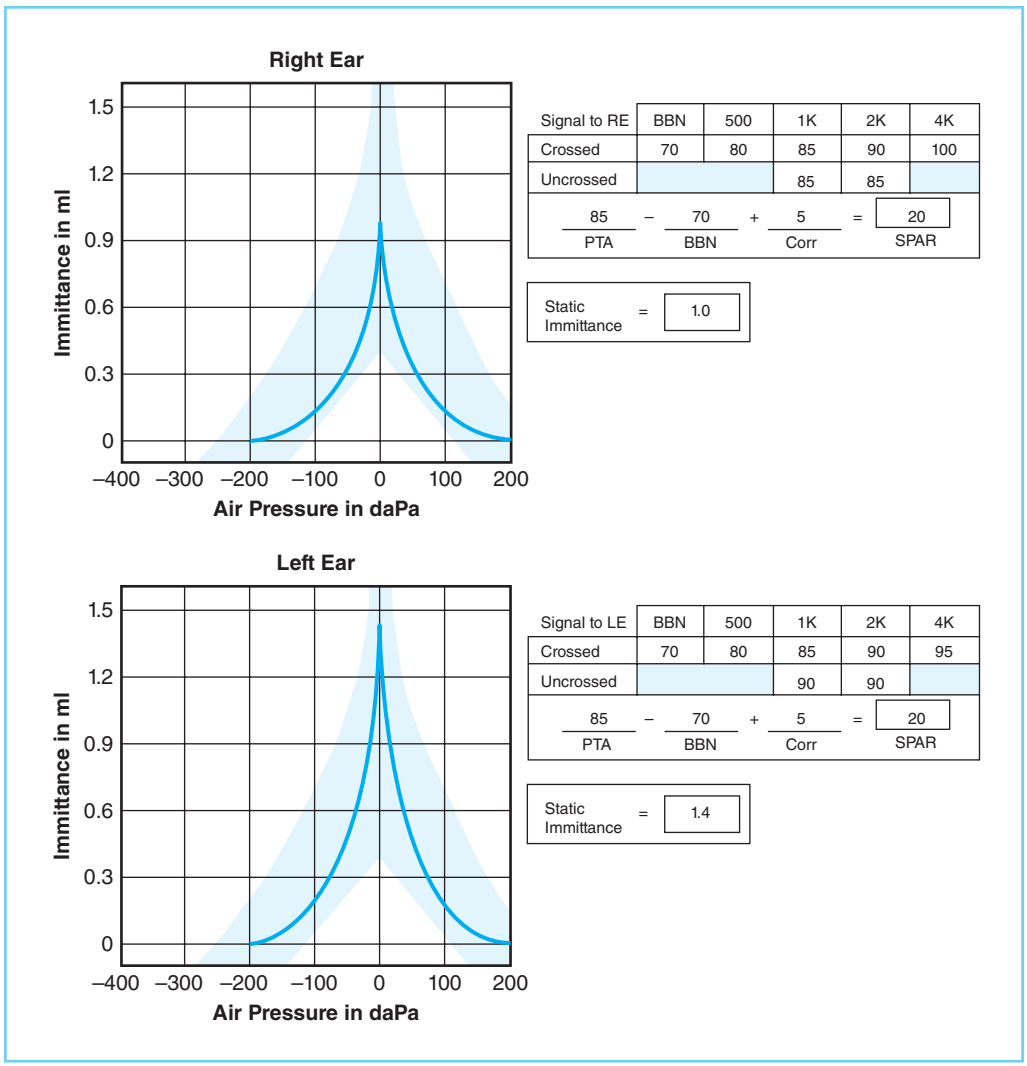
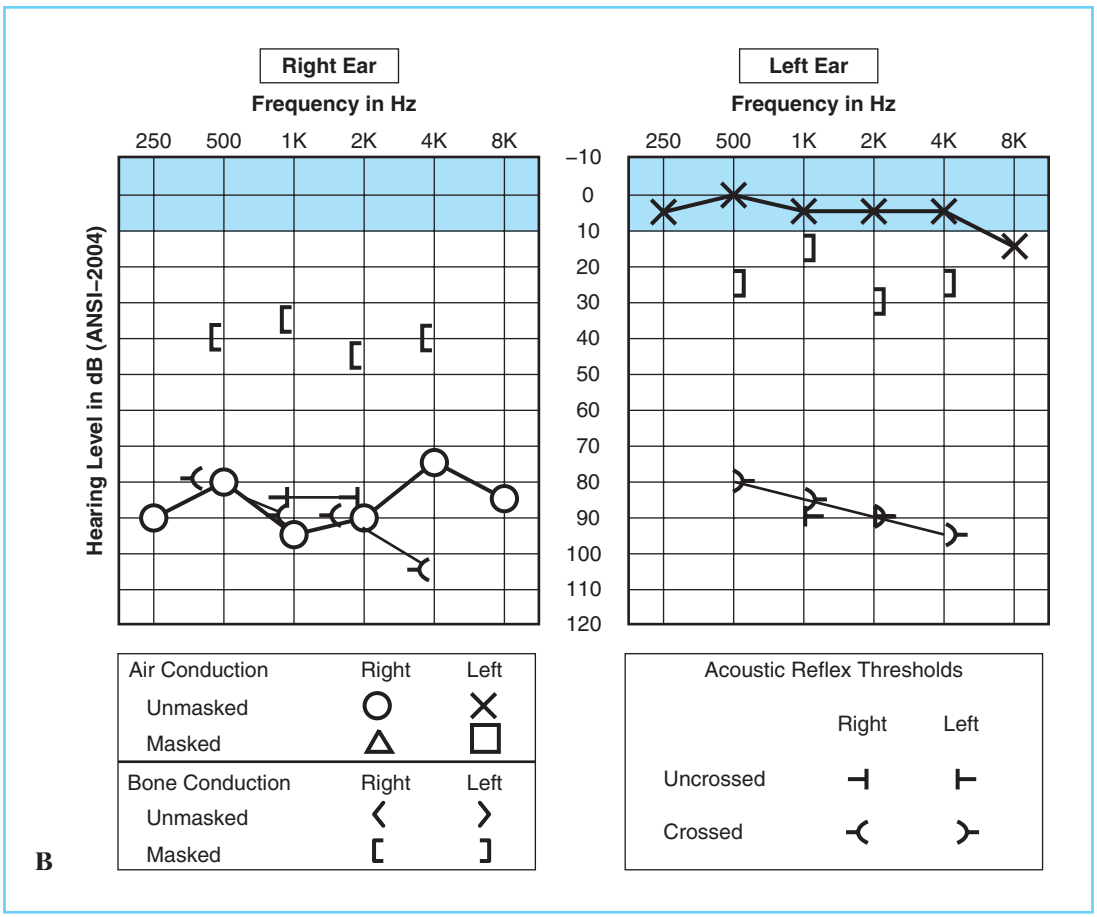


FIGURE 10-16 Hearing consultation results in a 30-year-old man with functional hearing loss. Immittance measures (A) are consistent with normal middle-ear function. SPARs predict normal hearing sensitivity bilaterally. Pure-tone audiometric measures (B) yielded responses that were inconsistent and considered to be at suprathreshold levels. Distortion-product otoacoustic emissions (C) are present bilaterally.

As is customary in cases of unilateral hearing loss, a Stenger test was carried out to verify the authenticity of behavioral thresholds. Results of a speech Stenger test are positive for functional hearing loss. Presentation of signals to the poorer ear resulted in interference



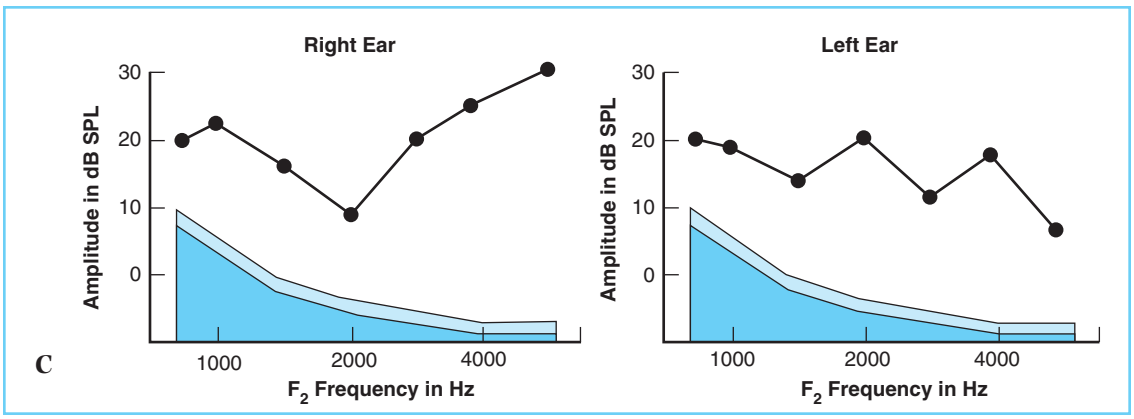
B

with hearing in the better ear at 20 dB, indicating no more than a mild hearing loss in the poorer ear.

Speech thresholds are better than the pure-tone thresholds by 20 dB, bringing into question the authenticity of either measure. Word-recognition testing resulted in unusual responses with rhyming words at levels at or below admitted pure-tone thresholds.

Otoacoustic emissions are shown in Figure 10-16C. OAEs are present bilaterally, indicating at most a mild hearing loss.

The patient was confronted with the inconsistencies of the test results, but no reliable behavioral thresholds could be obtained. He was scheduled for evoked potential audiometry but did not return for the evaluation.



Summary

- Although the overall goal of an audiological evaluation is to characterize hearing ability, the approach used to reach that goal can vary considerably across patients.
- The approach chosen to evaluate a patient's hearing is sometimes related to patient factors such as age and sometimes related to the reason that the patient has sought services or been referred for services.
- Audiologic assessment of otologic referrals is aimed at providing additional information to the physician to aid in diagnosis or to provide a metric for the success or failure of medical or surgical treatment.
- Audiologists are faced with two main categories of adult patients, those who are younger and have significant vocational communication demands and those who are older and have more complex auditory problems.
- The audiologist is faced with three main challenges in the assessment of infants and children.
- The first challenge in pediatric assessment is to identify children who are at risk for hearing loss and need further evaluation.
- The second challenge in pediatric assessment is to determine if the children identified as being at risk for auditory disorder actually have a hearing loss and, if so, to determine the nature and degree of the loss.

- The third challenge in pediatric assessment is to evaluate the hearing ability of preschool and early school-age children suspected of having auditory processing disorders.
- Regardless of the reason for functional hearing loss, the role of the audiologist is to detect that a functional component exists and to resolve the true hearing sensitivity.

Short Answer Questions

1. In determining an approach to evaluation, two important questions to be answered are: "What are the _____ for the evaluation?" and "What _____ will I use to test?"
2. Evaluative goals for an otologic referral include determination of the _____ of the disorder and the impact of the disorder on hearing _____.
3. Immittance audiometry is the most sensitive audiologic indicator of _____ disorder.
4. Information about middle-ear dysfunction that can be determined from _____ audiometry includes: _____ and _____ of the middle-ear system; the presence of a _____ in the tympanic membrane; and the presence of significant _____ pressure in the middle-ear space.
5. Information about middle-ear dysfunction that can be determined from _____-_____ audiometry is the presence of an _____-_____ gap.
6. Speech-_____ _____are primarily used as a cross-check for pure-tone thresholds.
7. The _____ _____ from _____ _____ (SPAR) test is useful for predicting the presence of cochlear hearing loss by comparing the average of pure-tone acoustic reflexes to acoustic reflexes elicited by _____-_____ signals.
8. The _____ of a hearing loss is determined by comparison of pure-tone thresholds between the two ears.
9. The _____ of a hearing loss is determined by comparison of the audiometric results to the results of previous audiometric evaluations.

10. Word-_____ scores that cannot be predicted from the pure-tone audiogram raise suspicion for _____ disorder. When word-recognition scores are worse at high intensities than at lower intensities, _____ is said to occur.
11. Quantifying the impact of hearing impairment on communication ability is known as hearing _____ assessment.
12. The primary goal for hearing screening of infants is to _____ infants at risk for significant sensorineural hearing loss and who require further _____ testing. Additionally, children should be identified who are at risk for _____ onset or _____ hearing loss.
13. Significant risk factors for hearing loss in children include: a _____ history of hearing loss; diagnosis of a _____ that has hearing loss as a characteristic feature; or infection with _____ (CMV).
14. The use of _____ auditory brainstem response testing is common for screening of infants for hearing loss because it does not require significantly skilled personnel for operation.
15. The use of _____ _____ is susceptible to false positives in screening the hearing of infants due to middle-ear issues.
16. To obtain accurate tympanograms in newborns and young infants, it is necessary to use a _____ Hz probe tone, rather than the typically used _____ Hz probe tone.
17. _____ _____ audiometry was historically used for testing of hearing in infants. In this testing approach, infants are observed for subtle behavioral responses that occur in response to suprathreshold sounds.

Discussion Questions

1. How might the strategy used to evaluate a patient who is seeking otologic care differ from the strategy used to evaluate a patient who is seeking audiologic care?
2. How might the strategy used to evaluate an adult patient differ based on age?
3. How might the strategy used to evaluate a pediatric patient differ based on age?

4. In what ways does the role of immittance audiometry change with patient population being assessed?
5. In what ways does the role of auditory evoked potentials in audiologic evaluation change with the population being assessed?
6. How might an audiologist's knowledge of medical etiologies of hearing loss contribute to the audiologic assessment?

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11

COMMUNICATING AUDIOMETRIC RESULTS

Learning Objectives

Talking to Patients
- Goal of the Encounter
- Information to Convey
- Matching Patient and Provider Perspectives

Writing Reports
- Documenting and Reporting
- Report Destination
- Nature of the Referral
- Information to Convey
- Sample Reporting Strategy

Making Referrals
- Lines and Ethics of Referrals
- When to Refer

Summary

Short Answer Questions

Discussion Questions

Resources

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- Describe the principles of communicating audiologic results to patients.
- Explain the difference between documenting test results and reporting test results.
- Describe how report writing goals will vary depending on the source of the referral.
- List and explain the components of a typical audiologic report.
- Explain the concept of lines of referral and the ethics relating to it.

COMMUNICATING results of the audiologic evaluation is an important aspect of service provision. It is important for patients and families to understand the outcomes and implications of audiometric tests and any next steps that must be taken. It is also important for results to be accurately reported in the patient's medical record, to the referral source, and to others as the patient requests. Finally, it is important to make proper referrals when indicated based on the outcome of the audiologic consultation. In all cases, it is important to maintain confidentiality of patient information in accordance with ethical and legal standards.

This chapter will provide a brief overview of the importance of communicating results to patients, some thoughts about effective reporting of results, and some strategies for making proper referrals.

TALKING TO PATIENTS

Once the evaluation process is completed, results must be conveyed to patients and, often, their families and significant others. There is no set formula for this process, and common sense in communicating results will serve you well as a clinician. Nevertheless, the beginning student will find it valuable to think through the goals of effective communication and to understand some of the barriers to achieving this effectiveness (for a complete review of counseling in audiology, see Sweetow, 1999; Clark & English, 2004).

Goal of the Encounter

What should your goals be during informational counseling following completion of the evaluation process? The first step, of

course, is simply to help patients understand what it is you learned from all of the testing.

While it may not seem difficult to convey what you learned, you might have just finished gathering tympanograms, acoustic reflex thresholds, static immittance, OAEs, air- and bone-conduction thresholds, speech thresholds, suprathreshold speech measures, an audiometric Weber, and who knows, maybe even a Stenger test. The bewildered patient is wondering about all of this, and your job is to make it simple and obvious.

As a new clinician, you will have a tendency to want to start at the beginning and explain the outcome of all of your testing. But the seasoned audiologist will start at the end of the story, providing the patient with a straightforward and simple statement of the overall outcome of the testing and then fill in the details about testing as needed, and only if needed.

There are at least three important goals that you should try to achieve during your informational counseling of patients:

1. help them to understand the nature and degree of their hearing impairment and its likely effect on communication ability;
2. give them words to use to describe their hearing loss, so that they can talk about and learn about the problem; and
3. provide them with a clear understanding of the next steps that need to be taken.

Information to Convey

One of the challenges of communicating with patients is to convey enough information for them to understand the nature of the problem without overburdening them with detail. Another challenge is to do so in a manner that is clear and that does not presume too much knowledge on the part of the patient.

Most audiologists begin discussing results by describing the type and degree of hearing loss. It is a rare audiology office that will not have a simple diagram of the ear readily available to assist in explaining how the ear works and how a disorder occurs. It is important to remember that most patients will have been exposed

to some rudimentary explanation of how the ear works at some point in school and that most will have long ago forgotten what they learned. Simplifying the explanation and using common terms for the anatomy and physiology will contribute to a better understanding on the part of the patient.

Audiologists differ on how to describe hearing sensitivity, but most of them use the audiogram as a tool for the explanation. An effective explanation of the audiogram follows much the same rules as an effective explanation of the anatomy of the ear. The simpler the language that is used, the more likely is the information to be conveyed. Words like *intensity, frequency,* and *threshold* are not always readily understood by patients, whereas *loudness, pitch,* and *faint sound,* while not precisely accurate, make a lot more sense to most people. The new student will benefit from trying to explain an audiogram to roommates, parents, and friends before he attempts his explanation on patients. There are tools available that can assist in the explanation of an audiogram, such as the speech-sound audiograms shown in Chapter 3 or the count-the-dots audiograms shown in Chapter 7. The aim of these approaches is to help the patient understand the impact of the sensitivity loss on the hearing of speech to provide a more thorough understanding of its impact on overall communication ability. There are also some generic delineations of communication ability based on general degrees of hearing loss, as shown in Table 11-1. To most patients, these explanations will simply verify what they already know, but there is great value in helping them to understand why they are having the problems they are having.

Explanations of the outcomes of other test measures can often be helpful in making the results clear to patients. For example, results of immittance measures, with a very simple explanation, may be helpful in conveying to patients that outer and middle ears are working just fine, but the inner ear is not. Or it might be helpful to convey to the parents of an infant that the flat tympanogram helps explain the mild sensitivity loss found on ABR testing. Similarly, it may be valuable to explain to patients that although they can no longer hear soft sound, once sound is made loud enough, their ability to recognize speech is excellent, or poor, or whatever it may be.

TABLE 11-1 Nature of communication disorder as a function of degree of hearing loss

Hearing Loss in dB	Degree of Loss	Communication Challenge
26–40	Mild	difficulty understanding soft speech; good candidate for mild gain hearing aids
41–55	Moderate	hears speech at 3 to 5 feet; requires hearing aids to function effectively
56–70	Moderately Severe	speech must be loud or close for perception; requires hearing aids to function adequately
71–90	Severe	loud speech audible at close proximity; requires hearing aids to communicate through audition
91+	Profound	cannot perceive most sound; requires cochlear implant to communicate through audition

It is usually not necessary to explain in detail the results of all test outcomes. Indeed, it is often counterproductive to burden the patient with excessive information. Rather, you should strive to emphasize the important summary information for them so that they leave with a clear understanding of the two or three most important points you want them to remember. That said, you may find that certain test outcomes help to explain their symptoms, and you may want to take time to provide validation of those symptoms.

Most audiologists find it useful to give the patients the right words to use to describe their hearing loss. Again, that may sound obvious, but it can help in a number of ways. If your report says that the patient has a mild sensorineural hearing loss, there is a good chance that the primary-care physician reading your report will use those same words. If you have conveyed those same words to the patient, there will not be confusion. This may help to avoid use of some of the more oblique terms like *nerve deafness* or other colloquialisms that add confusion. Giving the correct terminology also allows the patient the opportunity to access accurate information online more readily than the use of slang might.

One of the most important outcomes of this information counseling is setting the stage for treatment. For those patient with middle-ear disorder and conductive loss, facilitating the proper referral and conveying the importance of follow-up is crucial. For those patients with sensorineural hearing loss, it is at this point that you help the patient to understand how they might benefit from hearing aid amplification and other solutions. For the adult patient, a clear explanation of their candidacy for hearing aids or a cochlear implant and an enthusiastic but realistic prognostic statement about the potential benefits to be gained can be a very valuable first step in the process. For infants and children, it is at this point that you begin working with the parents to garner the resources to move forward with treatment and educational options. Regardless, it is crucial to convey in a clear and definitive manner what the next steps will be.

Matching Patient and Provider Perspectives

The patient perspective is unique. Patients may be quite familiar with audiometric test results, somewhat familiar, or completely unfamiliar. They may know what caused their hearing loss, may have some idea, or may be completely worried about the cause. They may wear hearing aids, want hearing aids, or hope to avoid hearing aids. Parents may have other children with hearing loss, neighbors who have children with hearing loss, or may never have thought about childhood hearing loss or its consequences. And so it is difficult to know what your individual patient's perspective might be. Nevertheless, there are some generalities that might help guide you.

The seasoned patient will require little explanation. Adult patients will want to know if the hearing has changed in any way or, if they already know that it has, will want to know to what extent it has changed. They will also be curious about technological enhancements in hearing aids and when to pursue a change.

First-time adult patients will want to understand the cause of the hearing loss, if it is not already known, and will want to ensure that it is not signaling a more significant health problem. They will want to understand how bad their loss is compared to others and to learn if their spouses were, in fact, right about how much hearing loss

they have. They will want to know if their loss is medically treatable and will come with a wide variety of levels of acceptance about the idea of hearing aid use. These patients will understand their problems and will want to understand why they are having them. They will not have a clue about the audiogram and will require time to understand the underlying nature of the disorder.

Parents of infants and young children identified with hearing loss will want to know, first and foremost it seems, what caused the loss. Although it may never be clear or it may take a multidisciplinary team approach with the neonatologist, otolaryngologist, and/or geneticist to determine the answer, the parents will ask you. So you need to be prepared to defer the question or discuss possibilities. Parents will be in varying stages of grief and possible denial about hearing loss, and you need to be prepared to understand this (for an overview, see Tanner, 1980; Clark & English, 2004). When they are prepared to deal with the issue, and for some parents it may be immediate, you need to be prepared to talk with them about eligibility for local and state services, educational services, and hearing aid or cochlear implant intervention. This is probably one of the times that you will be most challenged in terms of finding a balance between providing adequate information and too much information. The parents may not hear much after you tell them that their baby has a hearing loss, and so providing them with written information, web site URLs, and other resources that they can access once the reality of hearing loss sinks in will be a very valuable approach.

In contrast to the patient's unique perspective, your perspective on the patient's hearing loss will not be unique. He or she may be the twentieth patient you have seen this week with bilaterally symmetric, mildly sloping sensorineural hearing loss. The ABR you have just done on the infant may be the tenth this week that demonstrated what will undoubtedly be transient conductive disorder. You may be hearing for the thirtieth time this month that someone's spouse is making him or her get this hearing test and that if the spouse would only just quit mumbling. . .

One of the most challenging aspects of informational counseling of patients is remembering that this is each patient's only hearing loss. One of your challenges will be to avoid treating patients as

audiograms rather than for the unique communication disorders they present.

Another of your challenges will be to say enough but not too much. You will have to find the right blend of talking and listening for each patient. Newer providers have a tendency to fill silent gaps by talking a bit too much. Over time, it seems, it becomes easier to say less and still convey ample information adequately.

When you have finished providing information about the results of your evaluation, it is important that you clearly delineate next steps for patients. The next step may be as simple as sending the patient down the hall to the otolaryngologist. Or it may require coordinating services with the local school system, the state's early childhood program, your cochlear implant program, and so on. Stating the disposition clearly, scheduling the appointment, and discussing the next steps with patients is an important final step in the counseling process.

WRITING REPORTS

One important aspect in the provision of health care is the reporting of results of an evaluation or treatment outcome. The challenge of reporting is to describe what was found or what was done in a clear, concise, and consistent manner. The actual nature of a report can vary greatly depending on the setting and the referral source to whom a report is most often written.

In larger institutions, the report is placed in the electronic medical records for your later use or for review by the referral source, primary-care physician, or other health-care provider.

Documenting and Reporting

It is important to distinguish between *documentation* of test results and *reporting* of test results. Documentation is a fundamental necessity of patient care. It is important for continuity of patient care, for billing purposes, and for legal reasons. Documentation is simply the preservation of examination and test results in a patient file and must be maintained in all cases following the

provision of services. Reporting results is the summarizing of that documentation. As an example, when you carry out immittance testing, you will obtain a large amount of detailed information about the tympanogram, static immittance, reflex thresholds, etc. This is important information to keep as part of the patient record. However, what you write in your report might be "normal middle-ear function," an important and clear summary statement about these test results. Once you have summarized your evaluation in this way, the resultant report actually becomes a part of the documentation of the patient visit.

Audiology reports are generally of two types. The type of report is usually dictated by the setting, and in some cases both types are used within a setting based on the nature of the referral source or documentation requirements. One type of report is the *audiogram report*. The audiogram report usually consists of an audiogram, a table of other audiometric information, and space at the bottom for summary and impressions. The audiogram report is often used for reporting in hospital settings, where the results are added to the patient's electronic chart and may constitute both the documentation and the report for the medical record. The audiogram report is also often used in otolaryngology offices, where the audiometric evaluation is one component of the medical evaluation and is used to supplement the medical report generated by the physician. The great challenge in creating an appropriate audiogram report is to be thorough, since this may constitute the entirety of the audiologic record in a patient chart, while at the same time being clear and concise. Certain necessary information must be included, but it needs to be presented in a way that promotes communication between the audiologist and the consumers of the report.

The other common type of audiologic report is the *letter report*. This report is often dictated or computer generated. It is meant to either stand on its own or to accompany an audiogram and other test-result documentation. The report in this case serves as the summary of results and a statement of disposition of the patient. When written appropriately, it can be sent to a patient, a referral source, a school, or other interested parties without supporting documentation. It can also be used as a cover letter for supporting

documentation when the report is sent to referral sources or others who might understand what an audiogram, an immittance form, or a latency-intensity function represents. The great challenge in creating an appropriate letter report is to say enough, but not too much. The letter should state clearly the outcome of test results and the recommendations or other disposition related to the patient. In most cases, it should *not* serve as a lengthy description of the patient or the test procedures used to reach the outcome conclusions.

Reporting of test results can be a relatively simple and efficient process. The most important aspects of report writing are probably consistency and clarity. The purpose is to communicate in a manner that describes the results and disposition effectively. A list of dos and don'ts for report writing can be found in the accompanying Clinical Note. These should serve as general guidelines for the generation of the majority of reports that you write. Remember that the reader is busy and wants your professional interpretation and impression. Three of the more important do's are: (1) be clear, (2) be concise, and (3) be consistent.

Report Destination

The primary reason for report writing is to communicate results to the medical record or to the referral source. If the patient is self-referred, that is, she has come to you directly without referral, then your report may simply be the patient records that your office retains. If the patient is referred to you, then the primary destination of the report is back to the referral source. In this case, as a rule, your only obligation as a professional is to report back to the referral source, because that person has requested a consultation from you.

The patient may also request a copy of the report or that a copy be sent to additional health-care providers, schools, and so on. It is customary and appropriate to address a letter report to the referral source, with additional copies sent to the other requested parties. On occasion, there are circumstances under which an additional report is written to an individual or institution as a service to the patient. It is appropriate to write such a report, as long as in doing so the lines of referral are not breached. The concept of referral lines is introduced later in this chapter.

Report Writing Dos and Don'ts

Clinical Note

The following are some tips on report writing:

Do:

- Be clear
- Be concise
- Be consistent
- Be descriptive
- Summarize
- State outcomes clearly
- State recommendations clearly
- State disposition clearly
- Write for the reader
- Provide all relevant information
- Provide only relevant information
- Include lengthy information as a supplement

Don't:

- Write long reports
- Rehash case history to the referral source
- Report every aspect of the evaluation process
- Describe the nature of the case in elaborate detail
- Describe the nature of testing in elaborate detail
- Be interpretive unless clearly noted
- Use audiologic jargon
- Recommend audiologic re-evaluation without a reason

Nature of the Referral

Reporting of audiometric test results should be done in a clear enough manner that the report can be generally understood, regardless of the nature of the referral source. That is, the type and severity of the hearing loss are described the same whether the

report is being sent to a patient, a parent, or an otolaryngologist. However, conclusions and recommendations may vary considerably depending on the referral source.

Reports to the health-care community must be short and to the point. But even within that community there is often a need for different levels of explanation, particularly of the disposition of the patient. For example, the **otolaryngologist** will understand the steps that must be taken if the audiologist indicates that the patient is a candidate for hearing aid use. The **oncologist** may not. Reports to school personnel may include an explanation of the consequences of a hearing impairment. This same explanation might be unnecessary for, or certainly underutilized by, the medical community.

An **otolaryngologist** is a physician specializing in the diagnosis and treatment of diseases of the ear, nose, and throat.

An **oncologist** is a physician specializing in the diagnosis and treatment of cancer.

One of the important challenges in reporting, then, is to develop a strategy that combines consistency in the basic reporting of results with the flexibility to adapt the implications and conclusions to meet the expectations of the reader.

Information to Convey

The goal of any report is to communicate the outcome of your evaluation and/or treatment. Reporting is just that simple. If you always strive to describe your results succinctly and to provide the referral source, patient, or parent with essential information and a clear understanding of what to do next, you will have succeeded in writing an effective report.

One of the biggest challenges in report writing is to provide *all* relevant information while *only* reporting relevant information. Although thoroughness is an important attribute of documentation, succinctness is an important attribute of reporting.

One of the most useful ways to judge the appropriateness of the information that you are communicating in a report is to put yourself in the reader's shoes. As a reader, you probably lack one of two things, time or technical expertise. In either case, your interest in lengthy, detailed reports will be limited. Perhaps some examples will make this clear.

Suppose for a moment that you are a physician. You refer a patient to the audiologist to determine the extent to which the fluid that you have observed behind the tympanic membrane is causing an auditory disorder. What might you want to know? You would probably want to know whether or not middle-ear disorder is detected by immittance measures and, if so, what the nature of the results is. You would also probably want to know the degree of hearing loss the disorder is creating and the nature of the hearing loss, for example, whether it is a *conductive* or mixed hearing loss. Finally, you would want to know if speech perception measures or any other auditory measures suggest any evidence of additional cochlear or retrocochlear disorder. This is all information that would help you as a physician make appropriate decisions about diagnosis and treatment, and it should be summarized in a report. Okay, so what don't you care about? First, you don't care to hear about the patient's medical history. Why? Because you already know all about it. Second, you probably do not want to hear about the nuances of the audiologic tests that were carried out. Although important to the audiologist and imperative for the audiologic records, their descriptions serve simply as extraneous information that obscures the results and conclusions of the audiologist's evaluation or treatment. Third, you are probably not interested at this point in getting recommendations about nonmedical or nonsurgical intervention strategies.

Let us use another example. Suppose this time that you are the patient. You have decided to see the audiologist because your hearing impairment has reached a point at which you feel that hearing aid use might be appropriate. You would like a report for your records, and you would like to have a copy sent to your primary-care physician for hers. What do you care about? You are probably interested in a report describing the degree and type of hearing loss you have in both ears. You are also probably interested in written recommendations about the prognosis for pursuing hearing aid use. What don't you care about? Well, you don't care to read about your own medical history. You already know that. You also don't care about the specifics of the auditory tests. You simply want words to describe your problem and a cogent statement of the plans to fix it.

What, then, should be communicated in a report? What are the best strategies for doing so? As a general rule, the report should be a summary of evaluative outcomes. What is the hearing like in the right ear? The left ear? Where do we go from here? As another general rule, the report should not be a description of the testing that was done nor a description of the specific test results, except as they support the evaluative outcome. These are two important points. First, there is very seldom any reason to describe audiometric tests in a report. If the report is going to a referral source, it is safe to assume that the person receiving the report is familiar with the testing or does not care about the details. In most cases, an audiometric summary is sent with a report and provides all the details that anyone might want to see. Second, most audiometric test results are supportive of the general outcome and do not need to be described. For example, if a patient has a mild sensorineural hearing loss and normal middle-ear function, there is no reason to describe pure-tone air conduction results, bone-conduction results, the tympanogram, acoustic reflexes, speech audiometry, and so on. Simply stating the outcome is sufficient in a vast majority of cases.

For audiologic evaluations, a report usually consists of a brief summary of testing outcomes, an audiogram form with more specific information, and additional supplemental information as necessary.

The Report

An audiologic report typically includes a description of the audiometric configuration, type of hearing loss, status of middle ear function, and recommendations. Under certain circumstances, it might also include case history information, speech audiometric results, auditory electrophysiologic results, and a statement about site of the auditory disorder.

Case History. Sometimes a description of relevant information from the case history is useful in the initial portion of a report. Again, it is clearly an important part of the documentation in a patient record. But in most cases in a report, it should be very brief and serve more as an orientation as to why the consultation took place. Reports written to referral sources seldom need

a summary of why a patient was evaluated because the referral source would obviously know, being the source of the referral. Similarly, a report written to a patient seldom requires this information, because, clearly, the patient already knows all of this information.

There are times when a succinct statement can be made about some aspect of a patient's medical or communication history that might be new or relevant information to the person receiving the report. For example, for a patient who has suspected hearing loss secondary to noise exposure, a report might include a summary of relevant noise-exposure information.

The key to judging the need for extensive case history information lies in the nature of the referral source and the people or institutions to whom the report is being sent. In the vast majority of cases, reports are being sent either to the referral source, the patient, or the patient's parents. In most of these cases, a summary of relevant history is all that is necessary.

Type of Hearing Loss. If a hearing loss exists, it should be described as conductive, sensorineural, or mixed. If it is conductive at some frequencies and sensorineural at others, it should be considered a mixed hearing loss.

Degree and Configuration of Hearing Loss. Most audiologists describe degree of hearing loss as falling into one of several categories, minimal, mild, moderate, moderately severe, severe, or profound. If the audiometric pattern or configuration is that of a flat loss, the loss is often described simply as, for example, a moderate hearing loss. If the loss is not relatively flat, it is usually described by its configuration as either rising, sloping, high-frequency, or low-frequency, depending on its shape.

Describing the degree and configuration of hearing loss is not an exact science, and it should not be treated as such. Rather, the goal should be to put the audiogram into words that can be conveyed with relative consistency to the patient and among health-care professionals. To describe a hearing loss as a mild sensorineural loss at 500 Hz, moderately sloping mixed hearing loss in the mid-frequencies, and moderately severe sensorineural hearing loss in

the high frequencies, although perhaps accurate, is not very useful. Providing the words *moderate, mixed hearing loss* is probably much more useful to all who might read the report.

Sample terminology that can be used to consistently describe type, degree, and configuration of hearing loss is shown in Table 11-2.

Change in Hearing Status. When a patient has been evaluated a second or third time, it is important to include a statement of comparison to previous test results. This should be done even if the results have not changed. A simple statement such as, *hearing*

TABLE 11-2 Sample report writing terminology used to describe type and degree of hearing loss and audiometric configuration

Degree of Loss	Configuration	Type
Normal (−10 to 10)	high-frequency	conductive
Minimal (11 to 25)	low-frequency	sensorineural
Mild (25 to 40)		mixed
Moderate (40 to 55)		
Moderately-severe (55 to 70)		
Severe (70 to 90)		
Profound (>90)		
Examples Combining Degree and Type		
Mild high-frequency sensorineural hearing loss.		
Moderate mixed hearing loss.		
Minimal low-frequency conductive hearing loss.		
Examples When Degree Crosses a Category		
Mild sensorineural hearing loss through 2000 Hz; moderate above 2000 Hz.		
Mild low-frequency sensorineural hearing loss sloping to severe above 1000 Hz.		
Description of Change over Time		
Sensitivity is essentially unchanged since the previous evaluation.		
Sensitivity is decreased since the previous evaluation.		
Sensitivity is improved since the previous evaluation.		

sensitivity is unchanged/has decreased/has improved since the previous evaluation on (date), will suffice and will be an important contribution to the report.

Middle-Ear Function. It is often important to state the status of middle-ear function based on results of immittance audiometry, even if that status is normal. Much of the direction and course of treatment relates to whether or not the function is normal. When middle-ear function is normal, it should be stated directly without a delineation of immittance results.

When middle-ear function is abnormal, the nature of the immittance results should be described. It is useful to limit the description of the disorder to a few categories that can be conveyed consistently to the referral source. Once the disorder is described, the specific immittance results that characterize the disorder can be delineated. In general, middle-ear disorders fall into one of five categories:

1. an increase in the mass of the middle-ear system, characterized by a Type B tympanogram, low static immittance, and absent acoustic reflexes, often caused by otitis media with effusion and impacted cerumen;
2. an increase in the stiffness of the middle-ear system due to fixation of the ossicular chain, characterized by a Type A tympanogram, low static immittance, and absent acoustic reflexes, often caused by otosclerosis;
3. a decrease in the stiffness of the middle-ear system due to disruption of the ossicular chain, characterized by a Type A tympanogram, high static immittance, and absent acoustic reflexes, often caused by some form of trauma;
4. significant negative pressure in the middle-ear space, characterized by a Type C tympanogram, caused by Eustachian tube dysfunction; or
5. perforation of the tympanic membrane, characterized by a large equivalent volume and absent reflexes, often caused by tympanic membrane rupture secondary to otitis media or to trauma.

In reporting these results, only the type of middle-ear disorder and the immittance results should be described. The underlying

cause of the disorder is a medical diagnosis and is the purview of the physician. The audiologist's task is to identify and describe the disorder, not its cause.

Sample terminoloy that can be used to consistently describe immittance-measurement outcomes is shown in Table 11-3.

Sometimes middle ear function will be normal, but acoustic reflex measures will be elevated, consistent with sensorineural hearing loss or retrocochlear disorder. When the reflex results might be useful to the referral source in helping to diagnose such a disorder, then they should be described. Otherwise, they simply confirm the description of the type of hearing loss and are probably redundant.

Speech Audiometric Results. Results of speech audiometry are seldom useful to describe in a report. As a general rule, conventional speech audiometric measures are consistent with results of pure-tone audiometry. That is, the speech-recognition threshold is reflective of the pure-tone average, and speech-recognition scores

TABLE 11-3 Sample report writing terminology used to describe results of immittance measurements

Tympanometry and Reflexes
Normal middle-ear function
Middle-ear disorder: results are consistent with an increase in the mass of the middle-ear mechanism (type B tympanogram and absent reflexes in the probe ear)
Middle-ear disorder: results are consistent with an increase in the stiffness of the middle-ear mechanism (shallow type A tympanogram and absent reflexes in the probe ear)
Middle-ear disorder: results are consistent with a perforation of the tympanic membrane (or patent P.E. tube)
Middle-ear disorder: results are consistent with decrease in the stiffness of the middle-ear mechanism (deep type A tympanogram and absent reflexes in the probe ear)
Middle-ear disorder: results are consistent with significant negative pressure in the middle-ear space (type C tympanogram; reflexes absent or present)
Tympanometry Only
Immittance yielded a normal, type A tympanogram.

are consistent with the degree and configuration of hearing loss. As long as they are included on the audiogram form, there is no real need to describe them in a report because the information they provide is redundant and, thus, contributes little to the overall summary of results that you are trying to convey.

Sometimes speech audiometric results are poorer than would be expected from the results of pure-tone audiometry. In such cases, the results may be important to the diagnosis and should be included in a report. Here again, rather than providing a specific score on a test, the results should be summarized in a meaningful way. Statements such as *word recognition scores were poorer than expected for the degree of hearing loss or speech audiometric measures showed abnormal rollover of the performance-intensity function* serve to alert the informed reader to potential retrocochlear involvement without burdening the report with details.

When advanced speech audiometric measures are used to assess auditory processing ability, the same general rules apply. If results are normal, there is no need to describe them in a report. If results are abnormal, they should be described generally without details of the test procedures or too much specific information about test scores. Often, the report will be accompanied by an audiometric form that contains enough detail for readers with specific knowledge. Those without specific knowledge will not benefit from this information regardless of its availability, so it is even more important to summarize the information in a succinct and meaningful way in the body of the report.

Electrophysiologic Results. A variety of strategies are used to describe the results of auditory electrophysiologic measures. As a general rule, the more complicated the technology, the more compelled the writer seems to be to burden the reader with details of the testing itself. Again, however, you have the opportunity to treat this testing as any other audiometric measure by simply describing the outcome in your report. The details of how you reached that decision are better left as supplementary documentation for those who might understand it.

When auditory evoked potentials are used to predict hearing sensitivity, the results can be summarized in a standard audiologic

report. If results are consistent with normal hearing sensitivity, then a statement such as *auditory brainstem response predicted hearing sensitivity to be within normal limits* will suffice. If results are consistent with a hearing loss, then the report should state that these measures predict a mild, moderate, or severe, sensorineural or conductive hearing loss. A latency-intensity function might be sent along with the report to provide more detail for the curious reader.

When auditory evoked potentials are used diagnostically, the same rules apply. A general statement should be made about the overall outcome of the testing. When results are normal, a statement should be made that *absolute and interpeak intervals are within normal limits* and that these *results show no evidence of VIIIth nerve or auditory brainstem response abnormality.* When results are abnormal, they should also be described generally as, for example, the absence of a measurable response, a prolongation of wave I–V interpeak interval, a significant asymmetry in absolute latency of wave V, and so on. The results should then be summarized by stating that they are consistent with VIIIth nerve or auditory brainstem response abnormality.

Sample terminology that can be used to consistently describe electrophysiologic test results is shown in Table 11-4.

To some readers, the details of these evoked potential measures are important. They are interested in electrode montage, click rate, stimulus polarity, EEG filtering, etc. For these individuals, a summary containing this information as well as the waveforms may be useful. Most readers, however, are only interested in the outcome and your professional opinion about it. In a report, there is no need to burden this latter group because of the interests of the former. The report should summarize and make conclusions. Supplemental information can always be attached.

For an electronic patient record system, where the report and documentation may be combined, it is not a bad idea to sequence the report in such a way that the conclusions come first and the documentation last. This way, anyone reading the report will be able to get to the conclusion without having to wade through the details.

TABLE 11-4 Sample report writing terminology used to describe results of ABR and OAE measurements

Outcome	Results
Normal ABR	Auditory brainstem response (ABR) testing shows well-formed responses to click stimuli at normal absolute latencies and interwave intervals. There is no electrophysiologic evidence of VIII nerve or auditory brainstem pathway disorder.
Abnormal ABR	Auditory brainstem response (ABR) testing shows abnormal responses to click stimuli. Both the absolute latency of wave V and the I to V interwave interval are significantly prolonged.
Normal hearing	Auditory brainstem response (ABR) testing shows well-formed responses to click stimuli at intensity levels consistent with normal hearing sensitivity in the 1000 Hz to 4000 Hz frequency range.
Sensitivity Loss	Auditory brainstem response (ABR) testing shows well-formed responses to click stimuli down to ___ dB nHL. This is consistent with a ___ hearing loss in the 1000 Hz to 4000 Hz frequency range.
Conductive loss	Auditory brainstem response (ABR) testing shows well-formed responses to click stimuli down to ___ dB nHL by air conduction and down to ___ dB nHL by bone conduction. This is consistent with a ___ hearing loss in the 1000 Hz to 4000 Hz frequency range.
Normal OAEs	Distortion-product otoacoustic emissions are present and robust, suggesting normal cochlear function.
Absent OAEs	Distortion-product otoacoustic emissions are absent.

Site of Disorder. In general, there is no need to make a statement about site of disorder in a report. A conductive hearing loss is related to outer- or middle-ear disorder, and a sensorineural hearing loss is related to cochlear disorder. Occasionally, however, the audiologist will find it useful to give an overall impression of the possible site of disorder.

This is particularly useful if the patient has been referred for differentiation of a cochlear versus retrocochlear disorder or if a parent or referral source is interested in knowing the status of auditory processing ability.

Any statement of site of disorder should be based on an overall impression of results of the test battery. If an VIIIth nerve tumor is suspected as the cause of an auditory disorder and the referral source is interested in the audiologist's opinion, the report should state that the pattern of test results is consistent with cochlear disorder or consistent with retrocochlear disorder, depending on test outcomes. It should be emphasized that the site would be assumed to be cochlear and that a statement about cochlear site would be unnecessary unless there is some concern about retrocochlear disorder. In some cases, there is no *a priori* concern about retrocochlear disorder, but various audiometric measures suggest otherwise. In such cases, it is valuable for the audiologist to make a statement about the pattern of test results.

The same general ideas hold for assessment of auditory processing ability. If no concern is expressed, and routine testing is normal, no statement about site of disorder is necessary. However, if a diagnosis can be made based on routine testing, the report should state that the overall pattern of results is consistent with auditory processing disorder. Additionally, if a patient is referred for evaluation of central auditory function, the reports should state that the pattern of test results is consistent with auditory processing disorder or that there is no evidence of such disorder, depending on test outcomes.

Recommendations. The recommendations section of a report is generally the first section that is read by the reader. As in all other aspects of the report, recommendations should be clear, concise, and consistently stated. Recommendations generally fall into one of four categories:

1. no recommendations,
2. recommendations for re-evaluation,
3. recommendations for additional testing, or
4. recommendations for referral.

Sometimes there is no consequence to the audiometric test results, and no recommendations are necessary. For example, a patient with symptoms of dizziness may be referred to the audiologist to rule out cochlear contribution to the dizziness. All pure-tone, immittance, and speech audiometric measures may be normal if

the cochlea is not involved. As another example, a child may fail a school hearing screening because the testing was carried out in too noisy an environment. Results of the audiometric evaluation may be normal. What do you conclude? What do you recommend? Nothing. You can simply state that *no audiologic recommendations are indicated at this time.*

Occasionally there is a need to recommend audiologic re-evaluation. For example, if a child is undergoing medical treatment for otitis media, and you discover a conductive hearing loss, you may want to recommend that the child return for audiologic re-evaluation following the completion of medical management as a means of ensuring that there is no residual hearing loss that needs to be managed. As another example, an infant may have risk factors for progressive or delayed-onset hearing loss that requires periodic re-evaluation. Also, if a patient is exposed to damaging noise levels at work or recreationally, periodic assessment is indicated. In these cases, the recommendation of re-evaluation is appropriate and important.

Care should be taken to not overuse this recommendation. For example, in a pediatric practice, a recommendation for re-evaluation at some later date should not serve as a substitute for completion of testing in the immediate future.

Another common recommendation is for additional testing. For example, if behavioral testing could not be completed on a child or a patient with functional hearing loss due to a lack of cooperation, the audiologist may recommend additional testing with auditory evoked potentials.

Recommendations are also quite commonly made for referral purposes. The patient may be referred for a hearing aid consultation, cochlear implant evaluation, speech-language evaluation, medical consultation, otologic consultation, and so on. Although the audiologist must always be cognizant of the rules of referral as discussed later in the chapter, the responsibility for making appropriate referral recommendations is an important one.

Terminology that can be used to provide consistent recommendations is shown in Table 11-5.

TABLE 11-5 Sample report writing terminology used to describe recommendations

Disposition	Description
Back to Referral	To Dr. ___ as scheduled
	Return to Dr. ___
	Results copied to ___
Additional Testing	Medical consultation for evaluation of middle-ear disorder
	Hearing test following completion of medical management
	Continued monitoring of hearing sensitivity (annually, 6 months, etc.)
	If additional audiologic diagnostic information is needed, consider auditory brainstem response testing
	Evoked response audiometry to further assess hearing sensitivity
	Balance function testing pending medical clearance
	Medical consultation for evaluation of dizziness
Hearing Aids	Hearing aid selection following medical clearance
	Recommendations deferred pending otologic consultation
	Cochlear implant evaluation
	Hearing aid use is not recommended

The Audiogram and Other Forms

Under most circumstances it is customary to send an audiogram with a report. Because the audiogram has been a standard way to express hearing sensitivity for many years, it is widely recognized and generally understood by referral sources. As stated earlier, two strategies predominate, one the use of an audiogram form for both reporting and documenting and the other the use of a letter report with an audiogram and other forms attached.

The *audiogram report* is typically an audiogram, a table of information, and a summary at the bottom. It often serves as both

a report and documentation in the patient record in a hospital or audiologist's or physician's office. As such, it is often packed with information about the pure-tone audiogram as well as speech and immittance audiometry. Because it is so comprehensive, it is often difficult to read and interpret and can defy the important requirement of clarity in reporting. The requirement for thoroughness inherent in the patient record makes it even more important that the summary and conclusions are concise and to the point.

An audiogram may also accompany a *letter report.* In this case, the report is usually going out of the office or clinic, and a patient record is maintained electronically or in file form in the audiologist's office. The audiogram form can be designed to be less thorough, but clearer, to the reader. Detailed supporting documentation can be stored in the patient's file. An example of an audiogram that might accompany a letter report is shown in Figure 11-1.

It is not uncommon for an audiogram to include information about speech audiometry, either in tabular form, including speech-recognition threshold, word-recognition scores, and levels of testing, or in graphic form as a performance-versus-intensity function. The latter probably communicates better, although the former requires less space. Regardless, information about speech thresholds and word-recognition scores are often generally understood and should be included with the audiogram form.

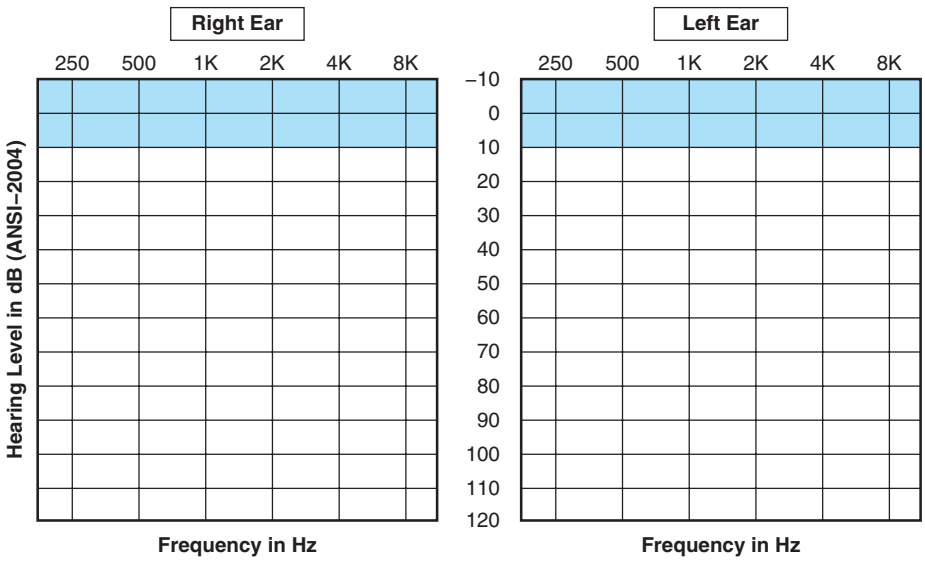
Most audiologists also send information on results of immittance audiometry. Again, the form can vary from a tabular summary on an audiogram to a separate sheet of paper showing the tympanogram and acoustic reflex patterns, along with a space for summary information. An example is shown in Figure 11-2. As in all cases, this information will be understood by some who might receive a report and be quite foreign to others. Therefore, care should be taken to provide a clear and concise interpretation on the letter report.

If auditory evoked potentials have been carried out, it is not uncommon for the results to be summarized on an auditory brainstem response latency-intensity summary form. This form shows

Hearing Consultation Results

Date: _____

Name: _____ Age: _____ Sex: ____ MRN: _____



Air Conduction	Right	Left
Unmasked	○	×
Masked	△	□
Bone Conduction	**Right**	**Left**
Unmasked	〈	〉
Masked	[	]
Reflex Thresholds	**Right**	**Left**
Uncrossed	⊣	⊢
Crossed	≺	≻

Summary

Right		Left
dB	PTA	dB
dB	SRT/SAT	dB
dB		dB
%	WRS@___dB	%
%	WRS@___dB	%
%		%
%		%

Impressions: _____

_____

_____

_____

_____

_____

_____

_____

Audiologist

FIGURE 11-1 Hearing consultation results form.

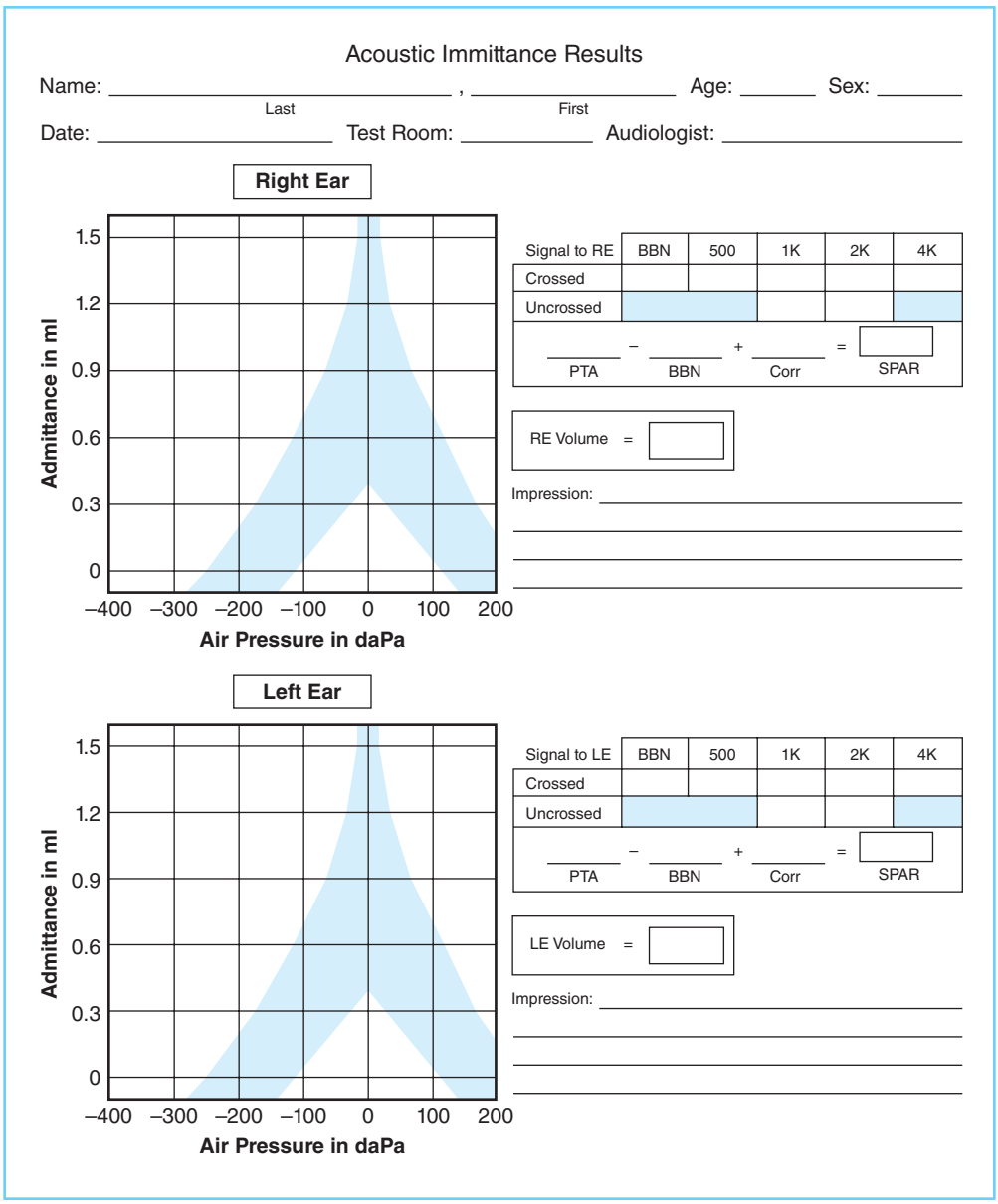


FIGURE 11-2 Sample immittance report form.

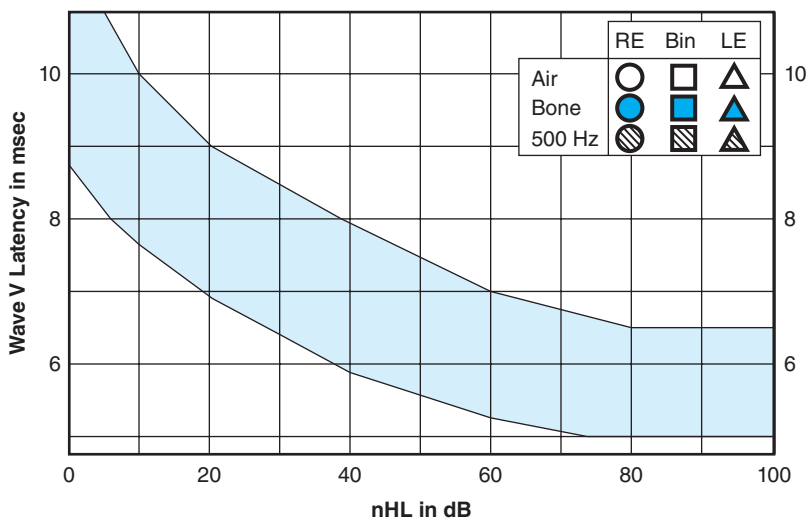
a graph of wave V latency as a function of stimulus intensity, along with summary information about relevant absolute and interpeak latencies. The form also includes a summary section in case the form is not accompanied by a letter report. An example

is shown in Figure 11-3. If the audiologist feels that the referral source will benefit from specific signal and recording parameter information, then actual waveforms with these data may also be included with the summary.

ABR Report Form

Name: _____ Age: _____

Audiologist: _____ Date: _____



Summary of Results At Click Level _____ dB nHL

	Absolute Latency Wave V	Interwave Intervals		
		I-III	III-V	I-V
RE				
LE				

Comments _____

_____

_____

_____

FIGURE 11-3 Sample ABR report form.

Supplemental Material

Clinical reports are simply not the place to include lengthy descriptions of testing procedures, outcomes, or rehabilitative strategies. Quite frankly, few people read lengthy reports; most just skip to the summary and recommendations. Nevertheless, there are important times to provide descriptive information, and it should be included as supplemental material to the main report and sent only to individuals who might read it.

Information that has proven to be useful as supplemental material includes, for example, pamphlets explaining:

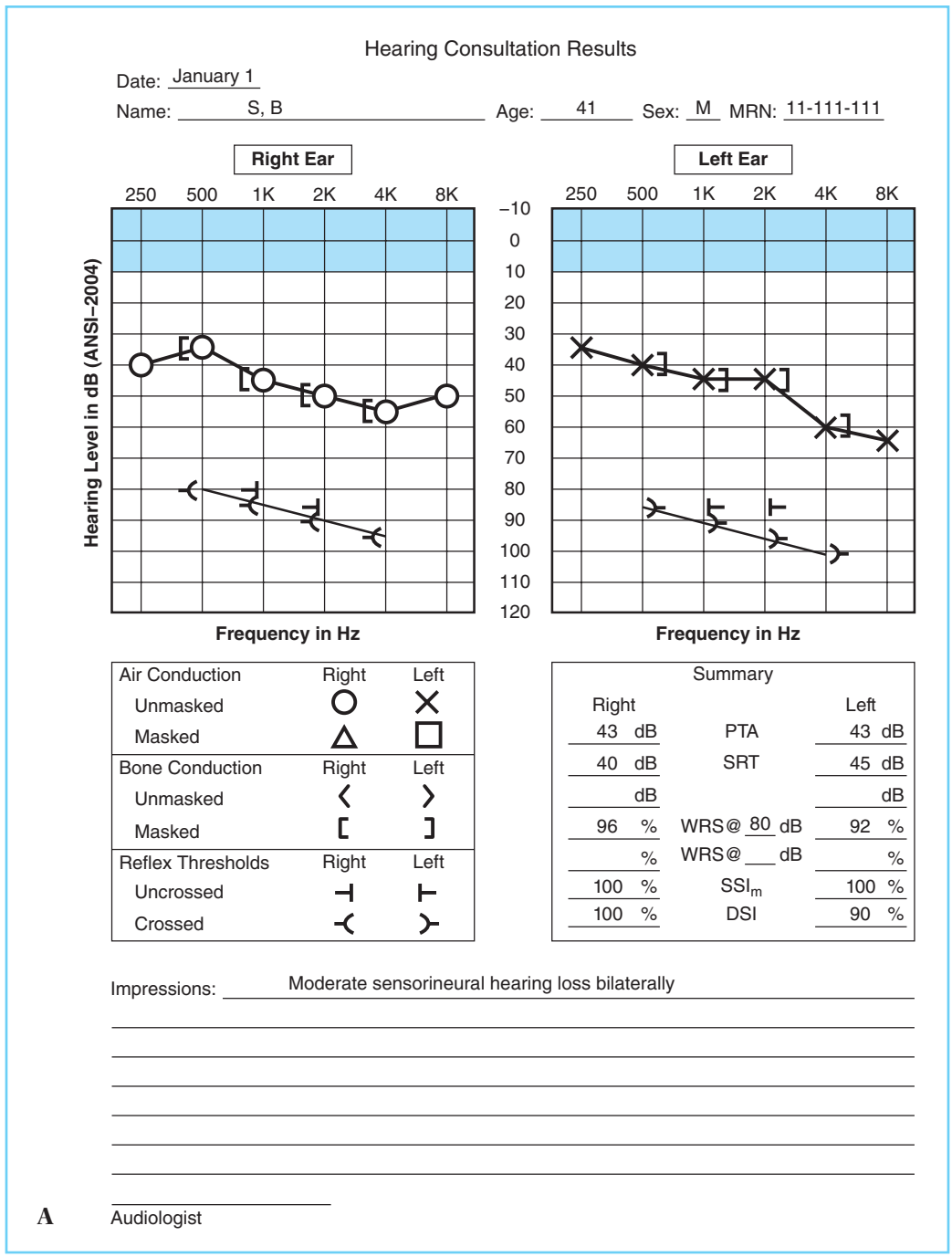
- the nature and consequence of hearing loss;
- the measurement and consequences of auditory processing disorder;
- home and classroom strategies for optimizing listening;
- the nature of tinnitus and its control; and
- the importance of hearing aids and how they can be obtained.

Information such as this is less likely to be read if it is included in a report than if it is presented as supplemental material. It also helps to make reports clearer and more concise.

Sample Reporting Strategy

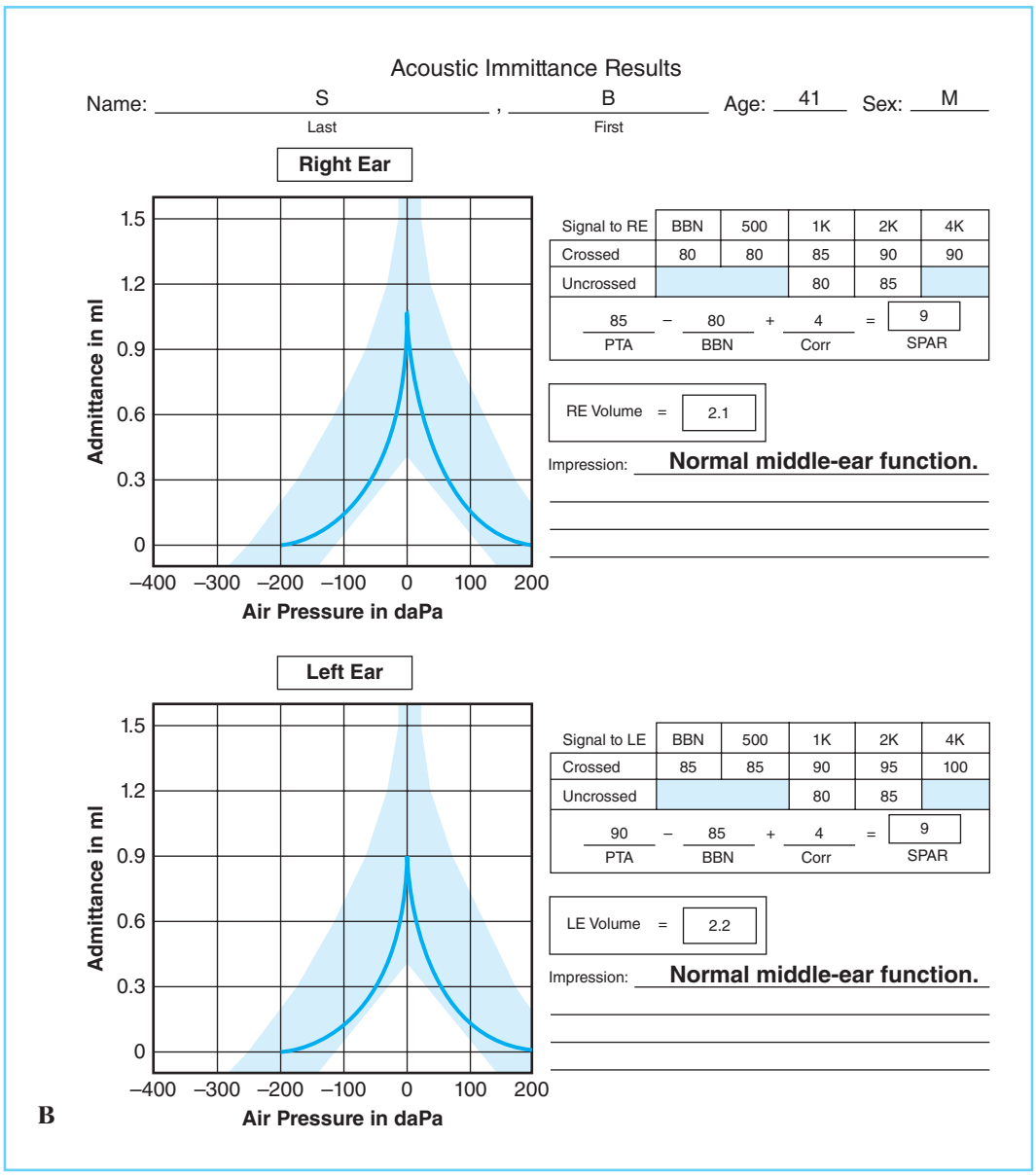
Experienced audiologists know that there is a finite number of ways they can describe the outcomes of their various audiometric measures. That is, there are only so many ways to describe an audiogram or the results of immittance audiometry. With a little discipline, over 90% of reports written can be generated from "stock" descriptions of testing outcomes.

An example of this strategy is shown in Figure 11-4. Results of the audiologic evaluation are shown in A and B. These results show a moderate, bilateral, symmetric, sensorineural hearing loss, with maximum word-recognition scores predictable from the degree of hearing loss and no evidence of abnormality. Results of immittance audiometry show normal Type A tympanograms and crossed and uncrossed acoustic reflexes within normal limits, suggesting normal middle-ear function. From these audiometric data, descriptors can be chosen that reflect these results in a clear and concise way.



A

FIGURE 11-4 Example of a reporting strategy, showing (A) hearing consultation results, (B) immittance results, and (C) a final report to the referral source.



The final results are shown in Figure 11-4C.

An example of a pediatric report is shown in Figure 11-5. Here, the template needs to be more flexible, but most of the reporting can be done with stock statements of testing outcome.

January 2

Hearing Consultation Results

Name: B.S.

Age: 41 years

Dear Dr. Referral

We evaluated your patient, B.S., on January 1. Audiometric results are as follows:

Right Ear

- Moderate sensorineural hearing loss.
- Acoustic immittance measures are consistent with normal middle-ear function.

Left Ear

- Moderate sensorineural hearing loss.
- Acoustic immittance measures are consistent with normal middle-ear function.

In view of the significant sensitivity loss, we recommend a hearing aid evaluation to assess the potential for successful use of amplification. Ear impressions were made, and a hearing aid consultation has been scheduled.

Sincerely,

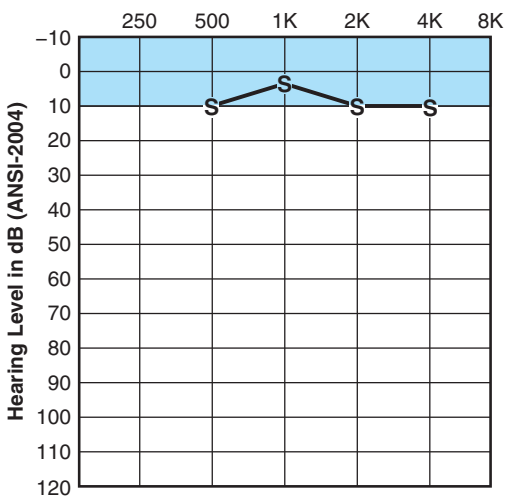
C Audiologist

It is important to remember that not all reports can be written using this approach. For example, results on a patient who is exaggerating a hearing loss need to be carefully crafted and do not lend themselves well to this type of standard reporting. Neither do some reports of pediatric testing. Nevertheless, the majority of outcomes and reports can be managed in this way.

Pediatric Hearing Consultation Results

Name: S (Last) , S (First) Age: 2-3 Sex: F

Sound Field Audiogram



Speech Audiometry

	Right Ear	Left Ear	Sound Field
ST	5 dB	5 dB	dB
SAT	dB	dB	dB
WRS	%	%	%
WR Level	dB	dB	dB
WR Materials:			
PSI-W	%	%	%
PSI-S	%	%	%

Key to Symbols

Warble Tones – – – – – – – – – S

Narrowband Noise – – – – – – – N

Bond Conduction – – – – – – – △

Testing Method: VRA

Earphone Results:

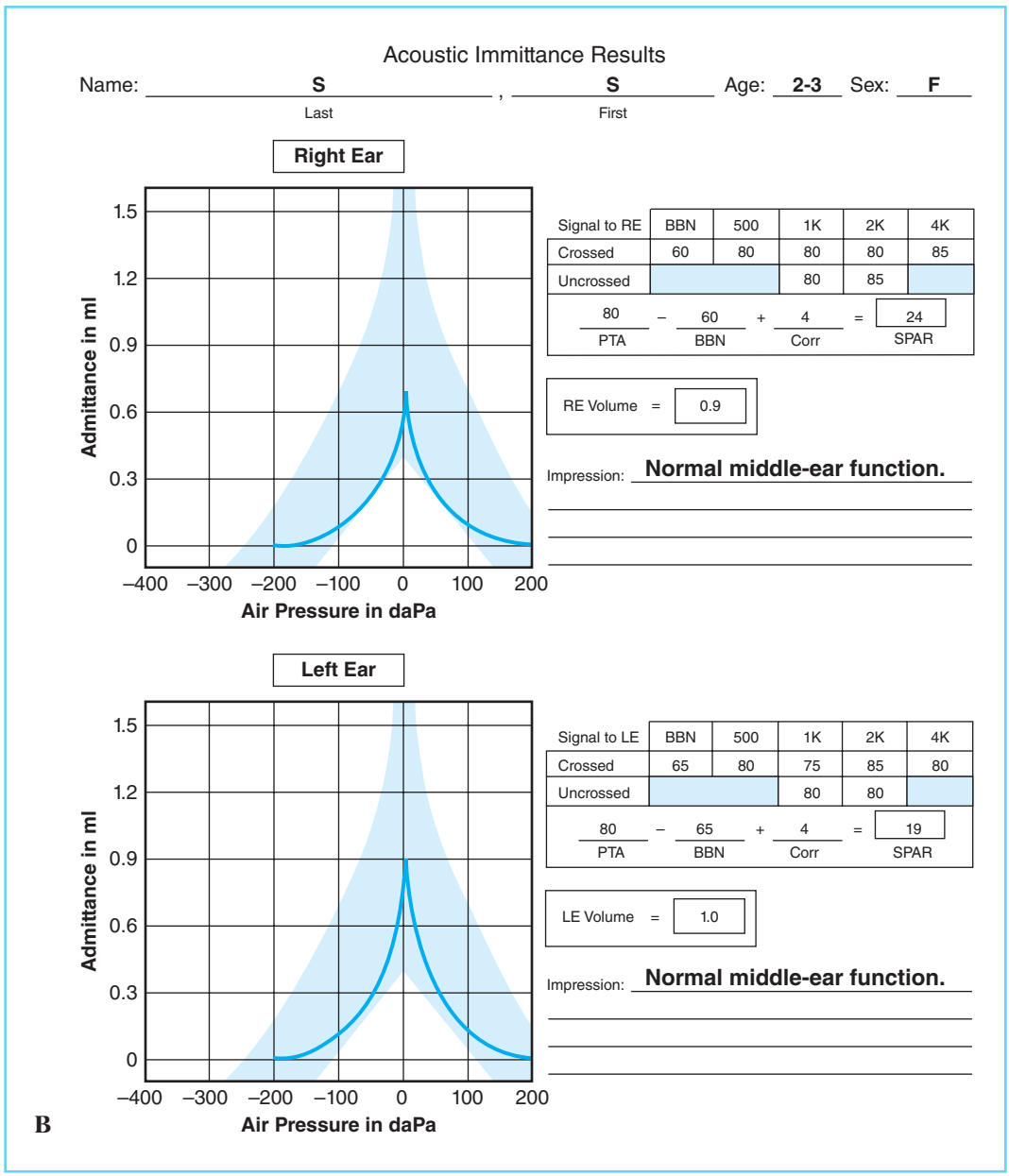
	Speech	500 Hz	1000 Hz	2000 Hz	4000 Hz
Right Ear	5				
Left Ear	5				

Comments: **DPOAEs were present across the frequency range bilaterally.**

A

FIGURE 11-5 Example of a pediatric reporting strategy, showing (A) hearing consultation results, (B) immittance results, and (C) a final report to the referral source.

The advantages of using this approach are important. First, it is a very efficient approach to report writing. In most cases the reporting can be completed before the patient leaves the clinic. Second, the accuracy of the report itself is enhanced by simply



B

reducing the opportunity for errors. Third, the approach creates a consistency in reporting test results that enhances communication. Finally, the approach facilitates the creation of a concise report.

January 2

Pediatric Hearing Consultation Results

Name: S.S. Age: 2–3 years

Dear Dr. Referral,

Your patient, S.S., was evaluated on January 1. The patient was evaluated due to parental concerns about speech development. Results are as follows:

Right Ear

- Responses to speech were observed down to 5 dB HL. In addition, the patient responded to warble-tones in the soundfield down to 10 dB at 500 Hz, 5 dB at 1000 Hz, 10 dB at 2000 Hz, and 10 dB at 4000 Hz. These results are consistent with normal hearing sensitivity in at least one ear.
- Acoustic immittance measures are consistent with normal middle-ear function
- Distortion product otoacoustic emissions (DPOAEs) are present and robust, suggesting normal cochlear function.

Left Ear

- Responses to speech were observed down to 5 dB HL.
- Acoustic immittance measures are consistent with normal middle-ear function
- Distortion product otoacoustic emissions (DPOAEs) are present and robust, suggesting normal cochlear function.

The overall pattern of results is consistent with normal hearing sensitivity and normal middle-ear function bilaterally. No audiologic recommendations are indicated at this time.

Sincerely,

C Audiologist

MAKING REFERRALS

Patients arrive in the audiology clinic for a hearing consultation for many reasons. One reason is that they have a hearing problem, want to have it evaluated, and call to make an appointment. That is, they are self-referred. In other cases, family members and friends encourage patients to have a hearing evaluation and refer them to an audiologist. In many other cases, patients are referred for a hearing consultation by another health-care provider, such as an otolaryngologist, pediatrician, or primary-care physician.

The nature of the referral to an audiologist dictates many things. As delineated in earlier chapters, the audiometric testing itself may vary as a function of the referral source, as may the nature of a clinical report. In fact, the audiologist's professional obligation varies depending on who is making the referral. The referral *in* dictates that obligation and influences the referral *out*.

Lines and Ethics of Referral

As a health-care provider, it is important to understand the lines of referral and the boundaries that are dictated by those lines. Audiologists play different roles in hearing health care, and those roles and their boundaries can vary significantly as a function of the reason for a referral. In one case, a patient might come directly to you to evaluate and manage his or her hearing care. In another case, you might be consulted for an opinion on the nature and degree of hearing loss as part of a patient's medical workup. What you say, to whom you communicate, and how you proceed can be very different in these two cases. Some examples may help to illustrate this concept.

If a patient is self-referred *and* is paying for the evaluation, the audiologist's complete obligation is to the patient. The outcome of testing and the disposition of a report are dictated by the interests of the patient. Therefore, if a patient does not want a report sent out, you are obligated to refrain from sending a report. There is an exception, of course, if the patient is not paying for the evaluation. In that case, the audiologist may also be obligated to report to the third party. But, in general, the audiologist is free to evaluate and manage the patient and to make whatever other referrals are deemed appropriate for the patient.

If a patient is referred to the audiologist by a physician for a hearing consultation to assist the physician in the medical diagnosis and treatment of the patient, then the audiologist's obligation is to the referral source. If the audiologist feels that the patient needs additional testing, needs to be referred to a medical specialist, needs hearing aids, and so on, the audiologist is obligated to make that recommendation to the referral source. This is an important concept and cannot be overstated. Under these circumstances, you as an audiologist are being consulted for your opinion, and that opinion should be given to the person who consulted you. You have not been asked to manage this patient, and you should not assume that authority.

If a patient is referred to the audiologist by a physician to assess the potential benefit from amplification and to provide it if necessary, then the physician is making a referral to you to manage the patient. In this case, your obligation is once again to the patient, with consideration to the referral source in terms of reporting the outcome.

The concept of lines of referral and the ethics related to it are fairly simple to manage if you know the answer to two questions: (1) who referred the patient? and (2) for what reason? The biggest challenge an audiologist faces is either not knowing the answer to one of these two questions or having the answer obscured for some reason. One of the challenging situations for any practitioner is the secondary referral, or the consult within a consult, wherein the audiologist might follow the line of referral, but the referral source may not. The accompanying Clinical Note entitled "Did You Steal that Patient?" provides an example of an instance where this confusion might occur.

Another source of trouble occurs when the audiologist is challenged by the patient or by his or her knowledge to refer the patient for more specialized treatment. An example is given in the accompanying Clinical Note entitled "Should You Refer Onward?". Here the audiologist is challenged by conflicting ethical issues. One is the critical concept of making referrals back to the referral source. The other is the important concern for the welfare of the patient. In such instances, the audiologist will do well to remember who is managing the patient and, thus, is ultimately responsible for the patient's care.

Clinical Note

Did You Steal that Patient?

One common source of confusion surrounding referral lines comes when there is a secondary referral, or a consult within a consult, and the audiologist is not clearly aware of the sequence that led to the patient sitting in the waiting room.

Let's look at an example. Audiologist 1 is in private practice in a professional building down the street from the medical center in which you work. She evaluates a patient who is interested in pursuing hearing aid use and notes the presence of a middle-ear disorder. The patient has significant sensorineural hearing loss bilaterally and will be a candidate for hearing aid amplification following management of the middle-ear disorder, but first things first. Audiologist 1 refers the patient down the street to an otolaryngologist who works in the same department that you do. The otolaryngologist evaluates the patient and, as a matter of routine, refers to you for an audiologic consultation, and, if indicated, a hearing-aid consultation. You graciously receive the referral, evaluate the patient, and begin the hearing aid process.

The problem here is that you do not know about Audiologist 1. Somewhere in the sequence of referrals, the information about the original referral source is lost, and you assume that this is an otolaryngology referral just like any of the others that you have managed that day. The patient may be equally confused, not always understanding the sometimes obscure relationships among health-care providers. Regardless of the source of the confusion, it is difficult to reach any conclusion other than that this hearing aid patient was inadvertently stolen from Audiologist 1, who simply made a referral in the patient's best interest for an otology consult.

continues

continued

The lesson and course of action here are simple. The lesson is that you are obligated to understand how this patient made it to your door. The course of action is to refer the patient back to Audiologist 1 once you discover the error.

This type of dilemma becomes more difficult if the patient decides at this point that your services are more desirable than those of Audiologist 1. Your actual obligation is to the source of the referral to you, the otolaryngologist. But you also have a professional obligation to your colleague. These challenges are usually managed best with open dialogue among heath-care providers.

Clinical Note

Should You Refer Onward?

A challenging referral dilemma often occurs when a patient who is referred to you by one medical practitioner requests that you provide referral information about more specialized medical care.

Perhaps the most common example of this occurs in the child who has chronic otitis media with effusion and is being treated by a pediatrician. In this example, the pediatrician refers to you as an audiologist to monitor the child's hearing status and middle-ear function.

A typical medical treatment approach for otitis media is the initial use of antibiotics. If the treatment fails to solve the problem, surgical placement of pressure-equalization tubes in the tympanic membrane may be indicated. The decision about how long to follow the antibiotic course and when to intervene with tube placement is often a difficult one for both pediatrician and otolaryngologist. Thrown into the mix may be an anxious

continues

Clinical Note

Clinical Note

continued

parent and an audiologist who is concerned about the long-term effects of otitis media.

At some point in the course of care, the parent may want more aggressive treatment of her child's problem. That parent may seek your opinion for a referral to an otolaryngologist, because of an unfounded fear that to ask such a question of the pediatrician would be offensive.

What is your obligation here? You will do well to remember the original line of referral. Did you see this patient initially and refer to the pediatrician? If so, your obligation is to the patient. Did the pediatrician initially refer the patient to you for an audiologic consult? If so, your obligation is to the referral source.

As in all things, dialogue among professionals is usually the best solution to referral issues.

When to Refer

As a health-care provider, the audiologist is obligated to understand when it is appropriate to refer a patient for additional assessment or treatment. Again, it is important to remember that the recommendation for referral out should be made back to the original referral source, whether that be another health-care provider or the patient. For audiologists, the most common referrals are made to otolaryngologists because of identification or suspicion of active otologic disease and to speech-language pathologists because of identification or suspicion of speech and/or language impairment.

Guidelines have been developed to assist health-care providers in identifying signs and symptoms of ear disease that warrant referral for otologic consultation. The American Academy of Otolaryngology suggests that there are seven signs of serious otologic

disease that warrant referral for evaluation by an otolaryngologist. The seven signs are:

1. ear pain and fullness;
2. discharge or bleeding from the ear;
3. sudden or progressive hearing loss, even with recovery;
4. unequal hearing between ears or noise in the ear;
5. hearing loss after an injury, loud sound, or air travel;
6. slow or abnormal speech development in children; and
7. balance disturbance or dizziness.

Based on the results of the audiologic evaluation, the audiologist should refer for otologic consultation if:

1. otoscopic examination of the ear canal and tympanic membrane reveals inflammation or other signs of disease;
2. immittance audiometry indicates middle-ear disorder;
3. acoustic reflex thresholds are abnormally elevated;
4. air- and bone-conduction audiometry reveals a significant air-bone gap;
5. speech recognition scores are significantly asymmetric or are poorer than would be expected from the degree of hearing loss or patient's age; or
6. other audiometric results are consistent with retrocochlear disorder.

There are also generally held guidelines for referring to the speech-language pathologist due to suspicion of speech-language delays or disorder. These include:

1. parental concern about speech and/or language development;
2. speech-language development that falls below expected milestones, as delineated in the next box;
3. observed deficiency in speech production; or
4. observed delays in expressive or receptive language ability.

Clinical Note

Hearing, Speech, and Language Expectations

If a child is suspected of having a speech or language problem, a referral should be made to a speech-language pathologist. The following questions reflect milestones in speech and language development that parents can expect from their child. Parents should consider these questions in evaluating their child's speech, language, and hearing development. Failure to reach these milestones, or a "no" answer to any of these questions, is sufficient cause for a speech-language consultation.

Behaviors Expected by 6 Months of Age

- Does your infant stop moving or crying when you call, make noise, or play music?
- Does your infant startle when he or she hears a sudden loud sound?
- Can your infant find the source of a sound?

Behaviors Expected by 12 Months of Age

- Does your baby make sounds such as *ba, ga,* or *puh*?
- Does your baby respond to sounds such as footsteps, a ringing telephone, a spoon stirring in a cup?
- Does your baby use one word in a meaningful way?

Behaviors Expected by 18 Months of Age

- Does your child follow simple directions without gestures, such as *Go get your shoes; Show me your nose; Where is mommy*?
- Will your child correctly imitate sounds that you make?
- Does your child use at least three different words in a meaningful way?

continues

Clinical Note

continued

Behaviors Expected by 24 Months of Age

- When you show your child a picture, can he or she correctly identify five objects that you name?
- Does your child have a speaking vocabulary of at least 20 words?
- Does your child combine words to make little sentences, such as *Daddy go bye-bye; Me water;* or *More juice*?

Behaviors Expected by 3 Years of Age

- Does your child remember and repeat portions of simple rhymes or songs?
- Can your child tell the difference between words such as *my-your; in-under; big-little*?
- Can your child answer simple questions such as *What's your name?* or *What flies*?

Behaviors Expected by 4 Years of Age

Does your child use three to five words in an average sentence?

Does your child ask a lot of questions?

Does your child speak fluently without stuttering or stammering?

Behaviors Expected by 5 Years of Age

Can your child carry on a conversation about events that have happened?

Is your child's voice normal? (is not hoarse; does not talk through his or her nose?)

Can other people understand almost everything your child says?

In addition to referrals to otolaryngologists and speech-language pathologists, the audiologist may also make referrals for educational evaluations, neuropsychological assessment, genetic counseling, and so on, depending on the nature of any perceived problems.

Summary

- Communicating results of the audiologic evaluation is an important aspect of service provision.
- Once the evaluation process is completed, results must be conveyed to patients and, often, their families and significant others.
- One of the challenges of communicating with patients is to convey enough information for them to understand the nature of the problem without overburdening them with detail.
- One of the most important outcomes of information counseling is setting the stage for treatment.
- One of the most challenging aspects of informational counseling of patients is remembering that this is each patient's only hearing loss.
- Another important aspect in the provision of audiologic care is the documenting and reporting of results of the evaluation or treatment.
- It is important to distinguish between documentation of test results and reporting of test results.
- The challenge of reporting is to describe what was found or what was done in a clear, concise, and consistent manner.
- The actual nature of a report can vary greatly depending on the setting and the referral source to whom a report is most likely written.
- The goal of any report is to communicate the outcome of your evaluation and/or treatment.
- One of the biggest challenges in report writing is to provide *all* relevant information while *only* reporting relevant information.
- An audiologic report typically includes a description of the audiometric configuration, type of hearing loss, status of middle-ear function, and recommendations.
- Under certain circumstances, an audiologic report might also include case history information, speech audiometric results, auditory electrophysiologic results, and a statement about site of the auditory disorder.

- Clinical reports should not include lengthy descriptions of testing procedures, outcomes, or rehabilitative strategies. Descriptive information should be included as supplemental material and sent only to individuals who might read it.
- As a health-care provider, it is important to understand the lines of referral and the boundaries that are dictated by those lines.
- The concept of lines of referral and the ethics related to it are fairly simple to manage if you know the answer to two questions: Who referred the patient? And for what reason?
- As a health-care provider, the audiologist is obligated to understand when it is appropriate to refer a patient for additional assessment or treatment.
- Referral challenges are usually managed best with open dialogue among health-care providers.

Short Answer Questions

1. Three components of communicating audiologic results are _____ to patients, writing _____, and making _____ to other health-care providers.
2. The primary goal for talking with patients following audiologic testing is to help the patient understand what was learned from testing. This can be accomplished by helping the patient understand the _____ and _____ of hearing impairment and its likely effect on communication ability; giving the patient _____ to use to describe their hearing loss; and providing the patient with a clear understanding of the next steps that need to be taken.
3. An important task in talking to patients is to present information in a manner that is _____ and does not presume too much _____ on the part of the patient.
4. It is necessary to remember in talking with patients that each patient perspective is _____ and varies based upon the patient's experience, knowledge, and motivation.
5. Experienced patients typically wish to know whether their hearing has _____ and whether there are technological _____ that may assist them with their hearing loss.

6. Among other things, inexperienced patients typically want to know about the _____ of their hearing loss; how bad their hearing loss is; whether their hearing loss is medically _____; and whether the hearing loss is related to other health problems.
7. Parents of children identified with hearing loss typically want to know about the cause of the hearing loss. They are often in various stages of _____ regarding the hearing loss. Upon learning that their child has a hearing loss, many patients are unable to cope with additional information. However, some parents may wish to have immediate information about habilitation and _____ options.
8. The _____ of results refers to the preservation of examination and test results in a patient file.
9. The _____ of results refers to the summarization of documentation.
10. The _____ report is typically a stand-alone document that includes the audiogram, table of other audiometric information, and summary and impressions.
11. The _____ report may be accompanied by an audiogram. It typically includes a summary of results and the disposition of the patient. This type of document may be sent to the patient, an outside referral source, a school, or other interested parties.
12. The three primary rules of report writing are to be _____, be _____, and be _____.
13. In considering the report _____, it is typical to keep reports from self-referred patients in the office, while reports from outside referrals are typically sent back to the referral source.
14. In reporting on the case _____, the goal is to provide relevant information to orient the reader as to why consultation took place.
15. In describing the nature of the hearing loss, the terms conductive, _____, or mixed should be used.
16. The _____ and _____ of the hearing loss should be described. The terms chosen to describe these are

meant to convey hearing sensitivity into words that can be used consistently for the patient.

17. When previous hearing evaluation data are available, reference should be made to any _____ in hearing status.
18. A statement regarding overall _____ _____ function should be made, followed by the specific _____ results that characterize the disorder.
19. A description of _____ audiometric results is seldom useful, unless these results are poorer than expected given the hearing loss, indicating a possible retrocochlear abnormality.
20. Electrophysiologic results are most helpful when _____ are provided first, followed by details about test results.
21. A cochlear site of disorder is assumed in a sensorineural hearing loss, unless results are interpreted as being consist with a _____ or _____ _____ disorder.
22. A statement of _____ for patient's is typically included so that patient's knows what they should do following the audiologic assessment.
23. Supplementary materials, such as _____, are often given to patients to provide more information regarding the relevant disorder or treatment issue.
24. The use of reporting _____ are helpful because they provide for greater consistency, reduce opportunities for error, and facilitate the creation of a concise report.
25. Two questions to be asked when determining the appropriate line of referral for a patient are: "_____ referred the patient?" and "For what _____ was the patient referred?"
26. Guidelines for referral to an _____ include evidence of outer- or middle-ear disorder from patient complaints/history, audiologic evidence of abnormal otoscopic exam, immittance measures, or pure-tone audiometry. Additionally, evidence of _____ pathology, such as asymmetric hearing loss, abnormally elevated acoustic reflex thresholds, or abnormal word-recognition scores, requires referral for evaluation.

27. Guidelines for referral to a _____-_____ _____ include parental concerns about speech-language development, development that falls below expected _____, or observed deficiencies in speech and/or language production.

Discussion Questions

1. Why might it be important to provide less information, rather than more information, to parents who are first being informed of their child's hearing loss?
2. How would you describe a conductive hearing loss to a patient?
3. How would you describe a sensorineural hearing loss to a patient?
4. In what ways would a report sent to an otolaryngologist differ from a report sent to a school administrator?
5. Explain the concept of lines of referral and obligation to referral sources.
6. Explain when it would be appropriate to refer a patient for additional assessment or treatment.

Resources

Clark, J. G., & English, K. M. (2004). *Counseling in audiologic practice.* Boston: Pearson.

Sweetow, R. (1999). *Counseling for hearing aid fittings.* San Diego: Singular Publishing Group.

Tanner, D. C. (1980). Loss and grief: Implications for the speech-language pathologist and audiologist. *Asha, 22,* 916–928.



12

INTRODUCTION TO AUDIOLOGIC MANAGEMENT

Learning Objectives

The First Questions
- The Importance of Asking Why
- Assessment of Treatment Candidacy

The Audiologist's Challenge
- Amplification—Yes or No?
- Amplification Strategies
- Approaches to Fitting Hearing Instruments
- Approaches to Defining Success
- Treatment Planning

Summary

Short Answer Questions

Discussion Questions

Resources

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- Define the goal of audiologic management.
- List and describe methods for maximization of residual hearing.
- Describe who is a candidate for amplification.
- List and explain patient variables that relate to prognosis for successful hearing aid use.
- Explain how the hearing needs assessment relates to selection and fitting of hearing-device technology.
- Describe how hearing-device success may be evaluated.

AS you have learned, the most common consequence of an auditory disorder is a loss of hearing sensitivity. In most cases, the disorder causing the sensitivity loss cannot be managed by medical or surgical intervention. Thus, to ameliorate the impairment caused by hearing sensitivity loss, audiologic treatment must be implemented.

The fundamental goal of audiologic management is to limit the extent of any communication disorder that results from a hearing loss. The first step in reaching that goal is to maximize the use of residual hearing. That is, every effort is made to put the remaining hearing that a patient has to its most effective use. Once this has been done, treatment often proceeds with some form of aural rehabilitation.

The most common first step in the management process is the use of hearing aids. More precisely, the most common treatment aimed at maximizing the use of residual hearing is the introduction of hearing aid amplification. The most common form of amplification is the conventional hearing aid. In some cases, other hearing assistive technology may be used to supplement or substitute for hearing aid use. In individuals with a severe or profound loss of hearing, a **cochlear implant** may be indicated.

A **cochlear implant** is a device that is surgically implanted into the cochlea to deliver electrical stimulation to the auditory nerve.

When hearing aids were first developed, they were relatively large in size and inflexible in terms of their amplifying characteristics. Hearing aid use was restricted almost exclusively to individuals with substantial conductive hearing loss. Today's hearing aids are much smaller, and their amplification characteristics can be programmed at will. Hearing aids are now used almost exclusively by those with sensorineural hearing loss.

Candidacy for hearing aid amplification is fairly straightforward. If a patient has a sensorineural hearing impairment that is causing a communication disorder, the patient is a candidate for amplification. Thus, even when a hearing impairment is mild, if it is causing difficulty with communication, the patient is likely to benefit from hearing aid amplification. If a patient has a conductive hearing loss, it can usually be treated medically. If all attempts at medical treatment have been exhausted, then the same rule of candidacy applies for conductive hearing loss. Conductive hearing loss may also be treated with bone conduction devices, including surgically implanted, bone-anchored hearing aids.

If a patient has hearing impairment in both ears that is fairly **symmetric**, it is a good idea to fit that patient with two hearing aids. In fact, up to 95% of individuals with hearing impairment are **binaural** candidates. Benefits from binaural hearing aids include enhancements in:

- audibility of speech originating from different directions,
- localization of sound, and
- hearing speech in noisy environments (for a review, see Davis & Mencher, 2006).

When a hearing loss is the same in both ears, it is considered **symmetric**.

When a hearing loss is moderate in one ear and severe in the other, it is considered asymmetric.

A person wearing two hearing aids is fitted **binaurally**.

A person wearing one hearing aid is fitted monaurally.

When a hearing loss occurs in both ears, it is **bilateral**.

When hearing loss occurs in only one ear, it is unilateral.

In addition, evidence exists that the use of only one hearing aid in patients with **bilateral** hearing loss may have a long-term detrimental effect on the ear that is not fitted with an aid (Silman et al., 1984; Silverman & Silman, 1990). Except for cost, there are no good reasons not to wear two hearing aids.

The process of obtaining hearing aids begins with a thorough audiological assessment. Following the audiological assessment, prudent hearing health care dictates a medical assessment to rule out any active pathology that might contraindicate hearing aid use. Following medical clearance, impressions of the ears and ear canals are usually made for customizing earmolds or hearing aid devices. When the devices are received from the manufacturer, they are adjusted and fitted to the patient, and an evaluation is made of the fitting success. After successful fitting and dispensing, the patient usually returns for any necessary minor adjustments or to discuss any problems related to hearing aid use. At that time,

self-assessed benefit or satisfaction is often measured as a means of assessing treatment outcome.

Although the goal of audiologic management is relatively constant, the approach can vary significantly depending on patient age, the nature of the hearing impairment, and the extent of communication requirements in daily life. For example, in infants and young children, the extent of sensitivity loss may not be precisely quantified, making hearing aid fitting of children a more protracted challenge than it is in most adults. In addition, extensive habilitative treatment aimed at ensuring oral language development will be implemented in young children, whereas little rehabilitation beyond hearing aid orientation may be required in adults.

Audiologic treatment will also vary based on the nature and degree of hearing impairment. For example, patients with severe and profound hearing loss are likely to benefit more from a cochlear implant than from conventional hearing aid amplification. As another example, patients with auditory processing disorders associated with aging may benefit from the use of assistive listening devices or other hearing assistive technology as supplements to their conventional hearing aids.

Finally, hearing treatment can vary depending on the communication demands that patients have in their daily lives. For example, an older patient who lives a solitary lifestyle will have different hearing needs than a patient with job-related communication demands and an active lifestyle. The type of amplification system required and the need for aural rehabilitation can vary considerably between these extremes of communication demand.

THE FIRST QUESTIONS

Audiologic management really begins with assessment—not only assessment of hearing but also assessment of treatment needs. The hearing evaluation serves as a first step in the treatment

process. Toward this end, there are some important questions to be answered from the audiologic evaluation. They include:

- Is there evidence of a hearing disorder?
- Can medically treatable conditions be ruled out?
- What is the extent of the patient's hearing sensitivity loss?
- How well does the patient understand speech and process auditory information?
- Is the hearing disorder causing impairment?
- Does the hearing impairment cause activity limitations or participation restrictions?
- Are there any auditory factors that contraindicate successful hearing-device use?

Answers to these questions will lead to a decision about the patient's candidacy for hearing aid amplification from an auditory perspective. Equally important, however, are the questions to be answered from an assessment of treatment needs. They include:

- Why is the patient seeking hearing aid amplification?
- How motivated is the patient to use amplification successfully?
- Under what conditions is the hearing loss causing communication difficulty?
- What are the demands on the patient's communication abilities?
- What is the patient's physical, psychological, and sociological status?
- What human resources are available to the patient to support successful amplification use?
- What financial resources are available to the patient to support audiologic treatment?

The answers to these questions help to determine candidacy for hearing aid amplification and begin to provide the audiologist with the insight necessary to determine the type and extent of the hearing treatment process.

The Importance of Asking Why

Why is the patient seeking hearing aid amplification? It sounds like such a simple question. Yet the answer is a very important step in the treatment process because it guides the audiologist to an appropriate management strategy. There are usually two main issues related to this *why* question, one pertaining to the patient's motivation and the other pertaining to the need-specific nature of the amplification strategy.

Prognosis is the prediction of the course or outcome of a disease or treatment.

The first reason for asking why a patient is pursuing hearing aid use is to determine, to the extent possible, the factors that motivated the patient to seek your services. Motivation is important because it is highly correlated with prognosis; **prognosis** is important because it is highly correlated with success and tends to dictate the strength and direction of your efforts.

Do you want to see an audiologist wince? Watch as a patient states that the only reason he or she is pursuing hearing aid use is because his or her spouse is forcing the issue. If this truly is the only reason that the patient is seeking hearing aid amplification, the prognosis for successful use is not positive.

A patient who is internally motivated to hear better is an excellent candidate for successful hearing aid use. The breadth of amplification options for such a patient is substantial. For example, patients with a moderate sensorineural hearing loss will benefit from conventional hearing aids in many of their daily activities. They might also find a telephone amplifier to be of benefit at home and work and are likely to avail themselves of the assistive listening devices available in many public theaters, churches, or other meeting facilities. Such a patient will use two hearing aids, permitting better hearing in noise and better localization ability, and will probably want advanced features in their hearing aids to ensure better adaptation to changing acoustic environments.

In contrast, a patient who seeks audiologic care as a result of external factors will find any of a number of reasons why hearing aid amplification is not satisfactory. The patient will find the sound of a hearing aid to be unnatural and noisy, the battery replacement

costs to be excessive, and the gadgetry associated with assistive technology to be a nuisance. Such a patient will insist on wearing one hearing aid and will complain about the difficulty hearing in noise when the aid is on. The patient will probably want a hearing aid with few processing features and be dissatisfied when it cannot be adjusted limitlessly to address the patient's hearing needs.

The contrast in motivation can be striking, as can the contrast in your ability as an audiologist to meet the patient's needs and expectations. Knowing *why*, from a motivation viewpoint, is an important first question.

Another reason that the *why* question is so important is that it can lead to successful yet unconventional solutions to the patient's hearing needs. Thirty years ago, this did not really matter. Hearing aids varied little, and there was no need to distinguish between conventional and **situation-specific amplification**, because situation-specific amplification was not readily available. Today, amplification options are numerous and growing. You will learn more in the next chapter about the burgeoning technology available to those with hearing impairment. The growing advantage is that amplification can be tailored to a patient's communication needs rather than used generically for all hearing losses and all individuals. The result is that patients can be treated more effectively by adapting the technology to the patient's situation and needs rather than by asking the patient to adapt to the technology.

Situation-specific amplification, or hearing assistive technology, includes such devices as FM systems, TV amplifiers, doorbell and telephone amplifiers, and other assistive listening devices designed to meet a specific need or situation.

A simple example of situation-specific amplification may serve to make the point. Suppose that a patient's only hearing concern is that she cannot hear the television when it is set to a volume that is comfortable for her spouse. In the past, there was a tendency on the part of the audiologist to look first to a general solution (i.e., conventional hearing aids) to this specific problem. The general solution was helpful, of course, but it could have been much better if it had been tailored to the patient's need to hear the television. Today's technology is making need- and/or situation-specific amplification so much of a reality that the question *why* is becoming ever more important.

Audiologist Profile

Jeanne A. Wharton, M.A.



Where I Live: Troy, Michigan

Where I Work: Detroit Public Schools. This large district has approximately 200 public schools and 150 nonpublic and private schools. Ten educational audiologists service the hearing needs of this district, including Early Intervention, Early-On, Head-Start, and four adjacent school districts located within Wayne County. The Detroit Public Schools has a speech and hearing clinic where we provide diagnostic testing. We also have portable audiometric equipment for testing in the schools.

What I Do: As an educational audiologist, I spend most of my time identifying or monitoring the hearing of Detroit-resident students ages 0–26 and determining and fitting appropriate FM amplification for hearing impaired children. I work with the teacher consultants of the hearing impaired and school speech-language pathologists to support the IEP team. I also counsel and/or in-service parents, teachers, and other educational personnel on hearing and the utilization of amplification equipment. I travel throughout the city of Detroit.

Why Audiology? Practicing audiology in the educational setting is very rewarding. I have always enjoyed working with the pediatric population and can apply my diagnostic and habilitative skills to help provide an optiminal listening environment for education.

Assessment of need can be carried out informally, or it can be carried out formally with a questionnaire. An example of a questionnaire that addresses the situational-specific needs of individuals with hearing impairment is shown in Figure 12-1. Either the formal or informal approach can lead the audiologist to an impression of whether the individual's amplification needs are general, requiring the use of conventional amplification solutions, or more specific, requiring a more tailored solution.

Once a patient's motivation and needs are known, the available audiometric and self-assessment data are used to determine candidacy for treatment and to help determine an effective amplification approach.

Sample Questions from the Abbreviated Profile of Hearing Aid Benefit

A	Always (99%)
B	Almost Always (87%)
C	Generally (75%)
D	Half-the-time (50%)
E	Occasionally (25%)
F	Seldom (12%)
G	Never (1%)

When I am in a crowded grocery store, talking with the cashier, I can follow the conversation	A B C D E F G
Unexpected sounds, like a smoke detector or alarm bell are uncomfortable	A B C D E F G
I have trouble understanding dialogue in a movie or at the theater	A B C D E F G
When I am listening to the news on the car radio, and family members are talking, I have trouble hearing the news	A B C D E F G
Traffic noises are too loud	A B C D E F G
When I am in a small office, interviewing or answering questions, I have difficulty following the conversation	A B C D E F G
When I am having a quiet conversation with a friend, I have difficulty understanding	A B C D E F G
When a speaker is addressing a small group, and everyone is listening quietly, I have to strain to understand	A B C D E F G
I can understand conversation even when several people are talking	A B C D E F G
It's hard for me to understand what is being said at lectures or church services	A B C D E F G

Answers are divided into subscales. Results are expressed as percentage of benefit for each subscale.

FIGURE 12-1 Sample questions from a self-assessment questionnaire, the Abbreviated Profile of Hearing Aid Benefit. (From The Abbreviated Profile of Hearing Aid Benefit (APHAB), by R. M. Cox and G. C. Alexander, 1985, *Ear and Hearing, 16,* 176–186.)

Assessment of Treatment Candidacy

The goal of assessment is to determine candidacy for audiologic management. The process for doing so includes several important steps. The first step is often the audiologic evaluation, which will determine the type and extent of hearing loss. Following the audiologic evaluation, the patient is counseled about the nature of the results and recommendations to assist in the decision about whether to pursue amplification. Once the decision is made to go forward, the assessment continues with an evaluation of the patient's communication needs, self-assessment of limitations and restrictions, psychosocial status, physical capacity, and financial status.

If the decision is made to pursue hearing aid use, medical clearance should be procured from a physician. This typically involves otoscopic inspection of the external auditory meatus and tympanic membrane, in an effort to ensure that no medical conditions exist that would contraindicate use of a hearing aid.

Audiologic Assessment

The audiologic assessment for treatment purposes is the same as that described in detail in Chapters 5 and 6. For the most part the strategies and techniques used for diagnostic assessment and treatment assessment are identical. The reasons for the assessment are different, however, and that tends to change the manner in which the outcomes are viewed. For example, air-conduction and bone-conduction audiometry are used to determine the extent of any conductive component to the hearing loss. Diagnostically that information might be used to confirm the influence of middle-ear disorder and for pre- and post-assessment of surgical success. From the audiologic treatment perspective, a conductive component to the hearing loss has a significant impact on how much amplification a hearing aid will need to deliver to the ear. Although the clinical strategy, instrumentation, and techniques are the same, the outcome has different meaning for medical diagnosis and audiologic treatment.

As always, assessment begins with the case history. The audiologist will begin here to pursue information about and develop impressions of the patient's motivation for hearing aid amplification, should it prove to be indicated by the audiometric results.

The next step in the evaluation is the otoscopic inspection of the auricle, external auditory canal, and tympanic membrane. The fundamental reasons for doing this are to inspect for any obvious signs of ear disease and to ensure an unimpeded canal for insert earphones or immittance probe placement. In addition, if the patient appears to be a candidate for amplification, the audiologist also uses this opportunity to begin to form an impression of the fitting challenges that will be presented by the size and shape of the patient's ear canal.

Immittance audiometry is used to assess middle-ear function in an effort to rule out middle-ear disorder as a contributing factor to the hearing loss. This is no different for treatment than for diagnostic assessment.

Air-conduction pure-tone audiometry is used to quantify hearing sensitivity across the audiometric frequency range. If immittance measures show middle-ear disorder, then bone-conduction audiometry is used to quantify the extent of any conductive component to the hearing loss. The air-conduction thresholds and the size of the conductive component are both crucial pieces of information for determination of the appropriate hearing aid amplification characteristics.

Speech audiometry is at least as important to the treatment assessment as it is to the diagnostic assessment. Speech recognition ability is an important indicator of how the ear functions at suprathreshold levels. If speech perception is significantly degraded or if it is unusually affected by the presence of background noise, the prognosis for successful conventional hearing aid use may be reduced. Conventional speech audiometric measures of word-recognition ability in quiet may be useful in this context, but more sophisticated assessment of speech recognition in competition is probably a better prognostic indicator of benefit from hearing aid use.

Determination of frequency-specific thresholds of discomfort can be an important component of the treatment assessment but is seldom carried out as part of a diagnostic assessment. A *threshold of discomfort* (TD) is just as it sounds, the level at which a sound becomes uncomfortable to the listener. Many terms are used to

describe this level, the most generic and perhaps useful of which is the threshold of discomfort. Some of the other terms and a technique for determining TDs are described in the accompanying Clinical Note. Determination of the TD across the frequency range is important because it provides guidance about the maximum output levels of a hearing aid that will be tolerable to the patient. This is particularly important in patients with tolerance problems and reduced dynamic range of hearing. More will be said about all of that in Chapters 13 and 14.

All of the information gleaned from the case history and audiologic evaluation is taken together to determine the potential candidacy of the patient for hearing aid amplification. Once the determination is made, a treatment assessment commences.

Treatment Assessment

The treatment assessment is carried out using a patient-centered approach and is designed to determine the self-perception and family-perception of communication needs; the patient's physical, psychological, and sociological status; and the sufficiency of human and financial resources to support hearing treatment. Specifically, the following areas are assessed in one manner or another:

- informal and formal assessment of communication needs,
- self- and family-assessment of activity limitations or participation restrictions,
- selection of goals for treatment, and
- nonauditory needs assessment, including:
  - motoric and other physical abilities,
  - psychosocial status, and
  - financial status.

Informal assessment of communication needs was discussed earlier. Its importance is paramount in the provision of properly focused hearing treatment services. Communication needs should be thoroughly examined prior to determination of an amplification strategy.

Formal assessment of communication needs and function is an important component of the treatment process. It is usually

Clinical Note

How to Determine a TD

Determination of a threshold of discomfort (TD) can be an important early step in the hearing aid fitting process. The purpose of determining discomfort levels is to set the maximum output of a hearing aid at a level that permits the widest dynamic range of hearing possible without letting loud sounds be amplified to uncomfortable levels. This can be critical to the patient's satisfaction, especially if the patient has tolerance problems.

Numerous terms have been used to describe the threshold of discomfort, including uncomfortable loudness (UCL), uncomfortable level (UL), upper limits of comfortable loudness (ULCL), uncomfortable loudness level (ULL), and loudness discomfort level (LDL). The term *threshold of discomfort* is a reasonable alternative to these because discomfort can be related, to quality of a signal as well as its loudness.

Many factors need to be considered in determining a discomfort level. Instructions to patients, type of signals used, and response strategies can all influence the measurement of TDs.

Following is a protocol for determining threshold of discomfort (after Mueller & Bright, 1994);

1. Provide concise instructions to the patient about the purpose of the test and the desired response. You are trying to find a level that is somewhere between "initial discomfort" and "extreme discomfort." That level is usually described as "definite discomfort" or "uncomfortably loud."
2. Provide patients with a list of descriptions, such as those in Figure 12-2, relating to the loudness of sounds that will be presented.

continues

Clinical Note

continued

3. Use pure-tone signals of 500, 1000, 1500, 2000, and 3000 Hz.
4. Use an ascending method, in 2 or 5 dB steps. Present the pure-tone signal to the patient and increase it until the listener indicates uncomfortable loudness. Reduce the intensity to a comfortable level and then increase again until it is uncomfortable. The TD is taken as the level that gives the perception of loudness between "loud but O.K." and "uncomfortably loud" on two out of three trials.

Mueller, H. G., & Bright, K. E. (1994). Selection and verification of maximum output. In M. Valente (Ed.), *Strategies for selecting and verifying hearing aid fittings* (pp. 38–63). New York: Thieme.

Loudness Levels

- Painfully loud
- Extremely uncomfortable
- Uncomfortably loud
- Loud, but O.K.
- Comfortable, but slightly loud
- Comfortable
- Comfortable, but slightly soft
- Soft
- Very soft

FIGURE 12-2 Response card containing a list of descriptions relating to the loudness of sounds that can be used to determine threshold of discomfort.

achieved with self-assessment measures of activity limitations (disability) or participation restrictions (handicap), many of which have been developed for this purpose. There are at least two important reasons for measuring the extent to which a hearing impairment is limiting or restrictive to a patient. One is that it provides the audiologist with additional information about the patient's communication needs and motivation. The other is that it serves as an outcome measure, that is, as a baseline assessment against which to compare the eventual benefits gained from hearing aid amplification.

Many self-assessment and outcome measures are available (for an overview, see Johnson & Danhauer, 2002). Some are designed for specific populations, such as the elderly; others are more generally applicable. Although designed to assess communication needs, they can also be helpful in getting a feel for patient expectations of hearing aid use.

One that is population specific is the HHIE, or Hearing Handicap Inventory for the Elderly (Ventry & Weinstein, 1982). The HHIE is a 25-item measure that evaluates the social and emotional aspects of hearing loss in patients who are elderly. An example of one of the questions that evaluates social impact is "Does a hearing problem cause you to use the phone less often than you would like?" An example that evaluates emotional impact is "Does a hearing problem cause you to feel embarrassed when meeting new people?" Questions are answered on a three-point scale of *yes, sometimes*, and *no*. Points are assigned for each answer, and total, social, and emotional scores are calculated.

Another self-assessment measure that enjoys widespread use is the APHAB, or Abbreviated Profile of Hearing Aid Benefit (Cox & Alexander, 1995). The APHAB consists of 24 items that describe various listening situations. A sample of these items is shown in Figure 12-1. The patient's task is to judge how often a particular situation is experienced, ranging from *never* to *always*. Answers are assigned a percentage, and the scale is scored in terms of those percentages. Results can then be analyzed into four subscales: (1) communication effort in easy listening environments; (2) speech-recognition ability in reverberant conditions; (3) speech recognition in the presence of competing sound; and (4) aversiveness to sound.

The Client Oriented Scale of Improvement (COSI) is another measure more tailored to individual communication needs (Dillon et al., 1997). The COSI consists of 16 standardized situations of listening difficulty. In this measure, the patient chooses and ranks five areas that are of specific interest at the initial evaluation and then judges the listening difficulty following hearing aid use. A variation on the same theme is the Glasgow Hearing Aid Benefit Profile (GHABP) (Gatehouse, 1999), which measures the importance and relevance of different listening situations in a more formal way. In this measure, patients are asked to select relevant

situations, indicate how often they are in such situations, how difficult the situation is, and how much handicap it causes. Following treatment, patients are asked how often they used the hearing aids in these situations and the extent to which they helped.

Some measures are intended for use simply to measure outcome rather than to assess needs. The International Outcome Inventory for Hearing Aids (IOI-HA) is a brief self-assessment scale that was carefully developed with good normative data for patients with hearing loss (Cox & Alexander, 2002). The IOI-HA consists of seven questions that explore various dimensions important to successful use of hearing aids. These include daily use, benefit, residual activity limitation, satisfaction, participation, impact on others and quality of life. As an example, the question that explores quality of life is: "Considering everything, how much has your present hearing aids changed your enjoyment of life?" Responses are made on a five-point scale, ranging from "worse" to "very much better."

Some audiologists will ask a patient to have a spouse or significant other complete an assessment scale along with the patient. By doing so, the audiologist can gain insight into communication needs that the patient may overlook or underestimate. The process has an added benefit of providing the family with a forum for communicating about the communication disorder.

The selection of goals for treatment is another important aspect of the audiologic management process. This is often accomplished informally or with measures such as the COSI and GHABP. One important purpose of goal setting is to help the patient establish realistic expectations for what they wish to achieve. Goals can be related to better hearing, such as improved conversation with grandchildren, or more to quality of life or emotional needs, such as feeling less embarrassed about not understanding a conversation. Setting of goals may also help in the selection process by emphasizing the need for a particular hearing aid feature or assistive technology.

The other assessment that needs to be done is of nonauditory factors that relate to successful treatment.

Physical ability, particularly fine motor coordination, can be an important factor in successful use of hearing aid amplification. Particularly in the aging population, reduced fine motor control can make manipulation of conventional hearing aids and hearing aid batteries a challenging endeavor. Assessment should occur prior to the time of fitting a particular hearing device.

Visual ability is also an important component of the communication process and can have an impact on hearing treatment. Most people benefit to some extent from the compensation afforded high-frequency hearing loss through the use of speechreading of the lips and face. A reduction in visual acuity can reduce the prognosis for successful hearing treatment.

Mental status, psychological well-being, and social environment can all have an impact on the success of a hearing management program. Memory constraints or other affected cognitive functioning can limit the usefulness of certain types of amplification approaches. Attitude, motivation, and readiness are all psychological factors that can impact hearing treatment. In addition, the availability of human resources, such as family and friends, can have a significant positive impact on the prognosis for successful hearing aid use. Although most audiologists do not assess these factors directly, most do use directed dialogue techniques during the preliminary counseling to assess these various areas for obvious problems.

Hearing aid amplification and fitting are expensive. A frank discussion of the expenses related to hearing aids is an important component of any treatment evaluation.

Once the assessment is completed, the treatment challenge begins. Prepared with a knowledge of the patient's hearing ability, communication needs, and overall resources, the audiologist can begin the challenge of implementing audiologic management.

THE AUDIOLOGIST'S CHALLENGE

The audiologist faces a number of clinical challenges during the treatment process. One of the first challenges is to determine whether the patient is an appropriate candidate for amplification

or whether the prognosis is such that hearing aids should not be considered. Certain types of disorders and audiometric configurations pose daunting hearing aid challenges. Thus, the first step in the treatment process is to determine whether the patient is likely to benefit from amplification. Once a decision has been made that the patient is a candidate, the treatment process includes a determination of type of amplification system, implementation of the actual fitting of the devices, validation of the fit, and specification of additional treatment needs.

Amplification—Yes or No?

As a general rule, most patients who seek hearing aids can benefit from their use. Thus, in most cases the answer to the question of whether a patient should pursue amplification is an easy *yes*, and the challenges are related to getting the type and fitting correct.

Even in cases in which the prognosis for successful hearing aid use is poor, most audiologists will make an effort to find an amplification solution if the patient is sufficiently motivated. In the extreme case, however, the potential for benefit is sufficiently marginal that pursuit of conventional hearing aid use is not even recommended. Some of the factors that negatively impact prognosis for success include:

- patient does not perceive a problem,
- not enough hearing loss,
- too much hearing loss,
- a "difficult" hearing loss configuration,
- very poor speech recognition ability,
- auditory processing disorder, and
- active disease process in the ear canal.

Although none of these factors preclude hearing aid use, they can limit the potential that might otherwise be achieved by well-fitted amplification.

A patient who does not perceive the hearing loss to be a significant problem is usually one with a slowly progressive, high-frequency hearing loss. This tends to be the patient who can "hear a (low-frequency) dog bark three blocks away" or could understand his

spouse "if she would just speak more clearly." Some of this denial is understandable because the loss has occurred gradually and the patient has adjusted to it. Many people with a hearing loss of this nature will not view it as sufficiently handicapping to require the assistance of hearing aids. As an audiologist, you might be able to show the patient that he will obtain significant benefit from hearing aid use, and you probably should try. But the prognosis for successful use is limited by the patient's lack of motivation and recognition of the nature of the problem. In this case, greatest success will probably come with patience. It is a wise clinical decision to simply educate the patient about hearing loss and the potential benefit of hearing aid use. Then, when the patient becomes more aware of the loss or it progresses and becomes a communication problem, he will be aware of his amplification options.

Some patients have a hearing loss, but it is not sufficient in magnitude for hearing aid use. The definition of "sufficient" has changed dramatically over the years. Currently, even patients with minimal hearing losses can wear mild gain hearing aids with success. As a general rule, if the hearing impairment is enough to cause a problem in communication, the patient is a candidate for hearing aids. Nevertheless, a certain minimum degree and configuration of loss must occur before hearing aid use is warranted.

Some patients have too much hearing loss for hearing aid use. Severe or profound hearing loss can limit the usefulness of even the most powerful hearing aids. You will learn in the next chapter that the amount of amplification boost or gain that a hearing aid can provide has its limits. In many cases of profound hearing loss, a hearing aid can provide only environmental awareness or some rudimentary perception of speech. Many patients will not consider this to be valuable enough to warrant the use of hearing aids. In these cases, cochlear implantation is often the treatment strategy that is most beneficial.

For some audiometric configurations, it is very challenging to provide appropriate amplification. Two examples are shown in Figure 12-3. One difficult configuration is the high-frequency precipitous loss. In this case, hearing sensitivity is normal through 500 Hz, and drops off dramatically at higher frequencies. There

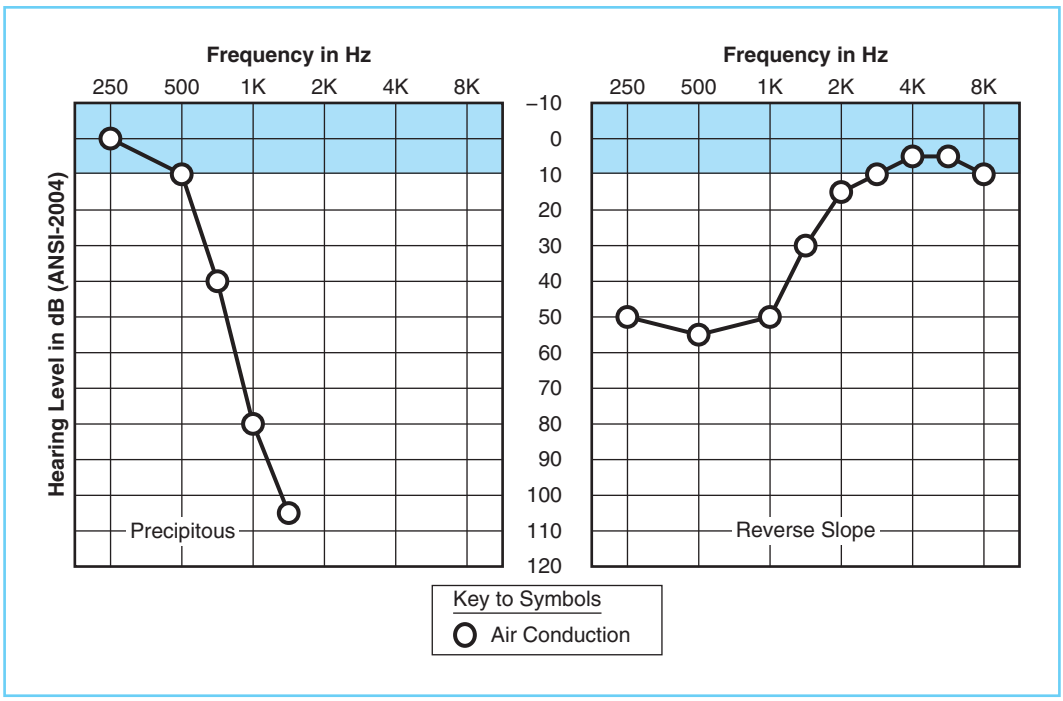


FIGURE 12-3 Two challenging audiometric configurations for the appropriate fitting of amplification.

may even be "dead" regions in the cochlea, where hair cell loss is so complete that no transduction occurs. Trying to amplify the higher frequency sounds excessively presents a whole series of challenges, not the least of which is that the sound quality is usually not very pleasing to the patient. Depending on the frequency at which the loss begins and the slope of the loss, these types of hearing loss can be very difficult to fit effectively. In some cases, patients with this configuration of hearing loss are candidates for cochlear implants. The other extreme is the so-called *reverse slope* hearing loss, a relatively unusual audiometric configuration in which a hearing loss occurs at the low frequencies, but not the high frequencies. The first problem with respect to amplification is that this type of loss seldom causes enough of a communication problem to warrant hearing aid use. When it does, certain aspects of the fitting can be troublesome, and the prognosis for successful fitting is somewhat limited.

Some types of cochlear hearing loss, such as that due to endolymphatic hydrops, can cause substantial distortion of the incoming sound, resulting in very poor speech-recognition ability. If it is poor enough, hearing aid amplification simply will not be effective in overcoming the hearing loss. Regardless of how much or what type of amplification is used to deliver signals to the ear, the cochlea distorts the signal to an extent that hearing aid benefit may be limited. Fortunately, this type of disorder is seldom bilateral, but when it is, hearing aid use will contribute to audibility but may not be satisfactory overall.

Auditory processing disorders in young children and in aging adults can reduce the benefit from conventional hearing aid amplification. In fact, it is not unusual for geriatric patients who were once successful hearing aid users to experience increasingly less success as their central auditory nervous system changes with age. The problem is seldom extreme enough to preclude hearing aid use, but these patients may benefit more from assistive technology to complement conventional hearing aid use.

There are some physical and medical limitations that can make conventional hearing aid use difficult. Occasionally a patient with hearing loss will have external otitis or ear drainage that cannot be controlled medically. Even if the patient has medical clearance for hearing aid use, placing a hearing aid in such an ear can be a constant source of problems. Other problems that limit access to the ear canal include canal stenosis and certain rare pain disorders. In such cases, amplification strategies other than conventional hearing aids must be employed. For example, a bone-anchored hearing aid, which bypasses the outer and middle ears and stimulates the cochlea directly, may be a very beneficial option.

These are some of the factors that make hearing aid fitting difficult. It should be emphasized again, however, that if a person is having a communication disorder from a hearing loss, there is a very high likelihood that the person can benefit from some form of hearing aid amplification. That is, the answer to the question of amplification is usually *yes*, although the question of how to do it successfully is sometimes challenging.

Amplification Strategies

Once the decision has been made to pursue the use of hearing aid amplification, the challenge has just begun. At the very beginning of the hearing aid fitting process, the audiologist must formulate an amplification strategy based on the outcome of the treatment assessment. Various patient factors will have an impact on the decisions made about amplification alternatives. These include:

- hearing loss factors, such as
  - type of loss
  - degree of loss
  - audiometric configuration, and
  - speech perception;
- medical factors, such as
  - progressive loss
  - fluctuating loss, and
  - auricular limitations;
- physical factors; and
- cognitive factors.

With these patient-related considerations in mind, the audiologist must make decisions about amplification strategies, approaches, and options, including:

- type of amplification system
  - conventional hearing aids
  - assistive technology
  - middle-ear or cochlear implant
- which ear
  - monaural versus binaural
  - better ear or poorer ear
  - contralateral routing of signals; and

- conventional hearing aid options
  - signal processing strategy
  - device style
  - hearing aid features.

The type of amplification strategy is dictated by various patient factors. Clearly though, the vast majority of patients with hearing impairment can benefit from conventional hearing aid amplification. It is only the exceptional patient that will go on to exclusive use of assistive technology or to a cochlear implant. And even in these cases, conventional hearing aids are likely to be tried as the initial amplification strategy. In general then, except in the rare circumstances described in the previous section, the decision is made to pursue hearing aid use.

The second group of options tends to be an easy decision as well. In most cases, the best answer to the question of which ear to fit is *both*. There are several important reasons for having two ears (Davis & Mencher, 2006). The ability to localize the source of a sound in the environment relies heavily on hearing with both ears. The brain evaluates signals delivered to both ears for differences that provide important clues as to the location of the source of a sound. This binaural processing enhances the audibility of speech originating from different directions. The use of two ears is also important in the ability to suppress background noise. This ability is of great importance to the listener in focusing on speech or other sounds of interest in the foreground. Hearing is also more sensitive with two ears than with one. All of these factors create a **binaural advantage** for the listener with two ears. Thus, if a patient has symmetric hearing loss or asymmetry that is not too extensive, the patient will benefit more from two hearing aids than from one hearing aid. There is one other compelling reason to fit two hearing aids. Evidence suggests that fitting a hearing aid to only one ear places the unaided ear at a relative disadvantage. This asymmetry may have a long-term detrimental effect on the suprathreshold ability of the unaided ear (Silman et al., 1984). Thus, in general, it is a good idea to fit binaural hearing aids whenever possible.

Enhanced hearing with two ears is called a **binaural advantage**.

Sometimes it is not possible to fit binaural hearing aids effectively. This usually occurs when the difference in hearing between the two ears is substantial. In cases where both ears have hearing loss, but there is significant asymmetry between ears, it is generally more appropriate to fit a hearing aid on the better hearing ear than on the poorer hearing ear. The logic is that the better hearing ear will perform better with amplification than the poorer hearing ear. Thus, fitting of the better ear will provide the best aided ability of either monaural fitting. There are exceptions, of course, but they relate mostly to difficult configurations on the better hearing ear.

The extreme case of asymmetry is in the case of unilateral hearing loss, with the other ear being normal. If the poorer ear can be effectively fitted with a hearing aid, then obviously a monaural fitting is indicated. If the poorer ear cannot be effectively fitted, then another option is to use an approach termed *contralateral routing of signals* (CROS). This approach uses a microphone and hearing aid on the poorer or nonhearing ear and delivers signals to the other ear either through bone conduction or via a receiving device worn on the normal hearing ear. Although this type of fitting is rare, it is often used effectively on patients with profound unilateral hearing loss due, for example, to a viral infection or secondary to surgery to remove an VIIIth nerve tumor.

Once the ear or ears have been determined, a decision must be made about the type of signal processing that will be used and the features that might be included in the hearing aids. This decision relates to the acoustic characteristics of the response of the hearing aids and includes:

- how much amplification gain to provide in each frequency range;
- whether the amount of amplification varies with the input level of the sound;
- what the maximum intensity level that the hearing aids can generate will be;
- how the maximum level will be limited;
- whether the hearing aids will have one setting or multiple settings;

- whether the hearing aid will have directional microphones and what kind;
- whether the aids will have feedback cancellation; and
- whether a t-coil or other wireless technology will be included.

Once the signal processing strategy and features have been determined, a decision must be made about the style of hearing aids to be fitted. In reality, the decisions might not be made in that order. Some patients will insist on a particular style of hearing aid, which may limit some of the features that can be included. In the best of all worlds, however, the audiologist would decide on processing strategy and features first and let that dictate the potential styles. There are two general styles of conventional hearing aids. One type is the *behind-the-ear* (BTE) hearing aid. It hangs over the auricle and delivers sound to the ear in one of three ways. One is the use of a custom-made earmold, referred to as a *closed-fit* technique. Another is through the use of a thin tube or other noncustom coupler, referred to as an *open-fit* technique. The third is also an open-fit strategy, but in this case the receiver of the hearing aid is placed into the ear canal with a custom or noncustom coupler. It is referred to as the *receiver-in-the-canal* (RIC) fitting. The other type is the *in-the-ear* (ITE) hearing aid. An ITE hearing aid has all of its components encased in a customized shell that fits into the ear. Subgroups of ITE hearing aids include *in-the-canal* (ITC) hearing aids and *completely-in-the-canal* (CIC) hearing aids. The decision about whether to choose an ITE or BTE hearing aid is related to several factors, including degree and configuration of hearing loss and the physical size and limitations of the ear canal and auricle. You will learn more about these devices and the challenges of fitting them in Chapter 13.

As you can see, the audiologist has a number of decisions to make about the amplification strategy and a number of patient factors to keep in mind while making those decisions. The experienced audiologist will approach all of these options in a very direct way. The audiologist will want to fit the patient with two hearing aids with superior signal processing capability, maximum programmable flexibility, and an array of features, in a style that is acceptable to the patient at a price that the patient can afford. That is

the audiologist's goal and serves as the starting point in the fitting process. The ultimate goal may then be altered by various patient factors until the best set of compromises can be reached.

Approaches to Fitting Hearing Instruments

Preselection of an amplification strategy, signal processing options, features, and hearing aid style is followed by the actual fitting of a device. There are a number of approaches to fitting hearing instruments, but most share some factors in common. Fitting of hearing instruments usually includes the following:

- estimating an amplification target for soft, moderate, and loud sounds;
- adjusting the hearing aid parameters to meet the targets;
- ensuring that soft sounds are audible;
- ensuring that discomfort levels are not exceeded;
- asking the patient to judge the quality or intelligibility of amplified speech; and
- readjusting gain parameters as indicated.

The first general step in the fitting process is to determine target gain. *Gain* is the amount of amplification provided by the hearing aid and is specified in decibels. *Target gain* is an estimate of how much amplification will be needed at a given frequency for a given patient. The target is generated based on pure-tone audiometric thresholds and is calculated based on any number of gain rules that have been developed over the years. A simple example is a gain rule that has been used since 1944, known as the half-gain rule (see Lybarger, 1988). It stated that the target gain should be one-half of the number of decibels of hearing loss at a given frequency, so that a hearing loss of 40 dB at 1000 Hz would require 20 dB of hearing aid gain at that frequency. A number of such gain rules have been developed to assist in the preliminary setting of hearing aid gain.

Current hearing aid technology permits the setting and achieving of targets in much more sophisticated ways. The audiologist can now specify targets for soft sounds to ensure that they are audible, for moderate sounds to assure that they are comfortable, and for

loud sounds to ensure that they are loud, but not uncomfortable. Many of these types of targets can be calculated from pure-tone air-conduction thresholds alone or in conjunction with loudness discomfort levels.

Once a target or targets have been determined by the audiologist, the hearing aids are adjusted in an attempt to match those targets. Typically, this is done by measuring the output of the hearing aids in a hearing aid analyzer or in the patient's ear canal. The gain of the hearing aids is then adjusted until the target is reached or approximated across the frequency range.

One important goal of fitting hearing aids is to make soft sounds audible. Often in the fitting process this will be assessed by delivering soft sounds to the hearing aids and measuring the amount of amplification at the tympanic membrane or, more directly, by measuring the patient's thresholds in the sound field.

Another important goal of fitting hearing aids is to keep loud sounds from being uncomfortable. Again, this can be assessed indirectly by measuring the output of the hearing aids at the tympanic membrane to high-intensity sound. Or it can be assessed directly by delivering loud sounds to the patient and having the patient judge whether the sound is uncomfortably loud.

Once the parameters of the hearing aids have been adjusted to meet target gains, the patient's response to speech targets is assessed. This can be accomplished in a number of ways, some of which are formal and some informal. The general idea, however, is the same: to determine whether the quality of amplified speech is judged to be acceptable and/or whether the extent to which speech is judged to be intelligible is acceptable. Should either be judged to be unacceptable, modifications are made in the hearing aid response.

Challenges in the fitting of hearing aids are numerous. Specific approaches, gain targets, instrumentation used, and verification techniques can vary from clinic to clinic or from audiologist to audiologist within a clinic. The goal, however, is usually the same: to deliver good sound quality and maximize speech intelligibility.

Approaches to Defining Success

With so many hearing aid options and so many different fitting strategies, one of the audiologists' biggest challenges is knowing when they got it right. That is, how does the audiologist know that the fitting was successful, and against what standards is it judged to be good enough?

Defining hearing aid success has been a challenging and elusive goal for many years. In the early years, when type of hearing aid and circuit selection were limited to a very few choices, the question was often simply of a yes or no variety—yes, it helps, or no, it doesn't. Today, there are so many options that validation of the ones chosen is much more difficult. In general, there are two approaches to verifying the hearing aid selection and fitting procedures:

- self-assessment outcome measures and,
- to a lesser extent, measurement of aided performance.

One important method for defining amplification success is the use of self-assessment scales. Examples were described earlier in this chapter. One or more of these measures is usually given to the patient prior to hearing aid fitting and then again at some later date after the patient has had time to adjust to using the hearing aids. The goal is to ensure that the patient is provided with some expected level of benefit from the devices. Self-assessment measures are now used extensively as a means of judging clinical outcomes of hearing aid fitting.

Another approach is to measure aided performance directly. This can be done with aided speech-recognition measures to assess the patient's ability to recognize speech targets with and without hearing aids. These measures are typically presented in the presence of background competition in an effort to mimic real-life listening situations. The goal of carrying out aided speech-recognition testing is to ensure that the patient is provided some expected level of performance. These measures can also be used if there is an issue about the potential benefits of monaural versus binaural amplification fitting. Another approach is to measure sensitivity thresholds in the soundfield with and without hearing aids. The difference in threshold is known as the *functional gain* of the hearing aid.

Treatment Planning

The fitting of hearing aids is the first component of the treatment plan. The process attempts to address the first goal, that of maximizing the use of residual hearing. From that point, the audiologist is challenged to determine the benefit of the amplification and, if it is inadequate, to plan additional intervention strategies. In all cases, the audiologist must convey to patients and families the importance of understanding the nature of hearing impairment and the benefits and limitations of hearing aids.

The need for and the nature of additional intervention strategies are usually not a reflection of the adequacy of the initial amplification fitting. Rather, needs vary considerably, depending on patient factors such as age, communication demands, and degree of loss.

Many patients do not require additional treatment. Theirs is a sensory loss, the hearing aids ameliorated the effects of that loss, and their only ongoing needs are related to periodic reevaluations.

For other patients, the fitting of hearing aids simply constitutes the beginning of a long process of habilitation or rehabilitation. Children may need intensive language stimulation programs, classroom assistive technology, and speech therapy. Adults may need aural rehabilitation, speechreading classes, telephone amplifiers, and other assistive technology.

Summary

- The fundamental goal of audiologic management is to limit the extent of any communication disorder that results from a hearing loss.
- The first step in reaching that goal is to maximize the use of residual hearing, usually by the introduction of hearing aid amplification.
- If a patient has a sensorineural hearing impairment that is causing a communication disorder, the patient is a candidate for amplification.
- The goal of the assessment is to determine candidacy for audiologic management.

- The treatment assessment determines the self-perception and family-perception of communication needs and function; the patient's physical, psychological, and sociological status; and the sufficiency of human and financial resources to support hearing treatment.
- The first step in the rehabilitative process is to determine whether the patient is likely to benefit from amplification.
- Patient factors, including hearing impairment, medical condition, physical ability, and cognitive capacity, impact the decisions made about amplification alternatives.
- Preselection of amplification includes decisions about type of amplification system, signal processing strategy, hearing aid features, and device style.
- Fitting of hearing instruments usually includes estimation of amplification targets, adjustment of hearing aid parameters to meet those targets, and verification of hearing aid performance and benefit.
- Many patients do not require additional treatment; for others, hearing aid fitting is only the beginning of the rehabilitative process.

Short Answer Questions

1. The goal for audiologic treatment is to limit the extent of any _____ disorder that results from a hearing loss. This first involves maximizing the use of any _____ hearing and then proceeding with some form of _____ rehabilitation.
2. The first step in the process of obtaining hearing aids is to have an _____ assessment. This is typically followed by a medical assessment to obtain medical _____ to pursue hearing aids.
3. Once _____ of the ears and ear canals are made for customization of earmolds or hearing aids, hearing aids can then be ordered from the manufacturer. Following delivery of the hearing aids, the aids are _____ for the patient's hearing loss and are fitted to the user.

4. Audiologic management approaches can vary significantly with patient _____, the nature of the hearing impairment, and the extent of _____ requirements in daily life.
5. A patient's _____ for pursuing a hearing aid is highly correlated with _____ for successful hearing aid use.
6. Components of the audiologic evaluation for treatment candidacy include the case history, _____ exam of the ear canal, immittance audiometry, _____-_____ audiometry, speech audiometry, and threshold of _____ measures.
7. Components of assessment for treatment candidacy include evaluation of communication needs, self-assessment of hearing _____, psychosocial status, _____ capacity, and financial status.
8. Self-assessment measures of hearing handicap can be informal or _____. Examples of formal measures include the Client _____ Scale of _____ (COSI), the Hearing _____ Inventory for the Elderly, and the Abbreviated Profile of _____ Aid _____.
9. In regard to physical status, both fine _____ skills and _____ dexterity are important factors to consider in the success of hearing aid use.
10. Some indicators for poor prognosis of successful hearing aid use include: the _____ does not perceive a problem; there is either not enough or _____ _____ hearing loss; the patient has a difficult hearing loss _____; or the patient has very poor speech _____ ability.
11. The type of amplification system used depend on patient variables. Some different types of hearing technology include conventional _____ _____, assistive technology, and middle-ear or cochlear _____.
12. Conventional hearing aids are available in two main device styles: _____-the-ear (BTE) and _____-the-ear (ITE) hearing aids.

13. The use of assistive technology that directs sound from a "dead" ear to the better hearing ear are called _____ routing of signal (CROS) hearing aids.
14. The improvements in communication ability that typically result from the use of two hearing aids rather than one is known as the _____ _____.
15. Measures that are made of hearing thresholds in soundfield with the use of amplification are known as _____ _____ measures.
16. Children with hearing loss typically need audiologic treatment planning that involves language stimulation, _____ assistive technology, and _____ therapy.
17. Adults with hearing loss often benefit from audiologic treatment planning that involves _____ instruction, _____ amplifiers, and other assistive technology.

Discussion Questions

1. Explain how audiologic management differs from diagnostic audiology. How do they overlap?
2. Describe the role that motivation plays in successful hearing aid use.
3. Explain the typical process for obtaining hearing aids.
4. Describe how patient variables impact audiologic management.
5. What are the benefits and limitations of using informal or formalized hearing needs assessments?
6. Describe how to determine a threshold of discomfort. What is the benefit of this measure?
7. Provide an example where you might NOT want to fit a patient with a hearing device. Why?

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13

THE AUDIOLOGIST'S TREATMENT TOOLS: HEARING INSTRUMENTS

Learning Objectives

Hearing Instrument Components
- Microphone and Other Input Technology
- Amplifier
- Receiver
- Controls

Electroacoustic Characteristics
- Frequency Gain Characteristics
- Input-Output Characteristics
- Output Limiting
- Signal Processing
- Other Processing Features

Hearing Instrument Systems
- Conventional Hearing Aids
- Hearing Assistive Technology
- Implantable Hearing Technology

Summary

Short Answer Questions

Discussion Questions

Resources

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- List and describe the major components of hearing instrument devices.
- Define and explain the concepts relating to acoustic response characteristics of hearing aids, including frequency gain characteristics, input-output characteristics, output limiting, and signal processing.
- Identify and describe styles of conventional hearing aids.
- Describe the features typically available in conventional hearing aids.
- Describe common available assistive listening devices and describe when they may be useful.
- Describe the components of a cochlear implant and other implantable hearing technology.

HEARING instrument technology advances at a rapid pace. Today's hearing instruments use digital signal processing, provide high fidelity sound reproduction, have adaptive directionality and feedback control, have low battery drain, and are readily programmable, providing tremendous flexibility for precise fitting (for a complete review, see Dillon, 2002; Valente et al., 2008).

Some aspects of hearing aids have not changed over the years. There is still a microphone to convert acoustical energy to electrical energy, an amplifier to boost the energy, and a receiver or loudspeaker to turn the signal back from electrical to acoustical energy. We still discuss the output of a hearing aid in terms of the amplification or gain that is provided across the frequency range and the maximum level of sound that is delivered to the ear. Similarities to past technology end there, however, as many of the old rules have changed or are changing.

If you were a student in the not-so-distant past, you would probably learn about antiquities such as **body-worn hearing aids** and **eye-glass hearing aids**. Now you might see these instruments in a hearing-aid museum. Today when you look at a picture of an in-the-ear (ITE) hearing aid, you may be looking at the next addition to that museum.

A body-worn hearing aid has its components encosed in a small box worn on the chest with a cord connected to a receiver worn on the ear.

Eye-glass hearing aids were an were an early style of hearing aid in which the microphone and amplifier were built into one or both sides of the eyeglass frames with earmolds attached.

The burgeoning technological advances can make it difficult for beginning students to appreciate some of the challenges

audiologists have faced over the years in the fitting of hearing aids. When you look at a picture of an ITE hearing aid today, it may not look much different than it did 5 years ago, but its capacity has advanced remarkably in even that short a period of time.

One way to view the advances in amplification is in terms of the technology pyramid shown in Figure 13-1. At the bottom of the pyramid is standard technology with something called linear amplification and simple output limiting. Linear amplification means that soft, medium, and loud sounds are all amplified to the same extent. Output limiting is the way that the maximum output is capped. The next step up the pyramid is miniaturization. This has allowed even the most sophisticated signal processing circuits to be fitted into a completely-in-the-canal (CIC) style of hearing aid. Above that is programmable technology, which provides extremely flexible control of



FIGURE 13-1 The progress of hearing aid technology.

hearing aid characteristics and multiple memories for programming different response parameters for different listening situations.

The next step up the pyramid is digital and directional technology. The change to digital processing brought tremendous advances in **nonlinear amplification**, output limiting, noise reduction, and feedback control, all with reduced power consumption and signal distortion.

Nonlinear amplification usually means that soft sounds are amplified more than loud sounds.

Digital signal processing permits the use of all technologies in the pyramid in a very flexible manner, in a small package, to meet the needs of patients. Directional microphones allow hearing aids to focus in space by enhancing signals in front and reducing those coming from behind. Although an old concept, enhancement in technology made directionality a very useful reality. The next step up the pyramid is a burgeoning strategy of providing a more open fitting of hearing aids to reduce the occluding effects of hearing aids and provide a more natural sounding amplification, especially to those with high-frequency hearing loss. Here, instead of blocking the ear canal with an earmold or in-the-ear hearing aid, sound is delivered through thin tubing that is coupled to the ear canal in a more open fashion. In some cases the hearing aid's loudspeaker has also been moved to the ear canal. Like directional technology, the idea comes from down low on the pyramid, but its routine application was made possible by technological enhancement.

At the top of today's hearing aid pyramid is the growing opportunity for wireless connectivity of hearing aids, permitting communication from one hearing aid to another and from both hearing aids to other electronic devices and signal sources.

In this chapter, you will learn about the fundamental characteristics of hearing aids and about some of the current signal processing strategies. You will also learn about hearing assistive technology, which is often used to supplement conventional amplification, and cochlear implants, which are the devices of choice for many patients with severe and profound hearing loss. Armed with a basic understanding, you should be able to appreciate the technological advances as they emerge into the reality of commercially available hearing instruments.

HEARING INSTRUMENT COMPONENTS

A hearing aid is an electronic amplifier that has three main components:

1. a microphone,
2. an amplifier, and
3. a loudspeaker.

A schematic of the basic components is shown in Figure 13-2. The *microphone* is a vibrator that moves in response to the pressure waves of sound. As it moves, it converts the acoustical signal into an electrical signal. The electrical signal is boosted by the *amplifier* and then delivered to the loudspeaker. The *loudspeaker* then converts the electrical signal back into an acoustical signal to be delivered to the ear. Power is supplied to the amplifier by a battery, which in some cases is rechargeable. Most hearing aids have some form of external control, usually a volume control, and some have a remote control.

Microphone and Other Input Technology

A microphone is a transducer that changes acoustical energy into electrical energy. A microphone is essentially a thin membrane that vibrates in response to the wave of compression and expansion of air molecules emanating from a sound source. As the membrane of the microphone vibrates, it creates electrical energy flow that corresponds to the amplitude, frequency, and phase of the acoustic signal. This energy is then preamplified before it is filtered.

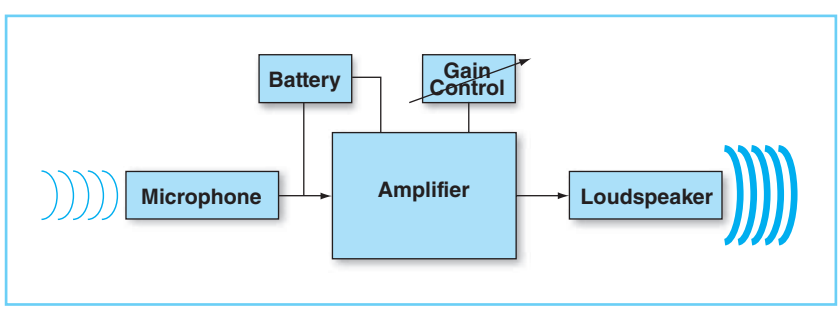


FIGURE 13-2 Schematic representation of the components of a hearing aid.

Conventional hearing devices use an **omnidirectional microphone**. An omnidirectional microphone provides wide-angle reception of acoustic signals. That is, it is sensitive to sound coming from many directions. Think about the tympanic membrane as our natural microphone. Because of its location, it benefits from the acoustic characteristics of the pinna, concha, and ear canal, all of which are important in spatial hearing, or localizing sound sources in space. Imagine that when we place a hearing aid in the ear canal or we hang it over the ear, we are moving that natural microphone from the eardrum to the side of the head, thereby reducing the spatial cues of the outer ear. In an effort to compensate for this, a **directional microphone**, which has a more focused field, is often substituted for the omnidirectional microphone. The purpose of using a directional microphone is to focus its sensitivity toward the front of the listener, thereby attenuating or reducing unwanted "noise" or competition emanating from behind the listener.

An **omnidirectional microphone** is sensitive to sounds from all directions.

A **directional microphone** focuses on sounds in front of a person.

Microphone technology has also been designed that provides the capability of both directional and omnidirectional microphone reception in the same hearing device. This is accomplished by using two microphones in the same hearing aid. In some devices, the microphone can be switched from omnidirectional to directional with a control on the hearing aid or by remote control. The sophistication of directional microphones has changed dramatically. The switching from omnidirectional to directional can now occur automatically and adaptively, so that the directionality is activated when the hearing aid senses background noise and changes the amount of directionality based on the extent of the noise (see, for example, Ricketts et al., 2005). Directional microphones are a feature of hearing aids designed to help patients hear in noisy environments.

There are also other ways that sound can be input into the amplifier of a hearing aid besides the conventional microphone. The idea here is to bypass the environmental microphone to deliver a signal directly to the hearing aid. One of the most basic techniques is direct audio input (DAI). DAI is just as it sounds; sound from some source is input into the hearing aid directly via a wire connector or "boot" that connects to a BTE hearing aid. Although still available, more modern strategies use some form of wireless technology.

One of the most common forms of alternative input technology is the telecoil or t-coil. A telecoil allows the hearing aid to pick up electromagnetic signals directly, bypassing the hearing aid microphone. This allows for direct input from devices such as telephones receivers, thus the name telecoil. In addition to telephone signals, a t-coil can also pick up signals from other sources that are used for remote-microphone strategies. You will learn more about remote microphones later in this chapter. A remote microphone is simply that, a microphone that is used by a talker, for example a teacher in a classroom. The signal from that remote microphone is then transmitted in some form to a loop of wire that then transmits the signal electromagnetically to the t-coil of the hearing aid. A telecoil can be activated by a switch on the hearing aid, by remote control, or automatically when the hearing aid senses an electromagnetic field. Today, when a patient holds a telephone up to a hearing aid, the hearing aid can automatically switch from the environmental microphone to the telecoil, thereby enhancing the sound from the telephone and eliminating the acoustic signals that would then be background noise.

A hearing aid may also have some other form of wireless receiver, such as a frequency-modulated (FM) receiver or other more modern wireless connectivity. An FM receiver can be built into a hearing aid or attached as a boot on a BTE hearing aid. The FM receiver acts like an FM radio, receiving signals from a transmitter and directing them to the amplifier of the hearing aid. Increasingly, modern hearing aids are equipped with other wireless connectivity solutions so that the hearing aid amplifier can receive signals directly from mobile phones, computers, personal music players, and so on.

Amplifier

The heart of a hearing aid is its power amplifier. The amplifier boosts the level of the electrical signal that is delivered to the hearing aid's loudspeaker. The amplifier controls how much amplification occurs at certain frequencies. The amplifier can also be designed to differentially boost higher or lower intensity sounds. It also contains some type of limiting devices so that it does not deliver too much sound to the ear.

Most patients have more hearing loss at some frequencies than at others. As you might imagine, it is important to provide more amplification at frequencies with more hearing loss and less amplification at frequencies with less loss. Thus, hearing aids contain a filtering system, which is adjustable, that permits the "shaping" of frequency response to match the configuration of hearing loss.

An example of the effects of shaping or filtering is shown in Figure 13-3. Here, the response of the hearing aid varies as a function of the filter settings on the hearing aid. When little filtering is used, the response of the device is relatively flat across the frequency range. When high-pass filtering is used (to pass the highs and cut the lows), the response of the hearing aid shows little amplification in the low frequencies and relatively greater amplification in the high frequencies.

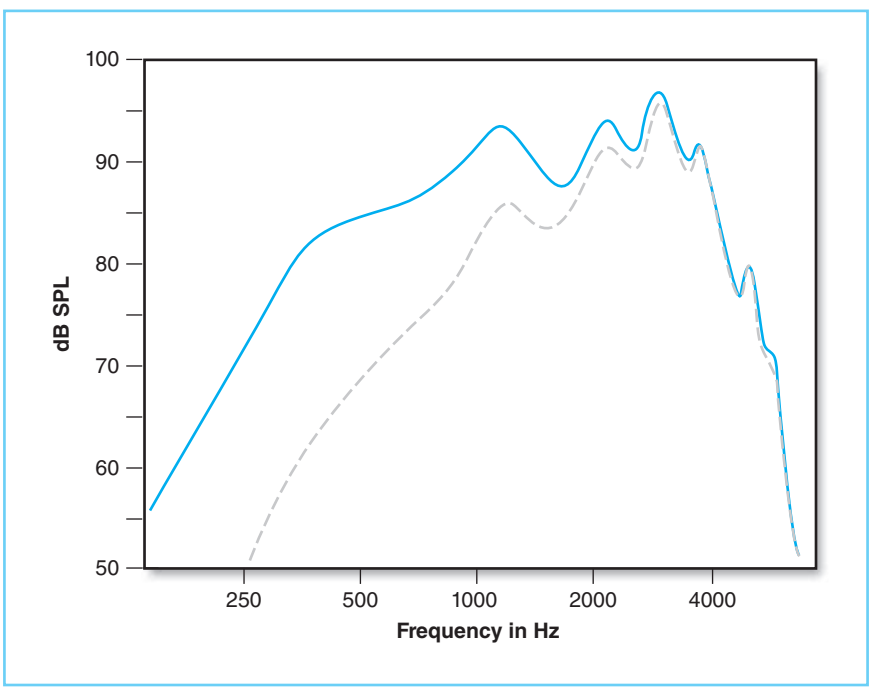


FIGURE 13-3 The effects of filtering on the frequency response of a hearing aid.

An amplifier can be designed to provide linear amplification or nonlinear amplification. *Linear* amplification means that the same amount of amplification, or gain, is applied to an input signal regardless of the intensity level of that signal. That is, if the gain of the amplifier is, say, 20 dB, then a linear amplifier will increase an input signal of 40 dB to 60 dB, an input of 50 dB to 70 dB, an input of 60 dB to 80 dB, and so on. This relationship is shown in Figure 13-4. *Nonlinear* amplification means that the amount of gain is different for different input levels. For example, a nonlinear amplifier might boost a 30 dB signal to 65 dB, but a 70 dB signal to only 80 dB. This relationship is shown in Figure 13-5. The vast majority of modern hearing aids provide predominantly nonlinear gain.

An amplifier also contains circuitry that limits its output. In the early days of hearing aids, the output was limited by simply putting a lid on it and not letting peaks of signals exceed a certain predetermined level. This output limiting technique,

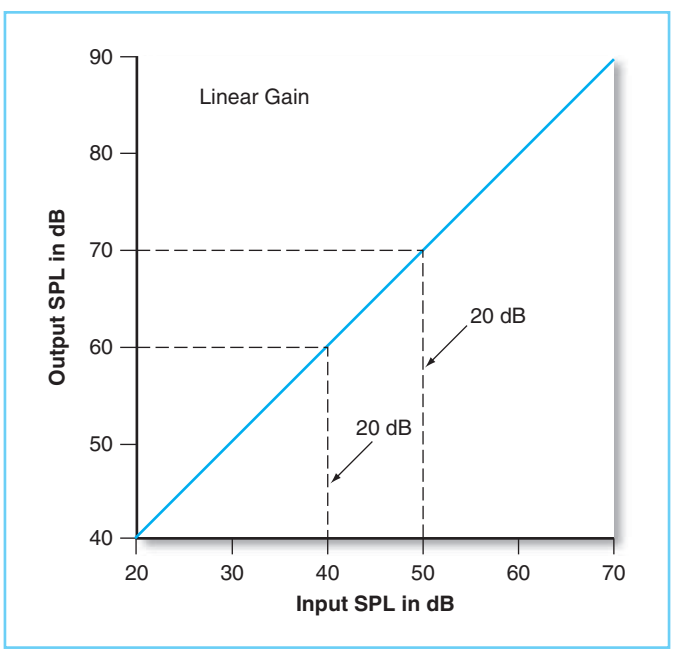


FIGURE 13-4 The relationship of sound input to output in a linear hearing aid circuit. Gain remains at a constant 20 dB, regardless of input level.

known as *peak clipping*, is shown schematically in Figure 13-6. Current technology uses *compression limiting*. Here, the amplifier is designed to become nonlinear as input signals reach a certain level, so that the amount of gain is diminished significantly at the maximum output level. This compression limiting technique is shown schematically in Figure 13-7. Compression

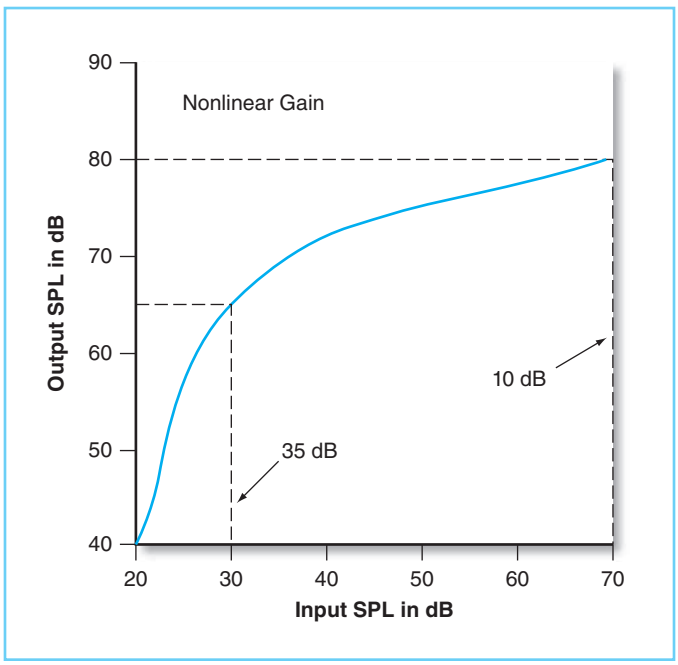


FIGURE 13-5 The relationship of sound input to output in a nonlinear hearing aid circuit. Amount of gain changes as a function of input level.

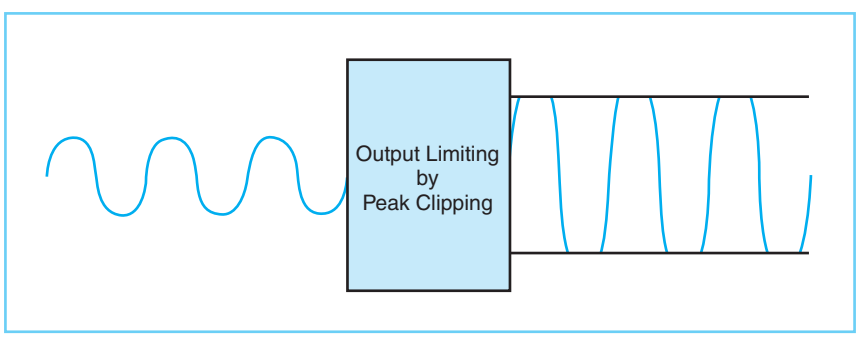


FIGURE 13-6 Schematic representation of output limiting by peak clipping.

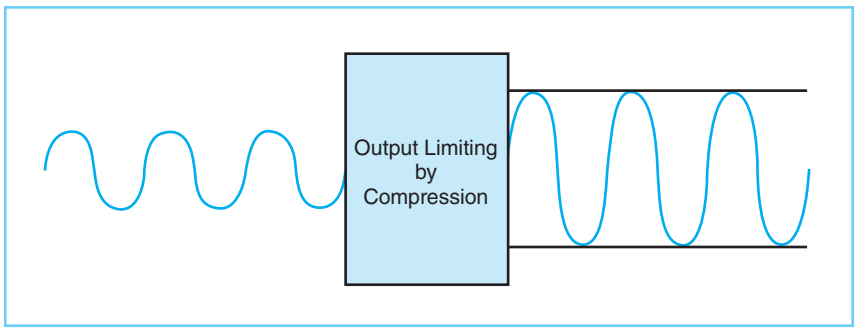


FIGURE 13-7 Schematic representation of output limiting by compression.

limiting introduces less distortion than peak clipping and has become the standard method of output limiting.

Modern hearing aid amplifiers have frequency responses with a wide and smooth bandwidth. That is, the upper frequency limit is extended into high frequencies, and the amplifier provides a relatively smooth or constant output across the frequency range. The wider and smoother the aid's frequency response is, the better the fidelity of signal reproduction and the better a person wearing the device will understand speech. In most patients, sensorineural hearing loss is greater in the higher frequencies. It is in these higher frequencies that consonant sounds, which carry so much of the meaning of speech, have most of their acoustic energy. In the early days of hearing aids, amplifiers had limited capacity for boosting the higher frequencies of speech that are so critical for its perception. Problems arose due to an inability to reduce distortion in the amplification of the high frequencies. This distortion made it difficult for hearing-device wearers to tolerate high-level speech or music, and there was a tendency to limit high-frequency amplification, thereby sacrificing fidelity for tolerability. Much of the difficulty in extending amplification to the high frequencies without distortion related not to amplifier limitations, but to the need to drive the amplifiers with low-power batteries. To obtain reasonable battery life, amplifiers were altered in ways that also exaggerated distortion. Enhancements in amplifier technology now permit high-fidelity signal reproduction of the high-frequency range of amplification without excessive power drain.

Receiver

The amplifier of a hearing aid delivers its electrical signal to a receiver, or loudspeaker. The loudspeaker is a transducer that changes electrical energy back into acoustical energy. That is, it acts in the opposite direction of a microphone.

The loudspeaker is also an important component of a hearing aid. Think for a moment what a good, high-fidelity stereo system sounds like when you are playing your favorite music through very good headphones or speakers. Now imagine what it would be like if you were to replace your good speakers with cheap ones. It would certainly be a waste of a good amplifier.

The receiver, or loudspeaker, of a hearing aid must have a broad, flat frequency response in order to accurately reproduce the signals being processed by the hearing aid amplifier.

Controls

The various parameters of a hearing aid amplifier are manipulated by software control. Older hearing aids had hardware controls, such as dials, switches, and **potentiometers**. Modern hearing aids usually have a hardware volume control and often a control for switching memory programs. Other parameters are adjustable by remote control or by computer-based software control.

A **potentiometer** is a resistor connected across a voltage that permits variable change of a current or circuit. On a hearing aid, it is a small dial that can be rotated to change some parameter of the response.

A hearing aid amplifier has a general response curve that characterizes the circuit. This response curve can be manipulated, usually to reduce or enhance the low- and/or high-frequency range. Thus, a given hearing aid amplifier is capable of producing responses over a generalized range. From this range, projections are made as to the degrees and configurations of hearing losses that can be fitted with the circuit. This is called a fitting range. An example is shown in Figure 13-8. The audiologist uses this kind of fitting range to determine the potential appropriateness of the circuit for a patient's audiogram. Under software control, the audiologist then manipulates the response curve to match that needed for the patient's hearing sensitivity.

Newer hearing aid circuits have a more generic frequency response that can be controlled extensively. The response within a range can be adjusted to vary significantly.

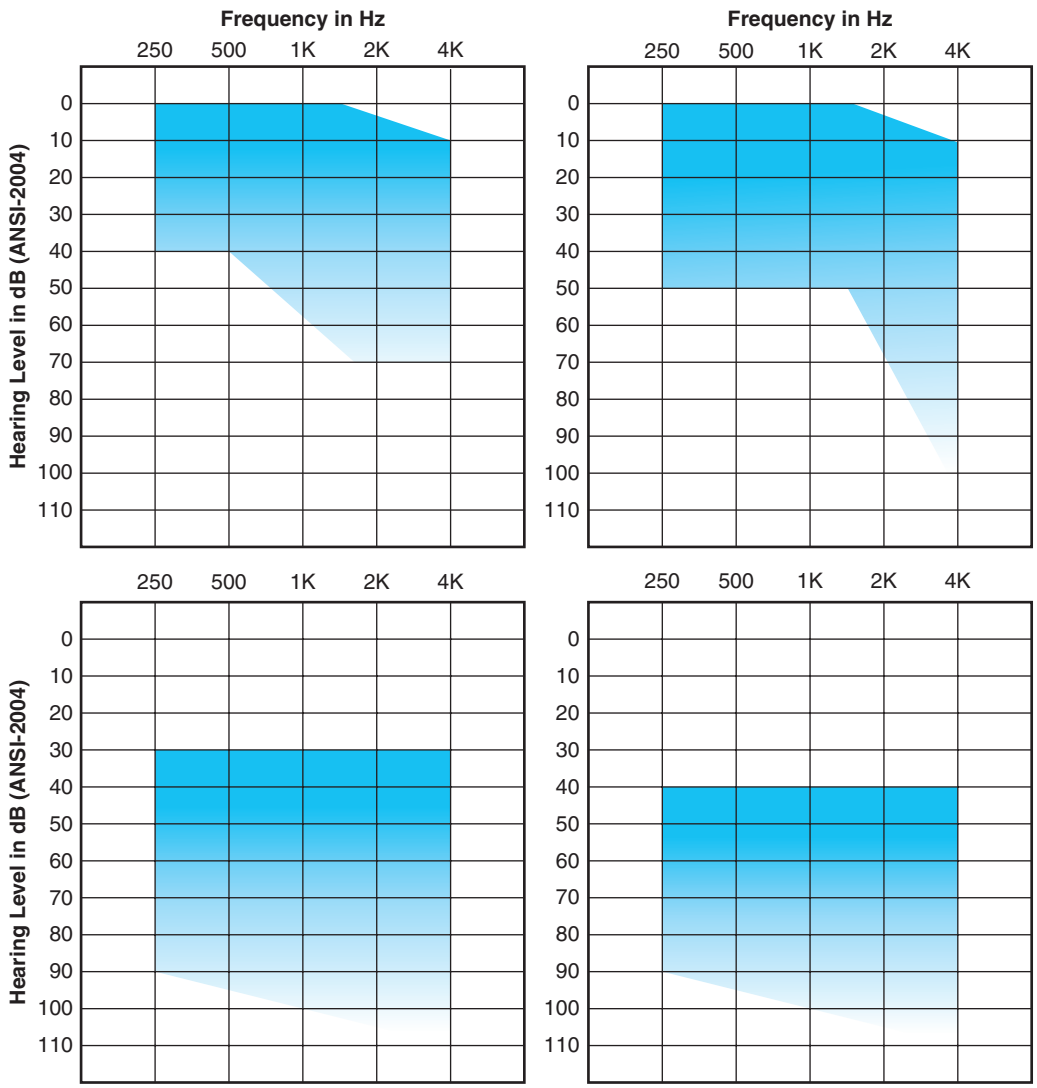


FIGURE 13-8 An example of a fitting range for four different hearing aids, ranging from a mild-gain to a power hearing device.

Manual Control

A conventional hearing aid will usually have one or two controls that the patient can manipulate. Controls usually include a volume or gain control and a switch to control on-off and/or memory selection.

On-off switches and volume controls can take many forms on a hearing aid. The classic on-off switch is the **MTO** switch, and the classic volume control is a rotating wheel, as shown in Figure 13-9. The MTO switch stands for **M**icrophone, **T**elecoil, **O**ff. *Microphone* means on; *telecoil* means that the microphone is turned off and that the telecoil of a hearing aid is activated to pick up signals from a telephone or other electromagnetic transducer; *off* means off. If a hearing aid does not have a telecoil, then the control is an M-O switch. In some hearing aids, the on-off switch is contained as part of the volume control wheel.

MTO means:
M = microphone,
T = telephone, and
O = off.

Modern hearing aids use a push button or other type of switch for changing settings, such as the t-coil or other memory options.



FIGURE 13-9 Photograph of a BTE hearing aid, with an MTO switch and rotating volume control. (Courtesy of Siemens Hearing Instruments, Inc., Piscataway, NJ.)

Programmable Control

Hearing aids are either completely digital in their control paths or have analog processing that is under digital control, allowing them to be *programmable*, or manipulable under computer control. Under such computer control, the response parameters of a hearing device can be manipulated with flexibility and relative ease. In some cases, the programming unit is a **proprietary**, standalone instrument, but in most cases, it is one that can be used for various makes of hearing devices and is controlled by proprietary computer software. A software platform known as Noah has become a standard interface for programming hearing aids. Hearing aid manufacturers provide proprietary software based on this platform to permit programming of their particular devices.

Proprietary means belonging to a proprietor, such as a hearing instrument manufacturer.

Sophistication of programmable hearing devices varies substantially. In its simplest form, a programmable hearing device is little more than a conventional linear hearing aid that allows computer control over variables that were formerly controlled by potentiometers and screwdrivers. The most sophisticated programmable device has numerous frequency **channels** with nonlinear compression circuitry that can be adjusted in all or some of the channels as well as several memories for storing responses programmed for different listening situations.

A **channel** is a frequency region that is processed independently of other regions.

Programmability of modern hearing instruments provides several benefits that lead to improved fitting capability. Because the electroacoustic parameters of a programmable device can be manipulated over a fairly broad range at the time of fitting, manufacturers can produce instruments in a one-size-fits-all manner. Flexibility and precision of electroacoustic adjustments can be made to fit an individual's particular hearing loss configuration. All of these adjustments are made at the time of the fitting or during follow-up appointments in a manner that provides appropriate amplification for a patient.

Most hearing instruments have acoustic parameters that can be manipulated over a wide range, permitting gain and output modifications as hearing loss progresses or fluctuates. This is particularly useful in fitting young children whose hearing ability may not be precisely quantified at the time of the initial evaluation.

Most hearing aids also have multiple memories that contain different acoustic responses. For example, one response may be appropriate for a certain acoustic environment such as telephone use, but inappropriate for listening in a noisy environment. Multiple memories make both responses available in the same hearing device.

ELECTROACOUSTIC CHARACTERISTICS

The acoustic response characteristics of hearing aids are described in terms of frequency gain, input-output, and output limiting. Gain of the hearing aid is the amount of sound that is added to the input signal. If a speech signal enters the hearing aid at 50 dB and is amplified to 90 dB, the amount of gain is 40 dB. The frequency gain response of a hearing aid is the amount of gain as a function of frequency. Because most hearing losses are greater at some frequencies than at others, the ability to manipulate gain selectively in different frequency regions is important. *Input-output characteristic* of a hearing aid is the amount of gain as a function of the input intensity level. The input-output function can be linear or nonlinear. *Output limiting* refers to the maximum intensity of the amplified signal. If a signal of 100 dB were delivered to a hearing aid that had 40 dB of gain, without a limiting circuit, the output would be 140 dB. Such a high-intensity signal would not only be intolerable, but would be damaging to the cochlea, so it is necessary to limit the maximum intensity level the hearing aid can generate.

Frequency Gain Characteristics

The most recognizable "signature" of a hearing aid is its frequency response. A frequency response curve is a graphic representation of the amplification characteristics of a hearing aid in decibels as a function of frequency. It is determined by delivering to the hearing aid a signal at a fixed-intensity level across the frequency range. Figure 13-10 illustrates the frequency response of a hearing aid.

The frequency response of a hearing aid is a standard that is used to describe its amplification characteristics. Often, the first step taken by an audiologist after receiving a hearing aid from the manufacturer is to evaluate the frequency response of the device on a hearing aid analyzer to ensure that it meets specifications.

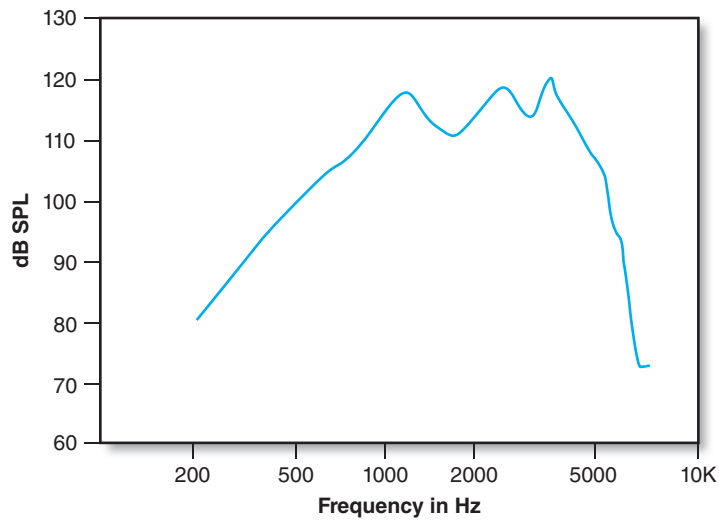


FIGURE 13-10 | Frequency response of a hearing aid.

The frequency response curve provides information about the *absolute* response of a hearing aid. Although important in describing the performance of an aid, we are usually more interested in the *relative* response of a hearing aid, or how much amplification was added at each frequency by the hearing aid. The most common way of describing this relative response is by a frequency gain curve. The term **gain** refers to the magnitude of amplification of sound by a hearing aid. In other words, gain represents how much the sound is boosted by the hearing aid amplifier. A frequency gain response is a graph of the gain produced by a hearing aid to a specified intensity level of a signal presented across the frequency range. Thus, it is a picture of the difference between the intensity level of the output of the hearing aid and the intensity level of the input. An example of a frequency gain response is shown in Figure 13-11.

Gain is the amount, expressed in dB, by which the output level exceeds the input level.

The frequency gain characteristics are important to the audiologist in the hearing aid fitting process. Most of the methods used for prescribing a hearing aid are based on providing a specified amount of gain at a given frequency, based on a patient's pure-tone audiogram. Thus, the audiologist is usually more interested

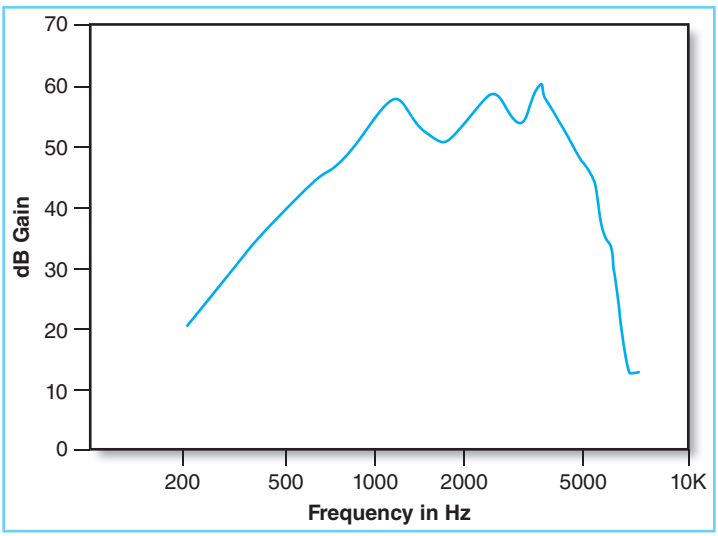


FIGURE 13-11 | Frequency gain response of a hearing aid.

in knowing the amount of gain provided to a given input level than the decibel level of the device's output.

Input-Output Characteristics

A frequency gain response provides information about the amount of gain produced for a given input intensity level. Now suppose you were interested in knowing the response at various input intensity levels. Figure 13-12 shows frequency response curves to signals presented at several intensity levels. If you were to take a single frequency and plot the output intensity level as a function of the input intensity level, you would have an input-output function of the hearing aid at a specified frequency.

The input-output characteristics of a hearing aid are important because they describe how a hearing aid functions at different intensity levels. That is, they tell us how many decibels the amplification increases with an increase in the input signal. For some hearing aids, this input-output relationship is a simple matter of a 1 dB increase in output for every 1 dB increase in input until the hearing aid's maximum level is reached. This is called a linear input-output relationship. For most hearing aids the input-output relationship changes throughout the intensity range in a nonlinear manner.

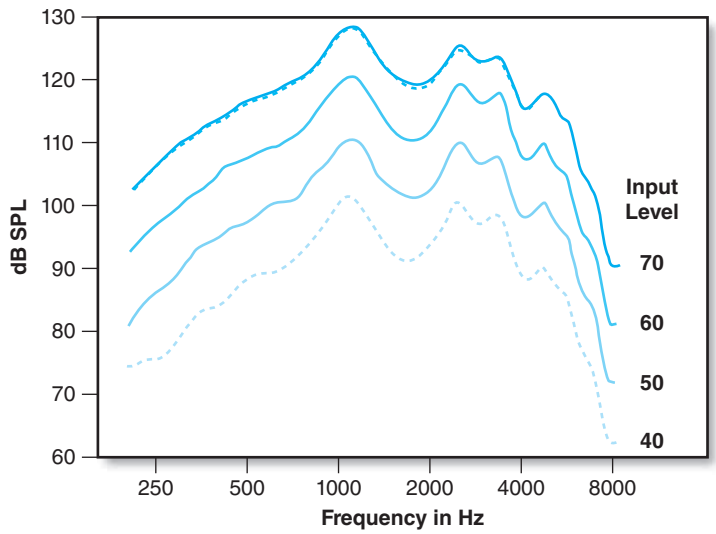


FIGURE 13-12 Frequency responses of a hearing aid to different input levels.

Linear Amplification

Linear amplification means that the relationship between input and output is proportional, so that low-intensity sounds are amplified to the same extent as high-intensity sounds. An example of a linear input-output function was shown previously in Figure 13-4. Here, for every dB increase in the input, there is a corresponding dB increase in the output.

Fitting of linear amplification was a fairly standard approach in the early years of hearing aids and remains applicable for conductive hearing loss and some mild sensorineural hearing loss.

A problem with this type of linear amplification is that it does not address the nonlinearity of loudness growth that occurs with sensorineural hearing impairment. You will recall from Chapter 3 that many patients with sensorineural hearing loss do not hear soft sounds, but can hear loud sounds normally. A linear device amplifies both soft and loud sounds identically. As a result, if a low-intensity sound is made loud enough to be audible, a high-intensity sound is

likely to be made too loud for the listener. This idea is shown schematically in Figure 13-13.

Nonlinear Amplification

Nonlinear amplification means that the relationship between input and output is not proportional, so that, for example, low-intensity sounds are amplified to a greater extent than high-intensity sounds. An example of a nonlinear input-output function was shown previously in Figure 13-5.

Nonlinear amplification is achieved with something called compression circuitry. *Compression* is a term that is used to describe how the amplification of a signal is reduced as a function of its intensity. Compression techniques are used both to limit the maximum output of a hearing aid and to provide nonlinear amplification across a wide range of inputs.

Wide-range nonlinear amplification is designed to "package" speech into a listener's residual dynamic range. Dynamic range, in this case, is a term used to describe the decibel difference between the level of a person's threshold of hearing sensitivity and

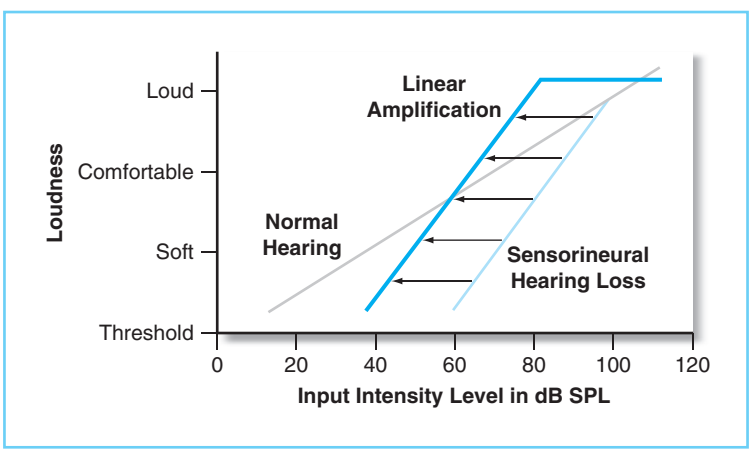


FIGURE 13-13 Schematic representation of loudness as a function of intensity level for normal hearing and for sensorineural hearing loss. A linear hearing aid amplifies both soft and loud sounds identically, making moderate intensity sound comfortable, but high intensity sound too loud.

the level that causes discomfort. In a normal-hearing person, that range is from 0 dB HL to about 100 dB HL. In a patient with a sensorineural hearing loss, that range is reduced. For example, a patient with a 50 dB hearing loss and a discomfort level of 100 dB has a dynamic range of only 50 dB. Compression circuitry used in nonlinear amplification is designed to fit speech signals into this reduced dynamic range. The idea is to boost the gain of low-intensity sounds so that they are audible but to limit the gain of high-intensity sounds so that they are not uncomfortable. The term *dynamic range compression* has been used to describe this nonlinear amplification process because it is meant to provide compression throughout a patient's range of useable hearing.

The need for nonlinear amplification is based on the knowledge that sensorineural hearing loss results in a reduced dynamic range and also on the knowledge that the loudness growth function in that ear is different from a normal ear. Again, the loudness growth of an ear with sensorineural hearing loss can be nonlinear, and the linearity may differ as a function of frequency. For example, our patient with the 50 dB hearing loss hears moderate-intensity sounds at reduced loudness but hears high-intensity sounds at normal loudness. A linear hearing aid amplifies all sounds to the same extent, so that low-intensity sounds become audible, moderate sounds become louder than desired, and high-intensity sounds become intolerable. Nonlinear, dynamic-range compression devices, in contrast, are designed in various ways to account for the nonlinear nature of loudness growth resulting from hearing impairment. Figure 13-14 illustrates the difference between linear compression and dynamic-range compression as it relates to an ear with sensorineural hearing loss and nonlinear loudness growth.

A number of nonlinear compression strategies have been developed to address the dynamic-range issue, and they vary in their approach and complexity. Some strategies are designed to provide compression over part of the dynamic range. Partial dynamic-range compression typically provides linear amplification for low input signals and some level of compression once the input reaches a certain level. Other strategies are designed to provide compression over a wider portion of the dynamic range.

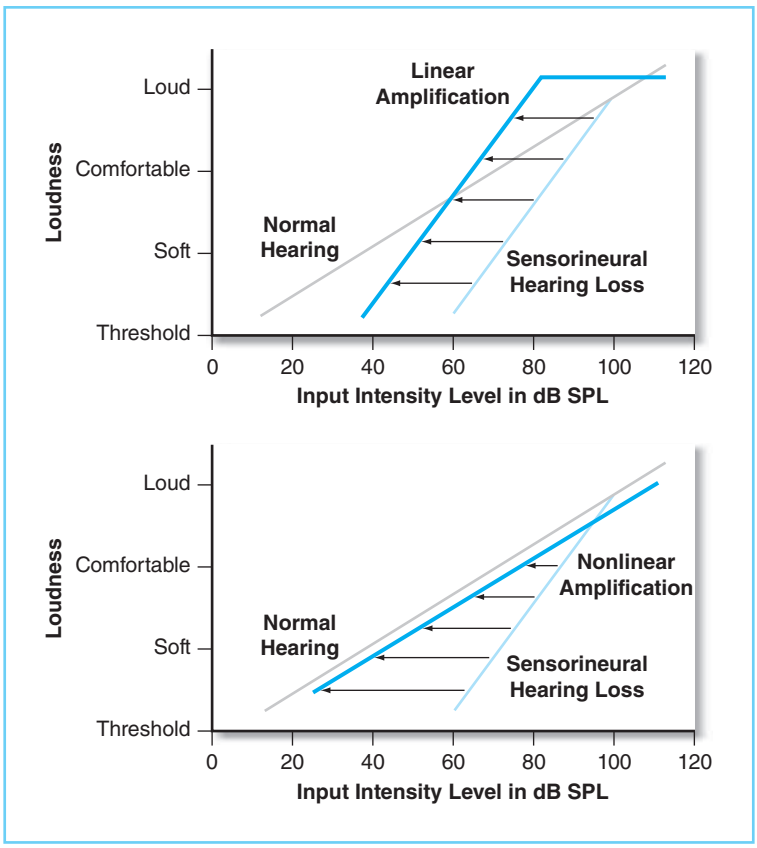


FIGURE 13-14 Schematic representation of the difference between linear and nonlinear amplification in an ear with sensorineural hearing loss and nonlinear loudness growth.

Wide dynamic-range compression has as its basis the enhanced amplification of quiet sounds and relatively reduced amplification of loud sounds. A person with a sensorineural hearing loss cannot hear soft sounds; therefore, these sounds need to be amplified. In contrast, at high levels, hearing may be essentially normal, and no amplification is needed. Thus, gain is high for low-level sounds and low for high-level sounds. These changes in gain are gradual enough throughout the dynamic range that they cannot be perceived by the listener. The overall effect is to make soft sounds audible, moderate sounds comfortable, and loud sounds loud, but not too loud.

For most systems, dynamic-range compression can be altered in multiple frequency bands. In this way, if a patient's dynamic range is reduced in one frequency range and nearly normal in another, the compression can be tailored to the frequency band where it is needed, and the other band can act as more of a linear amplifier.

Output Limiting

It is important that the output level of a hearing aid be limited to some maximum because high-intensity sounds can be both damaging to the ear and uncomfortable to the listener. Output limiting strategies are of two general types, peak clipping and compression limiting.

Peak Clipping

Peak clipping was a common early technique used to limit output. Peak clipping removes the extremes of alternating current amplitude peaks at some predetermined level. A schematic representation of this output limiting technique was shown previously in Figure 13-6.

Saturation is the level in an amplifier circuit at which an increase in the input signal no longer produces additional output.

Although peak clipping was effective in limiting hearing aid output, it produced substantial distortion when **saturation** was reached at high input levels. An alternative method is the use of compression to limit output in a more gradual manner.

Compression Limiting

Compression circuitry was developed in response to limitations inherent in peak clipping. A schematic representation of this output limiting technique was shown previously in Figure 13-7.

Many terms are used to describe compression, and it is not always easy to sort them out. One of the older terms used is *automatic gain control*, or AGC. AGC is used to describe both partial dynamic-range compression and output limiting compression.

Attack time is the amount of time it takes for compression to engage.

Release time is the amount of time it takes for compression to disengage.

The difference in these two types of compression strategies is in the threshold of activation, range over which compression occurs, ratio of input to output, and **attack** and **release time.**

Most compression parameters are adjustable, and some are automatically adjustable. The result is that compression limiting, and

compression in general, can be implemented in a flexible manner that allows patients to benefit from its effects without perception of its activation and functioning.

Signal Processing

Sophisticated, high-fidelity electronic processing of acoustic signals is commonplace in modern hearing aids. Hearing aids have progressed over the past decade from analog, to digitally controlled analog, to digital signal processing.

In analog hearing aids, acoustic signals followed an analog path that was under analog control. In digitally controlled analog (DCA) hearing aids, acoustic signals followed an analog path that was under digital control. In digital signal processing (DSP) hearing aids, acoustic signals are converted from analog to digital and back again, with digital control over various amplification parameters.

Modern hearing aids use DSP. The conversion from analog to digital occurred rapidly over the past few years but is now complete. Patients may still own older hearing aids that have analog processing, and any analog hearing aids that are still being made are likely to be digitally controlled, so it is of value for you to have a general understanding of the differences and the progression.

Analog was the predominant signal processing strategy used in hearing aids from their inception until recently. The term *analog* means that a signal is processed in a manner that is continuously varying over time. It is used in contrast to the term *digital*, in which a signal is represented as discrete numeric values at discrete moments in time. A waveform represented in analog and digital form is shown in Figure 13-15. The term *analog hearing aid* is a **neologism** that was created to describe conventional hearing aids when digital processing was introduced.

Neologism means a new word or a new meaning for an established word.

In analog processing, an acoustical signal was converted by a microphone into electrical energy in a continuously variable manner. The energy was filtered, amplified, and delivered to the hearing aid loudspeaker. Controls were mostly analog as well; for example, the volume or gain control provided adjustment along an uninterrupted continuum.

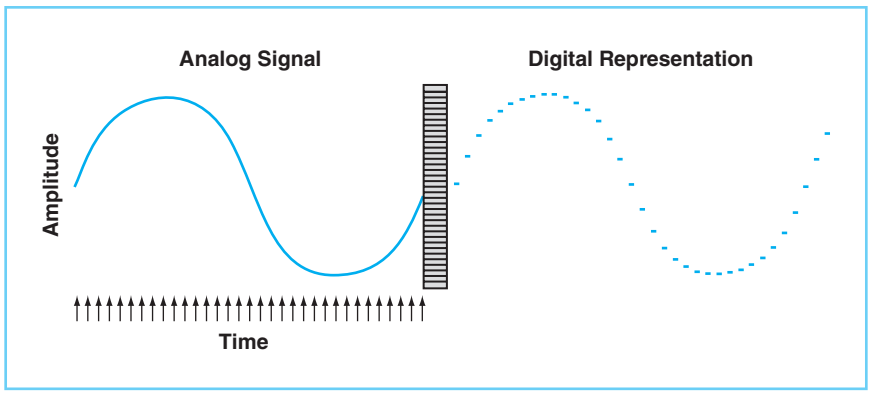


FIGURE 13-15 Schematic representation of a waveform converted from analog to digital form.

Analog signal processing was refined to deliver amplified signals with high fidelity and low distortion and to incorporate sophisticated compression-limiting and nonlinear dynamic-range compression circuitry.

There was a brief interim period of time before DSP became commonplace that a hybrid strategy was used, wherein analog signal processing was used for amplification, with digital control over the amplification parameters. Here, the acoustical-to-electrical-to-acoustical flow of energy was identical to the analog hearing aid. The difference was that adjustments to the frequency gain response, compression parameters, and other electroacoustic parameters were made under digital control.

The main advantage that digital control brought was the flexibility that resulted from the ability to program the devices. Digital control permited fine tuning of a hearing aid remotely via an interface that communicated with a personal computer or dedicated hearing aid programmer. As a result, fine adjustments could be made to the electroacoustic parameters of the hearing aid in real time while the patient was wearing the device.

In addition to a greater *range* of control, digital processing permitted a greater *number* of controls than the analog predecessor, so that gain control, frequency response, compression parameters,

output limiting, and other characteristics were under software rather than hardware control. Analog instruments, in contrast, were limited by size as to how many of these controls could be included in a single device.

The first commercially available DSP hearing aid was marketed in the late 1980s. However, due to size of the device, battery consumption, and other technological constraints of the time, the device did not gain widespread acceptance. During the same period, DCA devices were introduced, and their use became fairly routine.

In the latter part of the 1990s, DSP hearing aids were once again introduced to the market. This time, the design of the integrated circuit met the challenges of being small enough to fit in an ear-level hearing aid and having low enough power consumption to be practical.

A DSP hearing aid is different from an analog or DCA hearing aid in that the analog signals from the microphone are converted into digital form by an analog-to-digital converter. Once in digital form, the signals are manipulated by sophisticated processing algorithms and then converted back to analog form by digital-to-analog conversion. A schematic of a modern hearing aid is shown in Figure 13-16.

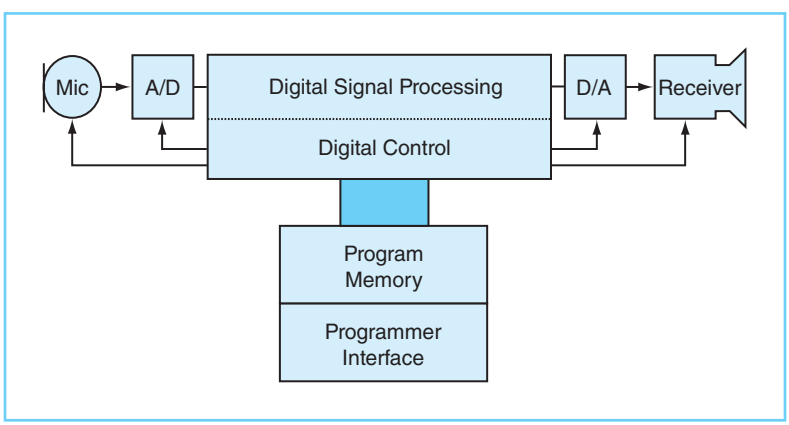


FIGURE 13-16 Schematic representation of a modern hearing aid.

Digital signal processing eliminated many of the barriers faced in trying to design analog circuits to fit in a small hearing aid and run on low-powered batteries. Indeed, the degree of sophistication of signal processing that is used in modern hearing aids is limited only by our conceptual framework of how hearing aid amplification should work.

The clinical value of real-time digital processing for achieving appropriate sound reproduction through a hearing aid became apparent quickly. Along with flexibility inherent in enhanced programmability, modern devices provide more precise and flexible frequency shaping, more sophisticated compression algorithms, better acoustic feedback reduction, and enhanced noise reduction algorithms (e.g. Kates, 2008).

Other Processing Features

Today's hearing aids include at least three electroacoustic features that make an important contribution to successful hearing aid fitting:

1. directionality,
2. noise reduction, and
3. feedback reduction.

We have already discussed directionality in terms of the use of two or more microphones. The actual hardware arrangement of these microphones allows for comparison of signals from the front and back. Under software control, decisions can be made about the strength and nature of sounds in front of and behind the patient, and the sensitivity of the microphones can be adjusted accordingly. As an example, if a patient is in a quiet environment, the aid can be programmed to be omnidirectional. When there is noise in the background, the relative sensitivity of the microphones can be adjusted to focus forward. This can be done automatically and adaptively, so that the directionality is activated when the hearing aid senses background noise and changes the amount of directionality based on the extent of the noise (e.g., Ricketts et al., 2005). Although directionality varies greatly as a function of instrument design, overall it has been found to be a very helpful feature for patients in noise.

A design goal of modern hearing aid circuitry is to reduce unwanted background noise while enhancing the signal of interest.

The biggest challenge faced in achieving this goal is that the signal of interest is usually speech but so is the background noise. All modern hearing aids have noise reduction circuitry that attempts to enhance speech and reduce noise. An example of one fundamental approach to this is that the sounds of ongoing speech are highly variable and of short duration, whereas some background noise is fairly constant in intensity and frequency. A simple DSP strategy is to reduce the gain of the hearing aid in the frequency band of the constant noise, while enhancing the gain in the frequency bands of the perceived speech. Modern strategies are gaining in sophistication and effectiveness and have been found to reduce some of the challenges that patients have hearing in noise.

Another processing strategy that has had a major impact on the fitting of modern hearing aids is acoustic feedback reduction. Acoustic feedback occurs when the amplified sound emanating from a loudspeaker is directed back into the microphone of the same amplifying system. This results in feedback, or whistling of the hearing aid. Most students are familiar with this concept from their experiences listening to public address systems. If the amplified sound of a public address system gets routed back into the microphone, a rather loud and annoying feedback occurs. You will learn later in this chapter that one of the more effective ways to reduce feedback is to physically separate the microphone from the speaker to an extent possible. Even with the most appropriately fitted hearing aids, however, feedback can still occur under certain circumstances. For example, when putting a telephone up to an ear with a hearing aid, the phone tends to direct any sound escaping from the ear canal back into the hearing aid microphone, resulting in feedback. Feedback suppression circuitry is designed to reduce or eliminate feedback by essentially searching for its resonating frequency and reducing amplification dramatically at that particular frequency (e.g., Greenberg et al., 2000; Kates, 2008; Parsa, 2006).

HEARING INSTRUMENT SYSTEMS

Aids to hearing come in many varieties. For convenience, we tend to talk about them as conventional hearing aids, hearing assistive technology, and implantable hearing technology. A conventional hearing aid is any device with the basic

Audiologist Profile

Rhiannon Workman, M.S. CCC-A



Where I Live: South Lyon, Michigan

Where I Work: Starkey Laboratories, Inc. Starkey is a worldwide company that designs, develops, and distributes comprehensive hearing solutions. The company has 35 facilities in more than 24 countries around the world, and the Starkey Hearing Research Center in Berkeley, California. Starkey is an industry leader in hearing instrument manufacturing. The Starkey staff includes researchers from a variety of fields, including engineering, psychology, audiology, neurophysiology, and psychoacoustics. Starkey provides diagnostic equipment, hearing protection products, wireless technology, and hearing solutions for every environment.

What I Do: I am the field representative for Michigan and Chicago. I spend most of my time working directly with audiologists, educating them about products and software, counseling, and fitting techniques. I regularly assist with hearing aid fittings to increase patient satisfaction. Additionally, I provide business and marketing support to assist my customers in expanding their practices and educating the community on hearing and hearing loss. In this capacity I am able to maintain individual patient care contact as well as professional relationships with many audiologists.

Why Audiology? I enjoy the diversity of experience that my work as an audiologist provides me. Whether finding a solution for a challenging hearing loss or helping colleagues grow their practices, I am consistently doing something different and rewarding.

microphone-amplifier-receiver components contained within a single package that is worn in or around the ear. An assistive device generally uses a remote microphone to deliver signals to an amplifier worn by the patient. An implantable device consists of an external microphone-amplifier-transmitter package that sends electrical signals to a receiver or electrode that has been implanted into the skull, middle ear, or cochlea.

Conventional Hearing Aids

Conventional hearing aids come in several styles and with a range of functionality. The most common styles of hearing aids

are known as behind-the-ear (BTE) and in-the-ear (ITE) hearing aids. A BTE hearing aid consists of the microphone, amplifier, and loudspeaker housed in a case that is worn behind the ear. Amplified sound is delivered to the ear canal through a tube that leads either to a custom-fitted earmold, a receiver in the canal, or some form of open-fit coupler. An ITE hearing aid has all of the components contained in a custom-fitted case that fits into the outer ear or ear canal. A device that fills the outer ear concha is known generically as an ITE. One variation is a device that is smaller and fits into the ear canal, known as an in-the-canal, or ITC, hearing aid. Another is a device that is an even smaller version that fits deeply in the canal, called a completely-in-the-canal, or CIC, hearing aid.

Behind-the-Ear

Figure 13-17 shows a picture of BTE hearing aids. The aid itself contains the microphone-amplifier-receiver in a package that hangs behind a patient's ear. The microphone is usually located on the top or on the back side of the device. External controls for patient manipulation, usually an on/off switch and volume control, are also located on the back side.

Sound emanating from the hearing aid receiver leaves through an earhook that extends over the top of the auricle and holds the hearing aid in place. From here, sound is directed through hollow tubing to some form of coupling in the ear canal.



FIGURE 13-17 Photograph of BTE hearing aids with two different styles of cases and controls. (Photos courtesy of Phonak)

The conventional approach to delivering sound to the ear canal is through use of an earmold. An earmold is a customized coupler formed to fit into the auricle. It is designed to channel sound from the earhook and tubing into the external auditory meatus. Earmolds come in a variety of shapes and sizes. Illustrations of some of the available earmold styles are shown in Figure 13-18. The acoustical properties of the sound that leaves the hearing aid are altered significantly by the tubing and earmold. Earmold and tubing modifications are often used to alter the frequency gain characteristics of the hearing aid in a controlled manner. The earmold may or may not be vented, depending on gain needs and requirements for ear canal ventilation.

An alternative to conventional BTE fitting is known as open-fit technology or open-canal fittings (for an overview, see Mueller, 2006). The term *open fit* pertains generally to the coupling within the ear canal that leaves the canal relatively unobstructed. The ear canal coupler is usually nonoccluding so that it does not completely fill the ear canal, and it is usually not a custom-made coupler.

Open-canal fittings are designed to fit high-frequency hearing loss in which hearing is normal in the low frequencies out to about 2000 Hz. The value of not occluding the ear canal is that low-frequency sound is free to pass through the ear canal in an unobstructed manner, permitting natural hearing in the lower frequencies. The higher frequencies are amplified and directed through a thin tube to a coupler in the ear canal. There is actually nothing

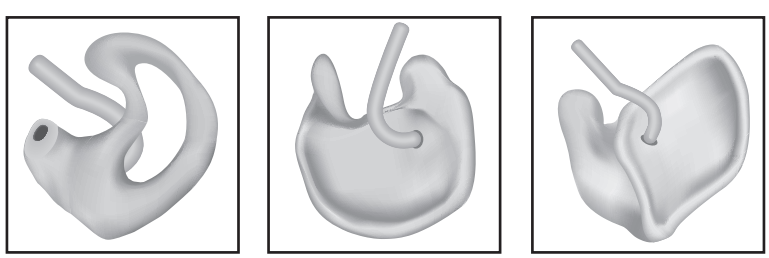


FIGURE 13-18 Illustrations of three common earmold styles. (Courtesy of Earmold Design, Inc.)

new about open-canal fittings. In the past they were known as tube fittings. Although the same concept, the application was considerably more difficult in the past due to technology limitations relating to limiting gain in the low frequency, feedback issues, and ease of fit and retention. The newer open-canal technology has effectively addressed these issues and has been very successful in fitting patients with milder, high-frequency hearing loss.

The open-fit concept has two variations. The more conventional has the receiver in the hearing aid. An example of an open-canal fit hearing aid with the receiver in the hearing aid is shown in Figure 13-19. The actual coupler of the tubing into the ear canal is usually not a custom-made coupler; rather it usually is a small sleeve or a dome-shaped coupler that comes in various sizes to fit different sized ear canals. If retention of the tubing or feedback is an issue, a custom-made coupler can be used. The more the ear canal is occluded, of course, the more the fitting resembles that of a conventional BTE.

The alternative open-fit variation has the receiver in the canal, the RIC fitting. An example of an RIC hearing aid is shown in Figure 13-20. The RIC fitting can be an open-canal fit, or it can be more of a conventional, occluded BTE fit. The advantages of



FIGURE 13-19 **Photograph of an open-canal hearing aid.** (Photograph courtesy of Oticon)



FIGURE 13-20 Photograph of BTE hearing aid with a receiver-in-the-canal (RIC) coupler. (Photo courtesy of Phonak)

moving the receiver into the ear canal is the separation of the receiver from the microphone, thereby reducing the potential for acoustic feedback and creating the opportunity for more hearing aid gain. In an RIC device, the thin tubing that is used with conventional open-canal devices is replaced by a thin wire that directs the amplifier output to the receiver.

In-the-Ear

ITE hearing aids are shown in Figure 13-21. Here, the microphone-amplifier-receiver are all contained in a custom-fitted case that fits into the concha of the auricle.

The microphone port is located on the hearing aid faceplate. This provides an advantage over BTE hearing aids in that the microphone



FIGURE 13-21 **Photograph of ITE hearing aids.** (Photograph courtesy of Oticon)

is located in a more natural location on an ITE. This advantage increases with ITC and CIC devices. External controls for patient manipulation, including a selection switch and volume control are also located on the faceplate.

An ITC or canal hearing aid is a smaller version of an ITE that tends to be fitted more deeply in the canal and extends outward into the concha to a lesser extent than an ITE. A canal hearing aid is shown in Figure 13-22.

Not unlike the ITE, the microphone ports and external controls are located on the hearing aid faceplate. Other controls, such as the computer interface port, are usually located in the battery compartment or on the inside surface of the case.

A CIC hearing aid is a small canal device that has its lateral end 1 to 2 mm inside the opening of the ear canal and terminates close to the tympanic membrane.

CIC hearing aids are shown in Figure 13-23. Here, the microphone-amplifier-receiver are all contained in a custom-fitted case that fits deeply into the ear canal. The microphone port is located on



FIGURE 13-22 Photograph of an ITC hearing aid. (Photo courtesy of Phonak)

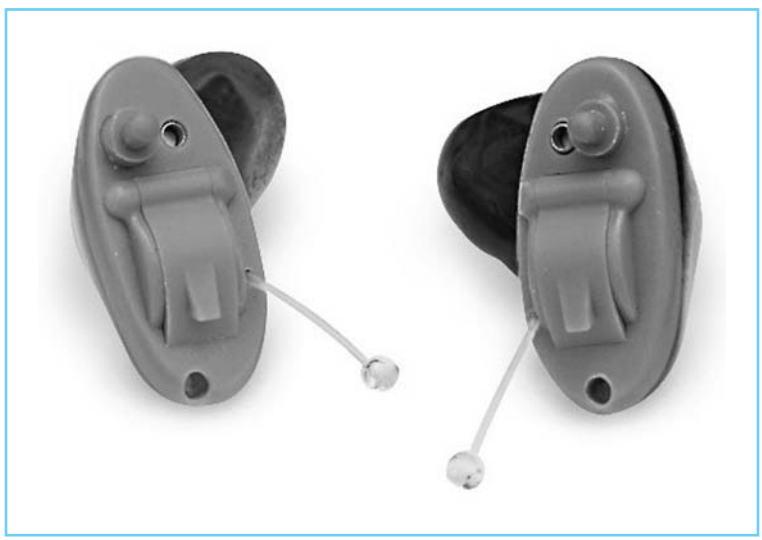


FIGURE 13-23 Photograph of CIC hearing aids. (Photo courtesy of Phonak)

the faceplate. There is also a thin filament protruding from the faceplate that serves primarily as an extraction device for the aid. Some hearing aids have this attached to a volume control for patient manipulation.

Style Considerations

Although the decision on which type of hearing aid to wear may be based on cosmetic considerations, several other factors must be considered.

Acoustic Feedback. First, there is the matter of acoustic feedback. As mentioned previously, if the amplified sound emanating from a loudspeaker is directed back into the microphone of the same amplifying system, the result is *acoustic feedback* or whistling of the hearing aid. One way to control feedback on hearing aids is to separate the microphone and loudspeaker by as much distance as possible. This solution favors the BTE hearing aid, in which the output of the loudspeaker is in the ear canal, and the microphone is behind the ear. This advantage may be enhanced with the RIC device, in which the receiver is in the canal, further separating it from the microphone. Another solution is to attempt to seal off the ear canal so that the amplified sound cannot escape and be re-amplified. The tradeoff here is usually between isolation of the microphone from the sound port and amount of output intensity that is desired. The higher the intensity of output, the more likely it is that feedback will occur. Thus, if a person has a severe hearing loss, greater output intensity is required, and greater separation of the microphone and loudspeaker will be necessary. Although electronic feedback reduction has reduced this problem to an extent, canal hearing aids are generally restricted to milder hearing losses, and more severe hearing losses benefit from the advantages of BTE hearing aids.

Occlusion. Placement of an earmold or hearing aid into the ear canal occludes the opening and creates three potentially detrimental problems. One is that it seals off the ear canal, reducing natural aeration of the external auditory meatus. In some patients, this can lead to problems associated with **external otitis.** Another problem is that plugging the ear canal creates an additional hearing loss, often referred to as **insertion loss.** This is particularly problematic in patients with normal hearing sensitivity in the low frequencies.

External otitis is inflammation of the outer ear.

The difference in SPL at the tympanic membrane with the ear canal open and the ear canal occluded by an earmold or hearing aid is called **insertion loss.**

The third problem is the occlusion effect and its impact on patients' perceptions of their own voices. Imagine if you plugged your ears and had to listen to yourself talk all day. Especially if you

have good hearing sensitivity in the low frequencies, your voice would be self-perceived as rather loud. This can be a significant problem for some patients.

A **vent** is a bore made in an earmold that permits the passage of sound and air into and out of the otherwise blocked external auditory meatus.

One solution to these problems is venting. *Venting* refers to the creation of a passageway for air and sound around or through a hearing device by the addition of a vent. A **vent** is a bore made in an earmold or in-the-ear hearing aid that permits the passage of sound and air into the otherwise blocked ear canal.

Venting creates both an opportunity and a challenge. The opportunity is that the electroacoustic characteristics of the hearing aid can be manipulated by the size and type of venting. Low-frequency amplification can be eliminated and natural sound allowed to pass through the hearing aid for patients with normal low-frequency hearing and high-frequency hearing loss. Thus, venting can be used to shape the frequency gain response in very beneficial ways. Generally, the larger the vent, the more pronounced is the effect. The challenge associated with this opportunity is related to feedback. The larger the vent, the more likely it is that amplified sound will find its way out of the ear canal and back into the microphone port. Various venting strategies can be used to reduce feedback problems, but there always remains some tradeoff between the amount of gain that can be delivered by the hearing aid and the amount of venting necessary to achieve a proper frequency gain response.

Another solution to the problems associated with occlusion is the use of open-canal fittings. Of course, the challenge of using open fittings and acoustic feedback is not unlike that encountered with venting.

Microphone Considerations

The choice of hearing aid style impacts both microphone placement and the potential effectiveness of directionality. As mentioned earlier in this chapter, our tympanic membranes are our natural microphones. Our ability to localize sound, indeed our spatial hearing in general, benefits from the natural influences of the auricle and concha. In addition, the auricle and concha increase high-frequency hearing by collecting and resonating sound above 2000 Hz. Thus, the closer the microphone is to the

tympanic membrane, the more the hearing aid can benefit from these natural influences. Conversely, the farther removed the microphone, the more the hearing aid will have to make up for the elimination of these influences.

In this way, CIC hearing aids can have a distinct advantage over other styles. In addition, by terminating close to the tympanic membrane, the residual volume of the ear canal between the end of the device and the membrane increases the sound pressure level by a significant amount across the frequency range. So the combination of the natural influences of the outer-ear structures and the deep insertion of a CIC requires less amplifier gain than a larger device to produce the same amount of amplification. Because less amplifier gain is required, feedback and distortion are reduced and battery life is increased.

Placing the microphone deeply in the ear canal has some other practical advantages, including the reduction of wind noise, ease of telephone use, and enhanced listening with headsets and stethoscopes.

One other microphone consideration relates to directionality. The best directionality is achieved in hearing aids by using two microphones, placed some distance apart. The effectiveness of directionality increases with distance, so that the farther apart the microphones are from each other, the better is the directional effect. This clearly favors larger hearing aids such as ITEs and BTEs. Because these larger devices have microphones that are farther removed from the tympanic membrane, directionality is more necessary than for CICs, so the increased effectiveness should provide some balance in terms of style consideration.

Durability

A final style consideration relates to durability of the instruments. In ITC and CIC instruments, all of the electronic components are placed within the ear canal and subjected to the detrimental effects of perspiration and cerumen. As a result, repair rates and downtime can be considerably greater for these smaller devices. This is frustrating to many patients and must be considered in the selection process.

Hearing Assistive Technology

Amplification systems other than conventional hearing aids have been designed for more specific listening situations. These devices are known collectively as hearing assistive technology (HAT) and include assistive listening devices (ALDs), alerting devices, signaling devices, and telephone amplifiers. Assistive devices are usually not used as general purpose amplification devices; rather, they are used as situation-specific amplification in a particular listening environment or situation.

Assistive Listening Devices

Among the devices considered to be ALDs are personal amplifiers, FM systems, and television listeners. In general, these devices are designed to enhance an acoustic signal over background noise by the use of a remote microphone. That is, rather than the microphone being built into the same case as the amplifier and receiver, it is separated in some way to close the gap between the signal source and the listener.

At least three categories of patients benefit from the use of ALDs. One category includes patients who simply do not receive sufficient benefit from their conventional hearing aids. As a general rule, individuals who have more severe hearing losses often find that supplementing hearing aid use with ALDs is necessary under certain circumstances. Other individuals, because of communication demands in their workplace or social life, welcome the additional use of ALDs. A second category includes patients who have amplification needs that are so specific that the general use of a hearing aid is not indicated. For example, some individuals feel as if their only communication problems occur when viewing television or attending church. For those individuals, an ALD tailored to that particular need is often an appropriate alternative to a conventional hearing aid. A final category includes patients who have hearing disorders due to changes in central nervous system function. The resulting auditory processing disorder is not necessarily accompanied by a loss in hearing sensitivity, but rather is characterized by difficulty understanding speech in background noise. For these patients, use of a remote microphone for enhancement of signal-to-noise ratio is more appropriate than amplification from a conventional hearing aid.

Hearing in the presence of background noise remains a problem for individuals with hearing loss and for those who wear conventional hearing devices. Strides have been made over the last few years to address this issue. In conventional ear-level hearing aids, the introduction of sophisticated compression strategies has enhanced listening in noise, as has the use of directional microphone systems. Despite this progress, some patients need additional assistance with hearing in unfavorable listening situations. In these patients, use of remote-microphone technology can provide substantial assistance.

Personal FM Systems

One type of ALD is a personal FM system. A photograph of a personal FM system is shown in Figure 13-24. The system consists of two parts, a microphone-transmitter and an amplifier-receiver.



FIGURE 13-24 Photograph of a personal FM system, including a transmitter (A), an ear-level receiver (B), and a neck-loop receiver (C). (Photos courtesy of Phonak.)

The microphone is connected to, or is a part of, the case that contains the FM transmitter. The person who is talking wears the microphone and transmitter. Signals from the transmitter are sent to a receiver via FM radio waves. The listener wears the amplifier-receiver, which acts like a FM radio and "picks up" the transmitted signal. The receiver is usually integrated into the hearing aid or coupled to the listener's ear via earphones or to hearing aid t-coils via a neck loop that transmits the signal.

The obvious advantage of this type of remote-microphone, personal FM system is that the listener's ear is no farther from the speaker than the microphone is from the speaker's mouth. Thus, the gap from the speaker to the listener is bridged, thereby eliminating the influence of all the intervening noise. This idea of signal-to-noise ratio enhancement is shown in Figure 13-25.

By detaching the microphone from the remainder of the amplification device, certain listening situations that can be very difficult for a patient using a conventional hearing aid are made much easier. These situations include listening in a classroom, restaurant, car church, theatre, or in a party situation.

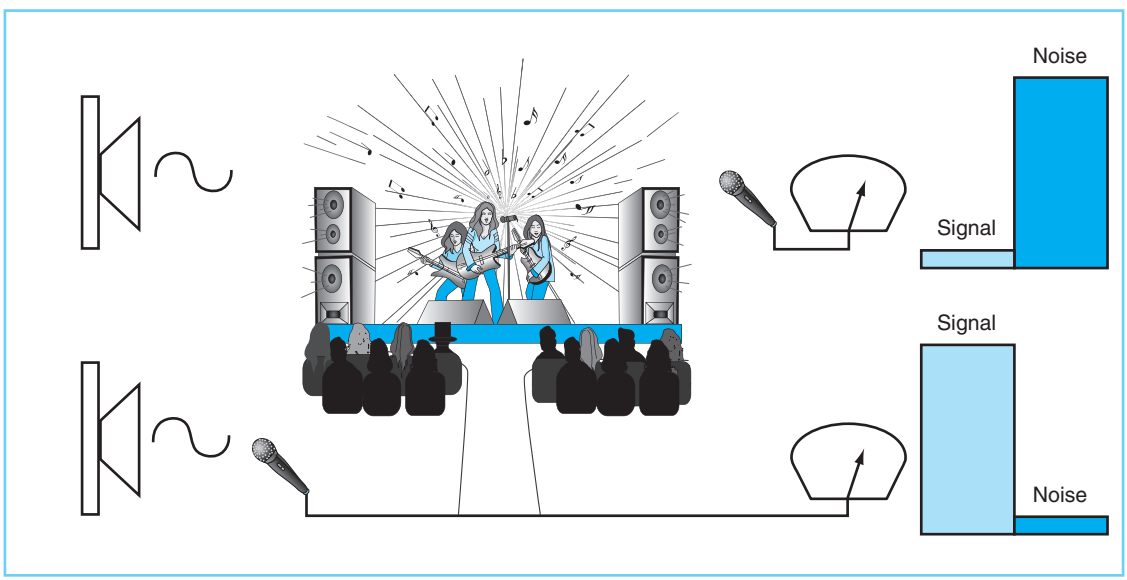


FIGURE 13-25 Schematic representation of the enhancement of signal-to-noise ratio by placing the microphone closer to the signal source.

Advances in both transmitter and receiver technology have placed remote-microphone technology into the mainstream. Some transmitters have sophisticated **array microphones**, which are designed for directionality. The transmitter can be enclosed in a small handheld case that can be directed at a sound source or handed to a speaker during communication in a noisy environment. FM transmitters can also be included in hearing instrument remote controls. Similar advances have been made on the receiver portion of the FM system. Entire FM receiver systems can be integrated into a conventional BTE or ITE hearing device or other coupler. An example of an FM "boot" or coupler for a BTE is shown in Figure 13-26. As these transmitters and receivers have become more practical and advanced, the use of remote-microphone technology has become a more common option.

An array is an orderly grouping. An **array microphone** system contains multiple microphones aligned in a row, designed for directionality.

Other Remote Microphone Systems

Personal FM systems are considered general purpose remote-microphone systems. Other systems are designed as instruments dedicated to a single purpose, such as television viewing. Television listeners are similar in concept to the FM system, except that the



FIGURE 13-26 Photograph of an FM "boot" on a BTE hearing aid. (Photo courtesy of Phonak)

transmitter is connected directly to the television. Audio signals from the television are transmitted, either by FM or by infrared light waves, to a dedicated receiver that is worn by the patient.

These types of dedicated systems are installed in many theaters. The transmitter is interfaced to the sound system of the theater, and patrons can request the use of a receiver during a performance. Again, some of the systems use FM waves as the carrier of the signal, and others use infrared light waves. Regardless, the effect is to bring the sound source closer to the listener's ear.

Personal Amplifiers

Another type of assistive listening device is called a personal amplifier. A photograph is shown in Figure 13-27.

A personal amplifier consists of a microphone that is connected to an amplifier box, usually by a cord. The microphone is held by the person who is talking. The signal is then routed to a small case, which is often about the size of a deck of cards. The box contains the battery, amplifier electronics, and volume control.

The loudspeaker is typically a set of lightweight headphones or an ear-bud transducer. By separating the microphone from the amplifier, it can be moved closely to the signal of interest. In doing so, the signal-to-noise ratio is enhanced.

Personal amplifiers are often used as generic replacements for conventional hearing aids in acute listening situations. A common example of personal amplifier use is in a hospital. Patients who are in the hospital without their hearing aids or who have developed hearing loss while in the hospital may need amplification during their stay. The personal amplifier provides a good temporary solution. A physician who specializes in geriatric treatment will often carry a personal amplifier while making rounds in case it is needed to communicate with a patient. Another common use for a personal amplifier is the patient receiving **palliative care** who needs amplification only on a temporary basis.

Palliate means to lessen the severity of without curing; **Palliative care** is that which is provided to patients with terminal illnesses.

Other Assistive Technologies

Assistive devices come in other forms as well. Telephone amplifiers are popular and are available in several forms. Some handsets have



FIGURE 13-27 Photograph of a personal amplifier. (Courtesy of Williams Sound®)

built-in amplifiers with a volume control. There are also portable telephone amplifiers that can be attached to any phone. The telephone receiver can also be adapted to transmit over FM waves to a personal FM system. There are also amplified receivers for mobile phones that communicate by Bluetooth or other wireless technology.

Other assistive technology available to individuals with hearing impairment has been designed to replace what is typically an acoustic signal with a different signal that can be perceived by one of the other senses. One of the most commonly used assistive device is a text telephone, whereby communication over the telephone lines is achieved by typing messages. Another type of assistive device is closed captioning of television shows. Closed captioning presents the dialogue of a television show as text along the bottom of the television screen. Other assistive technology includes alerting devices, such as alarm clocks, fire alarms, and doorbells, which are designed to flash a light or vibrate a bed when activated.

Implantable Hearing Technology

Three types of hearing devices are surgically implanted: cochlear implants, bone-anchored hearing aids, and middle-ear implants. In most cases, there are two components to the implant, one a device that is implanted in the ear or skull and the other an external device that delivers signals to the implant. The most common implantable device is the cochlear implant, which is used in patients who have hearing disorder severe enough to preclude successful use of conventional hearing aids. Bone-anchored hearing aids are used for patients with inoperable conductive loss or for single-sided deafness. Middle-ear implants are an emerging technology aimed primarily at patients with moderately severe to severe hearing loss.

Cochlear Implants

Individuals who have severe or profound deafness and do not benefit from conventional amplification are candidates for cochlear implants (for a comprehensive review, see Waltzman & Roland, 2007). Profound deafness results from a loss of hair cell function in the cochlea. As a result, neural impulses are not generated, and electrical activity in the auditory nerve is not initiated. A cochlear implant is designed to stimulate the auditory nerve directly. An electrode array is surgically implanted into the cochlea. The electrode array is attached to a magnet that is implanted into the temporal bone. Acoustic signals are received via a microphone attached to a sophisticated amplifier. The amplifier then sends signals to the electrode via the implanted magnet/receiver. When the

electrode receives a signal, it applies an electrical current to the cochlea, thereby stimulating the auditory nerve.

Cochlear implants are different from conventional hearing aids in that hearing aids simply amplify sound, whereas cochlear implants bypass the cochlear damage and stimulate the auditory nervous tissue directly. The potential advantages for patients with severe and profound hearing loss are numerous and include better high-frequency hearing, enhanced dynamic range, better speech recognition, and no acoustic feedback problems.

The major conceptual and technological advances in cochlear implantation are shown schematically in the technology pyramid in Figure 13-28. The first cochlear implant was a single electrode. It received fairly straightforward linear, analog processing from a

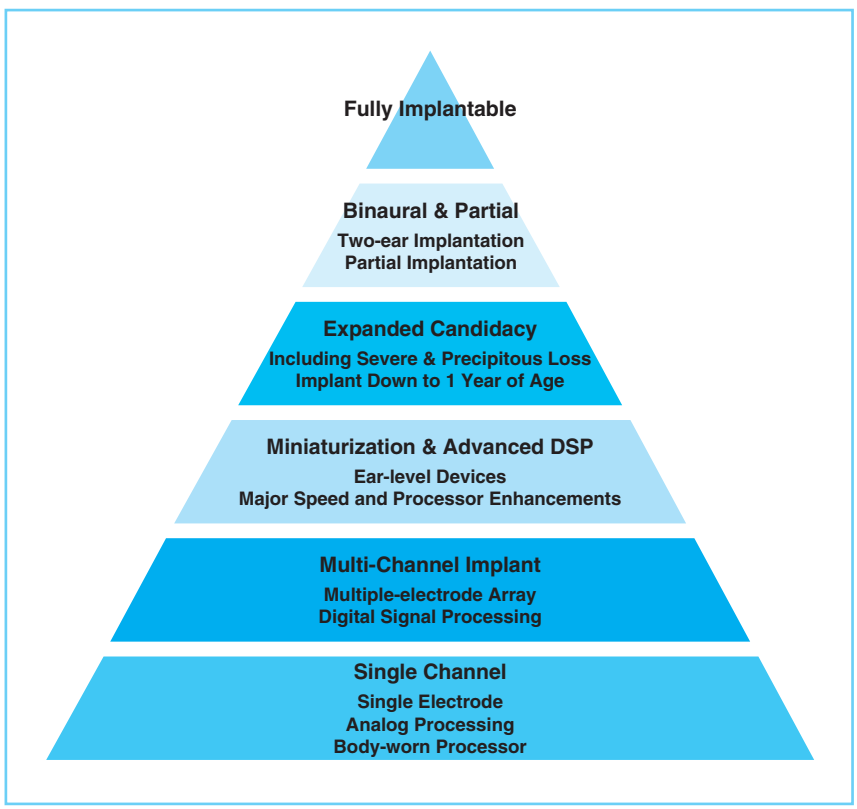


FIGURE 13-28 The conceptual and technological progress of cochlear implants.

body-worn amplifier. In the early days, the expectations were that the individual with deafness would benefit from sound awareness and that the device would serve as a useful aid to lipreading. The next major step was technological, with the development of a multichannel, multielectrode array with digital signal processing. With general technological advances relating to power supply and computer processing capacity and speed came more sophisticated algorithms for signal processing and for delivering the signals more effectively to the electrode array. The external processors also shrunk considerably in size. Along with these technological advances, it became apparent that the cochlear implant could be far more than just an aid to lipreading. Soon patients were able to have open-set speech recognition and even talk on the telephone with an implant. Success in adults lead to trials in children, and implants quickly became the standard of care for hearing treatment of young children with deafness. Implant use became so generally successful and widely accepted that it came to be applied to some patients with less hearing sensitivity loss if they could not benefit from conventional amplification. Today, many patients seek binaural implantation, and devices have been developed for partial implantation of those with precipitous hearing loss. Fully implantable cochlear implants are emerging from clinical trials.

Over the years, cochlear implants have been shown to be valuable in two groups of patients. Adults who have lost their hearing-**adventitiously** can derive substantial benefit from a cochlear implant. Young children with adventitious hearing loss or with congenital hearing loss that is identified early can also benefit substantially from a cochlear implant, especially when implanted at an early age.

A person who has lost his or her hearing **adventitiously** did so after acquiring speech and language.

Internal Components

The surgically implanted portion of a cochlear implant has two components, a receiver and an electrode array. A photograph of the implant is shown in Figure 13-29. The receiver is surgically embedded into the temporal bone. The electrode array is inserted into the round window of the cochlea and passed through the cochlear labyrinth in the scala tympani, curving around the modiolus as it moves toward the apex. A schematic drawing of the electrode array in the cochlea is shown in Figure 13-30.

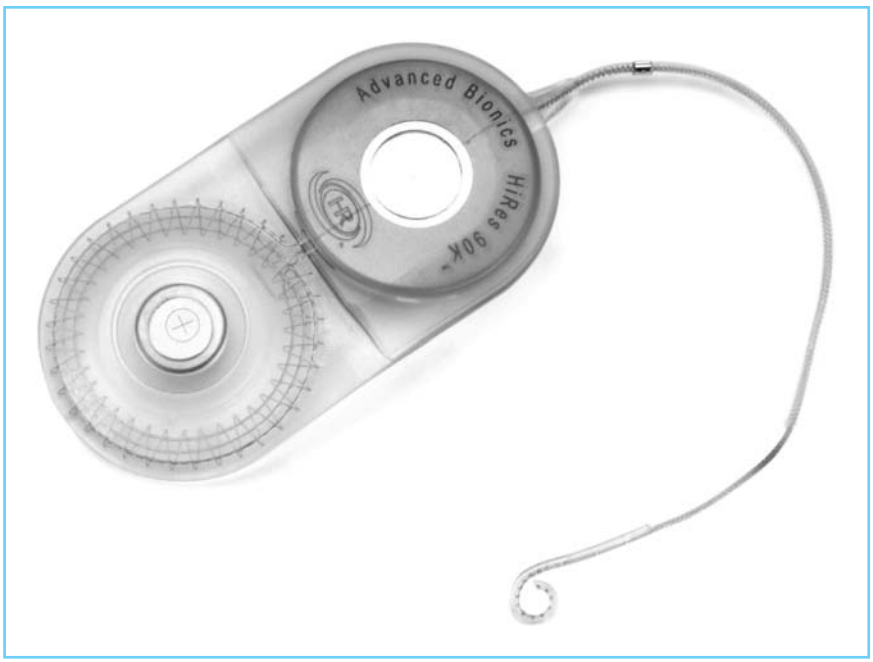


FIGURE 13-29 **Photograph of a cochlear implant receiver and electrode array.** (Courtesy of Advanced Bionics® Corporation)

The receiver is essentially a magnet that receives signals electromagnetically from the external processor. The receiver then transmits these signals to the proper electrodes in the array. The electrode array is a series of wires attached to electrode stimulators that are arranged along the end of a flexible tube. The electrodes are arranged in a series, with those at the end of the array nearer the apex of the cochlear and those at the beginning of the array nearer the cochlea's base.

External Components

The external components of a cochlear implant are similar to those of a conventional hearing aid. The microphone is located in an ear-level device. Output from the microphone is routed to an amplifier that uses digital signal processing. The amplified signal is delivered to a receiver, which, in this case, delivers signals to a transmitter coil. The transmitter coil has a magnet which holds

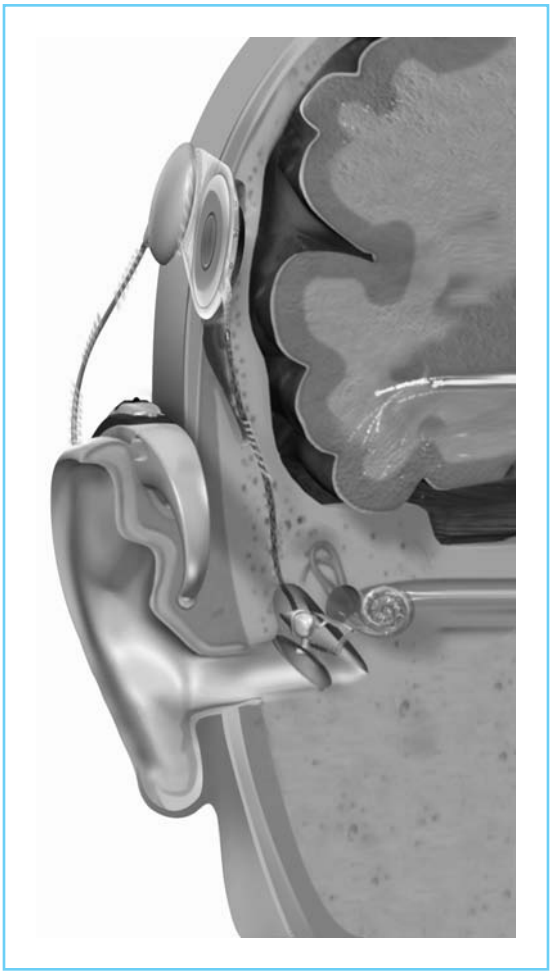


FIGURE 13-30 Schematic representation of an electrode array in the cochlea. (Courtesy of Advanced Bionics® Corporation)

it against the skin opposite to the internal receiver. The signal is then transmitted electromagnetically across the skin.

Photographs of the external components of a cochlear implant are shown in Figure 13-31. Because of the sophisticated nature of signal processing and the power needed to drive the electromagnetic coupling, these external components are often contained in a body-worn case. Ear-level processors can also be used, subject to processing and power consumption constraints.

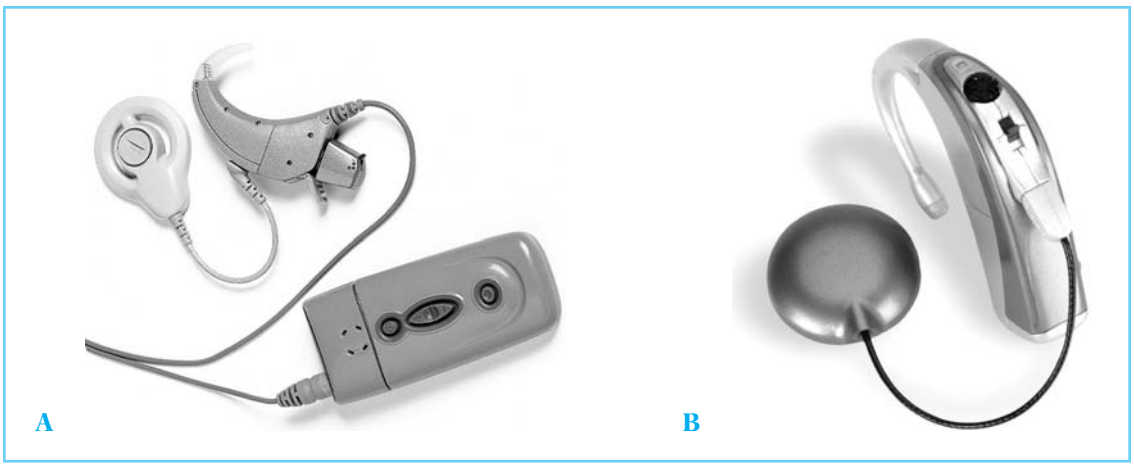


FIGURE 13-31 Photograph of the external components of two implant systems, (A) one with a body-worn processor (photo courtesy of Phonak) and (B) the other with an ear-level processor (photograph courtesy of Advanced Bionics® Corporation).

Signal Processing

Signal processing strategies used in cochlear implants are sophisticated algorithms designed to analyze speech into salient features and deliver the relevant parameters to the electrode array.

The strategies are numerous and complex, but all are based on analyzing frequency, intensity, and temporal cues from the speech signals and translating them to the electrode array in a manner that can be effectively processed by the residual neurons of the auditory nerve.

A simple example of the processing that can be done may be helpful in understanding the potential of cochlear implant signal processing. The spatial characteristics of the electrode array permit some degree of frequency translation to the ear. High-frequency information can be delivered to the basal electrodes, and low-frequency information can be delivered to the apical electrodes. The amount of stimulation of each electrode can be used to translate intensity information to the ear. In this way, the speech processor can detect and extract frequency and intensity information and deliver it at a specified magnitude to an electrode corresponding to the frequency range of the signal.

Bone-Anchored Hearing Aids

A bone-anchored hearing aid (BAHA) is a very different strategy from a cochlear implant and is intended for a very different population of patients. A BAHA consists of a titanium screw that is surgically placed into the mastoid bone. An external amplifier that is essentially a bone vibrator is snapped into the screw and sends vibratory energy to the screw, which in turn stimulates the cochlea via bone conduction.

A schematic drawing of how a bone-anchored hearing aid works is shown in Figure 13-32. The external device has a microphone, a battery, an amplifier, and a vibrating transducer. A basic linear amplifier is used to stimulate a normal or near-normal cochlea. The implant itself is simply a piece of metal that is sunk into the skull to help the bone vibrate efficiently.

At least two groups of patients benefit from the BAHA, patients with intractable or inoperable conductive hearing loss and patients with single-sided deafness (McLarnon et al., 2004). Patients with conductive hearing loss include those with atresia that has not or cannot be

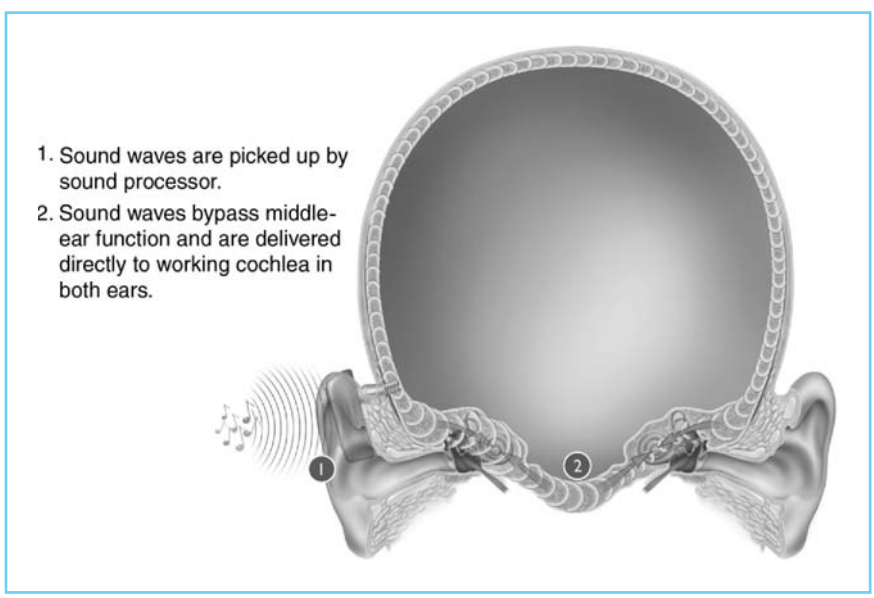


FIGURE 13-32 Schematic drawing of the BAHA external amplifier and implantable transducer, stimulating both cochleae via bone conduction. (Photography courtesy of Cochlear Americas)

surgically repaired or patients whose conductive losses can no longer be surgically repaired, usually due to multiple operations or long-standing disease process. Although the BAHA is an efficient vibrator of the skull and, thus, stimulator of the cochlea, there are limits to how much gain it can provide. As a result, cochlear sensitivity has to be reasonably adequate for optimum effectiveness. When it is, the BAHA is a very beneficial approach in these patients.

The other problem that can be addressed with a BAHA is profound unilateral hearing loss or single-sided deafness. Here the BAHA is acting as a CROS, or contralateral-routing-of-signal, hearing aid. That is, the device is implanted on the side with the hearing loss. Its microphone picks up sound on that side and transmits it to the other ear via bone conduction. To the extent that unilateral hearing loss is troublesome to an individual patient, the BAHA can be a very effective amplification solution.

Middle-Ear Implants

A third type of implantable hearing device is the middle-ear implant (for a review, see Wiet et al., 2003). The implants are of several varieties but are intended for the same purpose, to treat sensorineural hearing loss. The basic strategy behind a middle-ear implant is to drive the ossicles with direct stimulation so that they, in turn, deliver the vibratory energy to the cochlea.

Efforts have been made over the last few decades to perfect the technique for ossicular stimulation with varying degrees of success. One approach to middle-ear implantation is to affix a magnet to some portion of the ossicular chain and then drive the magnet to vibration through a neck loop or a coil worn on the head. The vibratory energy of the magnet sets the ossicles in motion and stimulates the cochlea.

Another approach is to place a small piston on the ossicles and drive them with the motion of the piston. There is a partially implantable version of this device that has an external unit to receive sound and deliver it to the internal processor. There is also a fully implantable version of this middle-ear device.

Another approach to middle-ear implantation is a fully implantable strategy that essentially uses the tympanic membrane as

the microphone. A small vibrator, called a piezoelectric crystal is attached to the malleus and is stimulated by tympanic membrane movement. The signal from the vibrator is then amplified and delivered to a similar driver that is attached to the stapes. A schematic of this middle-ear implant is shown in Figure 13-33.

Most patients who seek middle-ear implantation have moderately severe or severe hearing losses, losses that are significant enough to be a challenge for conventional hearing aids but not enough to require a cochlear implant. There are some real and some potential advantages to this approach. A totally implantable hearing aid can be worn all of the time (to bed, in the shower), cannot be seen, and has no acoustic feedback. The approach that uses the tympanic membrane as the microphone has the added advantage of preserving the spatial hearing cues of outer and middle ears. One advantage that seems to be universally applicable to this approach regardless of technique is that patients report that the devices delivery exceptional sound quality.

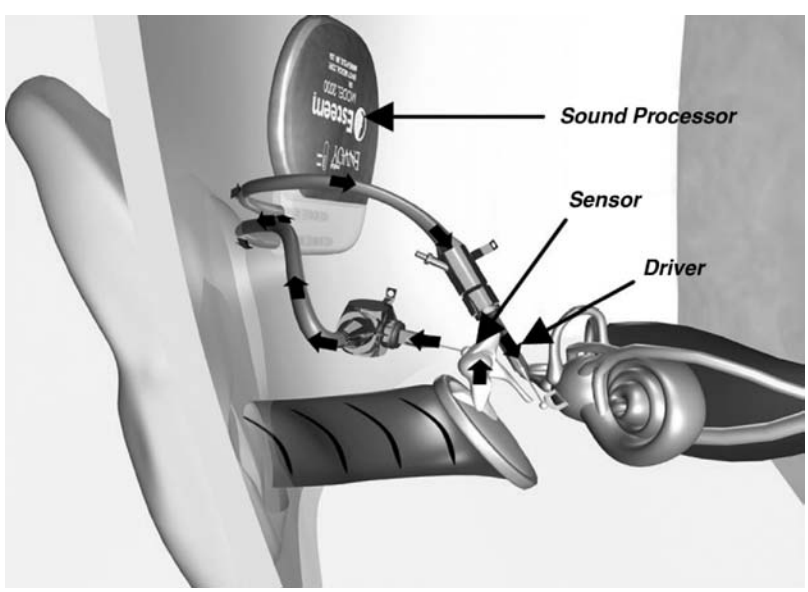


FIGURE 13-33 Schematic drawing of a fully implantable middle-ear device. (Courtesy of Envoy Medical)

Because middle-ear surgery of this nature is challenging and because of the costs and risks of surgery, middle-ear implantation does not yet enjoy widespread application. It seems only a matter of time before technological advances will make this a more readily available approach and one that is applicable to a wider range of patients.

Summary

- A hearing aid is an electronic amplifier that has three main components: a microphone, an amplifier, and a loudspeaker.
- A microphone is a transducer that changes acoustical energy into electrical energy.
- The heart of a hearing aid is its power amplifier, which boosts the level of the electrical signal that is delivered to the hearing aid's loudspeaker. The amplifier controls how much amplification occurs at certain frequencies.
- The loudspeaker is a transducer that changes electrical energy back into acoustical energy.
- The various output parameters of a hearing aid amplifier can be manipulated by software control.
- The acoustic response characteristics of hearing aids are described in terms of frequency gain, input-output, and output limiting.
- The frequency gain response of a hearing aid is the amount of gain as a function of frequency.
- The input-output characteristic of a hearing aid is the amount of gain as a function of the input intensity level.
- Output limiting refers to the maximum intensity of the amplified signal and is controlled by compression limiting, which reduces output gradually as a function of its intensity.
- In modern hearing aids, acoustic signals are converted from analog to digital and back again, with digital control over various amplification parameters.
- A conventional hearing aid is any device with the basic microphone-amplifier-receiver components contained within a single package that is worn in or around the ear. The most common styles of conventional hearing aids are known as behind-the-ear and in-the-ear.

- An assistive listening device generally uses a remote microphone to deliver signals to an amplifier worn by the patient. Among the devices considered to be ALDs are personal amplifiers, FM systems, and television listeners.
- A cochlear implant consists of an external microphone-amplifier-transmitter package that sends electrical signals to a receiver or electrode that has been implanted into the cochlea.

Short Answer Questions

1. When soft, medium, and loud sounds are all amplified by a hearing aid to the same extent, this is known as _____ amplification. _____ amplification occurs when soft sounds are amplified more than loud sounds.
2. The method by which the maximum output of a hearing aid is capped is known as _____ limiting.
3. In the _____ _____ method of output limiting, peaks of signals do not exceed a certain predetermined level.
4. In the _____ _____ method of output limiting, amplification becomes nonlinear as input signals reach higher level so amount of gain diminished significantly at maximum output level. Because this method introduces less _____, it is the standard method of output limiting for modern hearing aids.
5. Nonlinear amplification is accomplished by the use of _____ circuitry.
6. One feature available on most modern hearing aids is _____ _____, which allow for different response parameters for different listening situations.
7. An _____ microphone is sensitive to sound from all directions.
8. The presence of two or more _____ on hearing aids allows for hearing aids to focus in space by enhancing signals in front and reducing those coming from behind. These microphones are known as _____ microphones. Their use allows patients to hear better in _____.
9. In _____ processing, the signal is processed in a manner that is continuously varying over time. In _____

processing, the signal is represented as discrete numeric values at discrete moments in time.

10. The three main components of any hearing aid are the _____, _____, and _____.
11. A _____ is a vibrator that moves in response to pressure waves of sound. It converts an acoustical signal into an _____ signal.
12. A _____, a device available in most hearing aids, picks up electromagnetic signals directly, bypassing the hearing aid microphone. This allows for direct input from devices such as _____ receivers.
13. An _____ is a device that increases the strength of an electrical signal.
14. Hearing aid amplifiers shape the _____ _____ of a hearing aid to match the configuration of the hearing loss by differentially amplifying frequency bands.
15. A _____ is a device that converts an electrical signal back to an _____ signal to be delivered to the ear.
16. The amount of sound added to the input signal is known as the _____ of the hearing aid.
17. A plot of output intensity level as a function of input intensity level for a given frequency is known as an _____-_____ function.
18. The _____ _____ for an individual is the decibel difference between the level of threshold of hearing sensitivity and the level causing discomfort. The dynamic range for normal listeners is about _____ dB.
19. The amount of time taken for compression to engage is known as _____. The amount of time taken for compression to disengage is known as _____.
20. The phenomenon of _____ occurs when amplified sound emanating from a loudspeaker is directed back into the microphone of the same amplifying system.
21. The custom-fitted device that delivers amplified sound to the ear canal and couples a behind-the-ear hearing aid to the ear is known as the _____.
22. The addition of a bore made in the earmold or hearing aid which permits passage of sound and air in an otherwise

blocked ear canal, is known as _____. The _____ properties of the hearing aid output are changed with venting.

23. The use of personal _____ systems allows a signal from a microphone worn by the speaker to be delivered to the receiver worn by the listener via frequency modulated radio waves. This eliminates detrimental effects of _____ and intervening _____ on the acoustic signal.
24. A _____ _____ consists of a surgically implanted electrode array in the cochlea, a _____ implanted in the temporal bone, and a microphone, amplifier, receiver, transmitter coil, and _____ processor worn on the body.
25. A cochlear implant is appropriate for a patient with a hearing disorder _____ enough to preclude successful use of conventional hearing aids.
26. A _____-_____ hearing aid consists of a titanium screw surgically placed in the mastoid bone and an external amplifier snapped into the screw that sends vibratory energy to the cochlea.
27. A bone-anchored hearing aid is appropriate for a patient with inoperable _____ hearing loss or _____ -sided deafness.

Discussion Questions

1. Describe the major components of a hearing aid.
2. Describe how hearing aid technology has changed over time.
3. Explain how compression limiting has advantages over peak clipping as a method for limiting the output of a hearing aid.
4. What is acoustic feedback? How is this prevented in hearing aids?
5. How does digital signal processing differ from analog signal processing? What advantages does digital processing have over analog signal processing?

6. Describe directional microphone technology. What advantage does directional microphone technology have over only omnidirectional microphone technology?
7. List and describe some of the features available in current hearing aids. Why might an audiologist want to limit the number of features available for a given patient?
8. List and describe the components of a cochlear implant. Who is a candidate for a cochlear implant?

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14

THE AUDIOLOGIC TREATMENT PROCESS

Learning Objectives

Hearing Aid Selection and Fitting
- The Prescription of Gain
- Hearing Instrument Selection
- Hearing Instrument Fitting and Verification

Orientation, Counseling, and Follow-up

Assessing Outcomes

Post-fitting Rehabilitation
- Auditory Training and Speechreading
- Educational Programming

Summary

Short Answer Questions

Discussion Questions

Resources

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- Describe the factors that contribute to hearing aid selection.
- Explain how ear impressions are made.
- Describe quality control procedures for assessing hearing aid function.
- Explain the strategies used for verification of hearing aid fittings.
- Provide reasonable expectations for hearing aid use.
- List and describe post-fitting measures of hearing aid success.
- Describe post-fitting rehabilitation/habilitation.

THE fundamental goal of audiologic management is to reduce the communication problems that result from hearing loss. The first step in that process is to maximize the patient's access to sound. Once that is achieved, audiologic management often proceeds with some form of aural rehabilitation.

As you learned in Chapter 13, there are innumerable options for audiologic treatment of hearing loss, including conventional hearing aids, cochlear implants, assistive listening devices, and so on. By far, the most common first treatment option for making sound more accessible is the use of conventional hearing-aids.

Once the needs assessment has been done, the style and options for hearing aids are selected, and the process of hearing aid fitting begins.

HEARING AID SELECTION AND FITTING

Hearing aids are selected and fitted based on an individual's communication needs, degree of hearing loss, audiometric configuration of the loss, loudness discomfort levels, and other factors relating to style choice. Impressions are then made of the ear canal for custom earmolds or hearing aids. Once the hearing aids and/or earmolds are received from the manufacturer, the aids are subjected to quality control of both form and electroacoustic function. The hearing aids are then programmed based on the patient's audiometric outcomes and needs. Verification of the frequency response is usually made by **probe-microphone measurement**.

Probe-microphone measurement is an electroacoustic assessment of the characteristics of a hearing aid at or near the tympanic membrane using a probe microphone.

A small microphone is placed near the tympanic membrane, and the responses of the hearing aids to speech or speech-like sounds are determined for different levels of input. The hearing aids are then adjusted so that the responses approximate the desired targets. The electroacoustic analysis is verified further with formal or informal assessment of quality, loudness, and/or speech perception. The hearing aids may then be adjusted again if perceptual expectations are not met. Thus, the process of hearing aid selection and fitting usually follows this course:

1. selection
2. quality control
3. programming
4. verification
5. adjustment

The Prescription of Gain

The process of selection and fitting of hearing aids changed abruptly with the advent of digital hearing aids. Because of the inherent flexibility of the digital signal processing platform of modern hearing aids, a given hearing aid can be programmed to fit a wide range of degree and configuration of hearing loss. This was not always the case.

In the past, we selected the actual device or hearing aid circuit to match what we thought a patient's hearing loss might require. The first step in the hearing aid selection process back then was to determine the target frequency gain responses based on the audiogram. Once the target was determined, the audiologist would browse through a book of hearing aid specifications and find gain characteristics that approximated the prescribed target. A hearing aid was then ordered with circuitry that seemed to have the best match.

Today, in general, the factor that separates one hearing aid from another is related to features and processor algorithms rather than to the frequency gain response of the hearing aid. This is a fundamental change. Now we select hearing aids based on their features and program them to deliver a response that matches the prescriptive targets.

The targets have changed as well, due in part to enhanced knowledge and in part to enhanced opportunity. The opportunity to program hearing aids in a very flexible way now permits targeting over a wide range, requiring us to understand better what those targets should be.

It is useful to have a basic understanding of the evolution of the prescriptive approach to better understand the approaches of today (for a review, see Sammeth & Levitt, 2000). The earliest approach to what was known as selective amplification was to prescribe frequency gain characteristics based on audiometric thresholds.

A threshold-based prescriptive method is designed to specify frequency gain characteristics that will amplify average conversational speech to a comfortable or preferred listening level. The underlying assumption here is that the audiogram can be used to predict this comfort level. A number of prescriptive rules were developed over the years for this purpose. As an example, the half-gain rule prescribes gain equal to one-half the amount of hearing loss; a third-gain rule to one-third of the loss. Most prescriptive rules started with this type of approach and then altered individual frequencies based on some empirically determined correction factors.

An example might be helpful. One popular early threshold-based procedure, which still serves as the basis for some approaches today, was that of the National Acoustic Laboratory (NAL) (Byrne & Dillon, 1986). The early NAL-R formula expressed gain as the amount of hearing loss (HL) as follows:

$$250\ \text{Hz} = (0.31 \times \text{HL}) - 17\ \text{dB}$$

$$500\ \text{Hz} = (0.31 \times \text{HL}) - 8\ \text{dB} + (0.05 \times \text{HL})$$

$$1000\ \text{Hz} = (0.31 \times \text{HL}) + 1\ \text{dB} + (0.05 \times \text{HL})$$

$$2000\ \text{Hz} = (0.31 \times \text{HL}) - 1\ \text{dB} + (0.05 \times \text{HL})$$

$$3000\ \text{Hz} = (0.31 \times \text{HL}) - 2\ \text{dB}$$

$$4000\ \text{Hz} = (0.31 \times \text{HL}) - 2\ \text{dB}$$

$$6000\ \text{Hz} = (0.31 \times \text{HL}) - 2\ \text{dB}$$

The result is the targeted gain at each frequency. Figure 14-1 shows the amount of gain that would be prescribed for a hearing loss using this approach.

Efforts were also made to prescribe gain based on threshold and discomfort levels. One early notable effort that has also stood the test of time is the desired sensation level (DSL) method (Seewald, 1992). The DSL was originally designed for fitting hearing aids in children. It prescribed gain based on both thresholds and discomfort levels, which were predicted from those thresholds. A newer alternative, the DSL[i/o] was designed to enhance audibility of soft sounds (Cornelisse et al., 1995) and is used in many modern fitting systems.

As signal processing technology improved, the need grew to develop improved prescriptive formulas. For example, prescriptive procedures were developed in response to wide dynamic range compression amplifiers. In these approaches, targets were determined for soft, moderate, and loud sound (VanVliet, 1995). More recent procedures combine the linear approach of the early threshold-based prescription methods with different prescription requirements for soft and loud sounds (Byrne et al., 2001).

Early digital signal processing hearing aids were designed to replicate state of the art analog processing, such as wide dynamic range compression. As the strategies for DSP progressed beyond the simple replication of analog technology, the need has grown for enhanced targeting strategies. This has led to the development of processing-strategy-specific targets that are often proprietary for a given approach.

There are other considerations for determining targets, including the type of hearing loss and whether one or both ears are being fitted. For example, when there is a conductive component to the hearing loss, target gain is usually increased by approximately 25% of the air-bone gap at a given frequency. When the hearing aid fitting is binaural, the target gain for each ear is usually reduced by 3 to 6 dB to account for binaural summation.

Modern hearing aids are programmed under computer control with software provided by the manufacturer of the device. Each

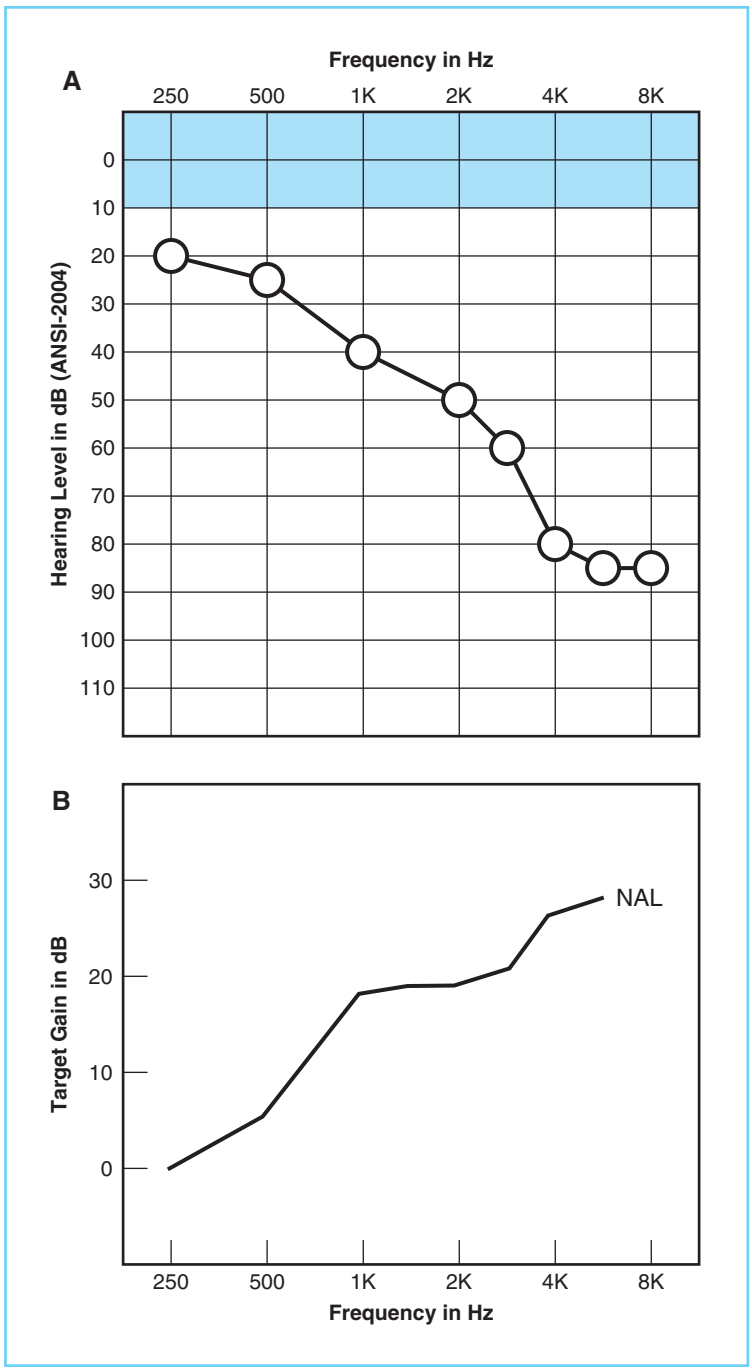


FIGURE 14-1 Pure-tone audiometric results (A), and the corresponding gain targets (B) as prescribed on the basis of the NAL-R method.

software program is slightly different, but most recommend a prescriptive approach for their particular hearing aids. They also provide the audiologist with the flexibility to change gain and other parameters as might be indicated by the hearing loss, the audiologist's preference, or other factors.

Hearing Instrument Selection

The process of hearing instrument selection is one of systematically narrowing choices until a reasonable approximation of the patient's hearing and treatment needs are met. Once the decision has been made to pursue conventional hearing aid amplification, the process begins by determining the style and features of the hearing aids that will be most appropriate for the patient's hearing loss and communication needs.

As you learned in Chapters 12 and 13, there are a number of challenges and options that need to be addressed during the hearing aid selection process. These include:

- binaural versus monaural fitting,
- hearing aid style,
- number and size of user controls,
- occlusion issues,
- gain processing options,
- telecoil and other wireless options,
- remote-microphone options,
- noise reduction considerations,
- feedback suppression possibilities,
- directional microphone, and
- device costs.

In reality, many of these factors interact with each other. Just as an example, if a decision is made to get a hearing aid with adaptive directionality, it is probably at a technology level in which all devices will also have multiple memories and advanced processing.

Some of the decisions are made by the audiologist; others by the patient. If it were up to the audiologist, all patients would have binaural hearing aids with directionality, wireless connectivity, a

remote microphone option, and every other feature that ensures a successful fit and a happy patient. More often than not, however, reality plays a role in these decisions, and compromises are made. This speaks to the need for a communication needs assessment as part of the treatment evaluation process.

The selection process usually begins with a discussion of hearing aid style and the relative benefits and challenges of ITEs and BTEs. Although the hearing loss may dictate this decision, both types can be used to fit a broad range of hearing loss. More often than not, the decision is one of patient preference, usually based on appearance, convenience issues, or past experience.

Once the style has been chosen, the feature/technology level must be determined. Hearing aid manufacturers tend to group features of hearing aids by levels of technology. The groupings vary among manufacturers and are by no means a static categorization; they may even vary among styles within a given manufacturer. The one constant, though, is that the higher the technology level, the higher the financial cost of the device.

The selection of the appropriate feature and technology level becomes a negotiation with the patient about communication needs and the cost-effectiveness of the various solutions.

Once all of these decisions have been made, the audiologist will have narrowed the selection process down to a tractable set of device options. The audiologist will then compare these options against the knowledge of devices available from several manufacturers and make a decision about exactly which hearing aids to order for the patient.

Hearing Instrument Fitting and Verification

Hearing aid fitting has two important components, getting the actual physical fit of the device right and getting the electroacoustic characteristics of the device right. Both require significant technical knowledge and skill, and both require a bit of artistic talent. The general process of fitting and verification includes:

- ear impressions,
- quality control,

Audiologist Profile

Don D. Kim, Au.D.



Where I Live: Denver, Colorado

Where I Work: HearingCare, Inc. is an audio-vestibular private practice that provides diagnostic, treatment, and rehabilitation services in three separate offices in Denver metropolitan area. Our staff consists of two Doctors of Audiology, one hearing aid dispenser, one pre-doctoral extern, one audiology technician, and one office manager.

What I Do: When I'm not skiing or hiking, I manage our South office in Englewood, Colorado. In the clinic, I am responsible for the audiologic care of my patients, which includes audio-vestibular diagnostics, treatment, and rehabilitation. My other responsibilities include managing the physician marketing programs, public relations events on the radio or on television, and the day-to-day duties of running and managing an office. Because we do rely on our referring physicians, I hold monthly physician lunch-and-learn events to educate physicians and other health-care providers about audiology and the services we provide.

Why Audiology? My mathematics and computer science majors did not present many appealing career options besides engineering, my initial career path. In addition, my father is a nuclear engineer, and I saw no need for another one in the family. I had a last minute change of heart in college and wanted to pursue a career in health care. Audiologists are by far more fun and interesting than I had ever anticipated!

- device programming,
- verification of fit, and
- verification of function.

Ear Impressions

The fitting process usually begins with the making of impressions of the outer ear and external auditory meatus. These impressions are used by the manufacturer to create custom-fitted earmolds or in-the-ear hearing aids. The quality of the impression dictates the quality of the physical fit of the hearing instruments.

The impression-making process is simple and systematic. The first step is inspection of the ears and ear canals to ensure that they are clear for the introduction of impression material. The inspection process includes an evaluation of:

- the skin of the canals to ensure that no inflammation exists,
- the amount of cerumen in the canals to ensure that it is not impacted or will not become impacted as a result of the process, and
- the tympanic membranes to ensure that they can be visualized and do not have obvious perforations or disease process.

If excessive cerumen is present, it should be removed before proceeding with ear impressions.

If any concern exists about the condition of the outer-ear structures, it is prudent to seek a medical opinion before making the impression or, on occasion, even medical assistance while making the impression.

The next step in the process is to place foam or cotton blocks deep into the ear canals to protect the tympanic membranes from impression material. These blocks should have a string attached for easy removal. Once the blocks are in place, the ear canals are filled with impression material. This is soft material that is mixed just before it is placed into the ear canals and sets shortly after it is in place. After a period of time sufficient for the material to set, the ear impressions are removed from the ears, inspected for quality, and shipped to the manufacturer.

The nature of ear impressions is generally the same across earmolds and custom hearing aids, with a few exceptions. When ear impressions are being made for CIC hearing aids or earmolds for profound hearing loss, care must be taken to make very deep impressions of the ear canal.

When ear impressions are being made into earmolds for use with behind-the-ear hearing aids, decisions will need to be made about the style of earmold, the material to be used, and the style and size of tubing and venting. Earmold materials vary in softness

and flexibility. Some materials are nonallergenic. The decision on which material to use is usually based on concerns relating to comfort and feedback. The decisions to be made on bore size, tubing, and venting will impact the frequency gain of the hearing aid (Valente et al., 2000) and must be made with knowledge and care.

When ear impressions are being made for in-the-ear hearing aids that will have directional microphones, they may need to be marked for proper horizontal placement of the microphones.

Quality Control

When hearing aids are received from the manufacturer, they should be inspected immediately for the quality of appearance and function.

The first step is to look at the hearing aids and assess their appearance. Custom hearing aids or earmolds should be inspected to ensure that style, color, and venting are correct. The switches and controls should be checked to ensure that the proper ones were included and that they function.

Electroacoustic analyses of the hearing aids should be conducted to ensure that their output meets design parameters in terms of frequency gain, maximum output, and input-output characteristics. In addition, hearing aids are required to meet specified standards of performance, including minimum hearing aid circuit noise and signal distortion. Measurement of these aspects of performance should be included in any electroacoustic analysis.

A picture of a hearing aid analyzer is shown in Figure 14-2. The analyzer contains a test chamber in which the hearing aid is placed. The chamber has a loudspeaker to deliver test signals to the hearing aid. The hearing aid is placed into a specially designed 2cc coupler, which is attached to a microphone. The amplified signal is sent to the analyzer, which is a sophisticated sound-level meter.

Hearing aid analyzers are designed to describe the acoustic output of a hearing aid in terms of specifications of the American National Standards Institute's Standard for Characterizing Hearing Aid Performance (ANSI S3.2-2003). The standard electroacoustic



FIGURE 14-2 Photograph of a hearing-aid analyzer and test box.
(Photograph courtesy of Frye Electronics, Inc. Tigard, OR.)

analysis of a hearing aid provides information about the hearing aid's gain, maximum output, and frequency response. It also provides a measure of circuit noise, distortion, and battery drain. The standard analysis runs two frequency response curves, one with a 60 dB SPL input and the hearing aid set at what is called reference test gain, and the other the output sound pressure level with a 90 dB SPL signal (OSPL90) with the volume control in its full-on position. Results of this analysis are compared to the hearing aid specifications provided by the manufacturer to ensure that the hearing aid is operating as expected.

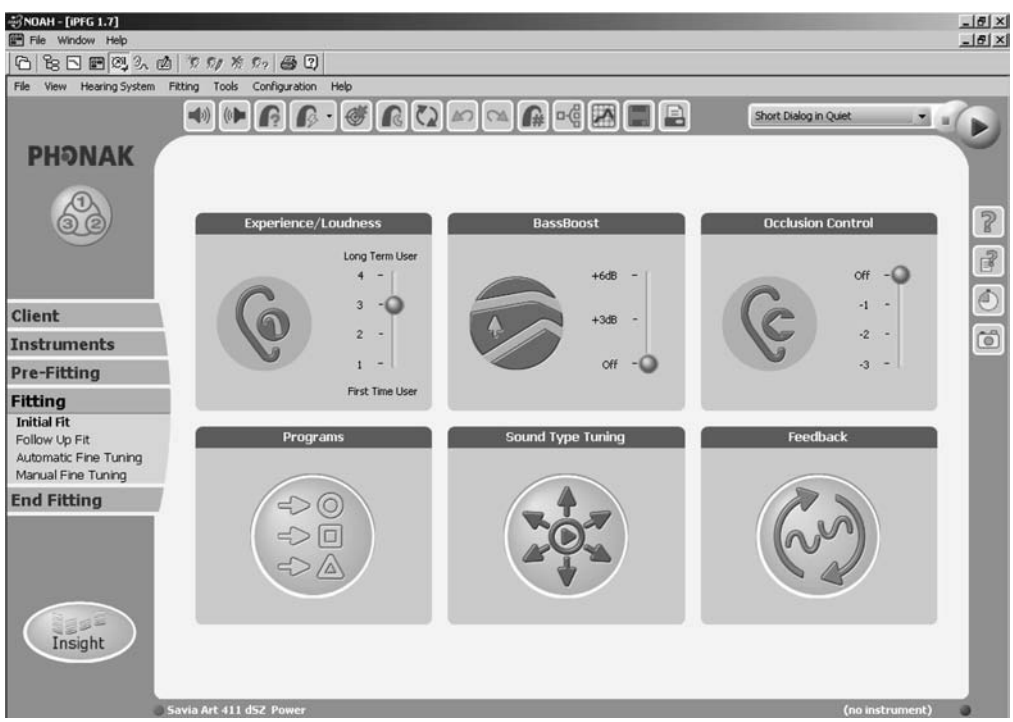
Following the electroacoustic analysis, a listening check should be performed to rule out excessive circuit noise, intermittency, and negative impressions of sound quality. Any controls should also be manipulated to ensure that they work and do not add noise to the amplified signal as they are changed.

Fitting and Verification

The first step in the fitting process is programming the hearing aids. This can be done immediately following the selection appointment but before the aid is ordered, or it can be done after the hearing aids are received but before the patient arrives for the fitting

appointment. Most hearing aid manufacturers preprogram the devices with their predictions of what will be the best hearing aid response for the patient's hearing loss. Regardless, the audiologist will have a number of decisions to make in order to program the hearing aids to match what is already known about the patient's communication needs.

Programming is accomplished via computer software that is proprietary for each manufacturer. A sample of two software screens from the same manufacturer is shown in Figure 14-3. The first screen (A) shows software options to illustrate some general categories of programming control. The second screen (B) shows the hearing aid response to different levels of input and illustrates some of the changes that can be made to the response.

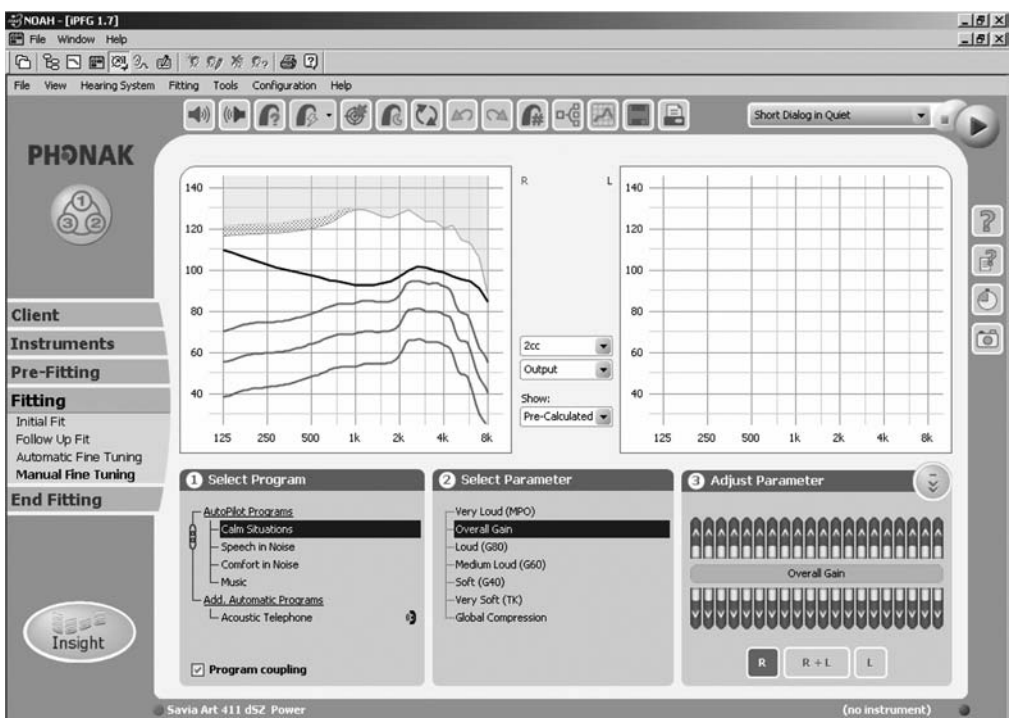


A

FIGURE 14-3 Sample of hearing aid programming software screens, showing (A) categories of programming control and (B) hearing aid response curves. (With permission from Phonak)

The basic response of the hearing aid will be derived from the patient's audiogram based on a prescriptive target. Manufacturers normally use proprietary targets that match the assumptions underlying their signal processing strategy. The audiologist can then adjust almost any parameter of the response as needed.

Most interface software is designed to guide the audiologist through the decision process. The actual interface can vary considerably across manufacturer software programs. Some decisions that are to be made are based on patient characteristics, such as age or experience using a hearing aid. For example, beginning users seem to benefit initially from less gain than might be prescribed for their hearing losses once they adjust to the amplification. For experienced users, response settings may



B

vary depending on the type of processing used in the past. Other decisions that need to be made include:

- **Program Organization.** How are the memories or programs to be organized? Should multiple memories be used, or is the patient better off with just two?
- **Telecoil Preference.** Should the patient use auto or manual telecoil? Should the telecoil be on both ears or on one ear with the other ear on microphone?
- **Power-on Delay.** Should the power come on immediately or be delayed so that the patient can insert the device without feedback?
- **Manual Controls.** Should manual controls be activated or deactivated?
- **Response Review.** Are the gain response, maximum output, and prescriptive formula appropriate?

The answer to all of these questions and more will depend on the style and feature/technology level of the device and on the age, hearing loss, experience, and communication needs of the patient.

Once the hearing aid has been programmed, preparation is complete, and the fitting process with the patient begins.

The first step in the fitting process with the patient is to assess the physical qualities of the devices, including their fit in the ears, the patient's perception of their appearance, and the patient's ease in manipulating the devices. This should include an assessment of:

- security of fit,
- absence of feedback,
- appropriateness of microphone location,
- physical comfort,
- ease of insertion and removal,
- ease of **VC** rotation, and
- overall patient manipulation.

VC = volume control

Assessment of the physical fit of the devices is important. They should fit securely without excessive patient discomfort, the gain should exceed the usable level before feedback occurs, and

the microphones should not be obstructed by any **auricular** structures. If the fit is not adequate, the hearing aids or earmolds can be modified to a certain extent.

The **auricular** structures are the external or outer ear.

Patient comfort with using the devices is equally important. The patient should be able to insert and remove the devices without excessive difficulty and should be able to operate the controls easily.

Assessment should also be made of the occlusion effect. This can be done informally by having the patient speak and describe the quality of his or her voice. If the voice sounds hollow or muffled, alterations will need to be made to reduce the occlusion effect.

The general strategy of fitting and verification is one of

- device programming,
- gain verification,
- output verification,
- feature verification, and
- programming adjustment as indicated.

Audiologists use a number of techniques to fit hearing aids and verify their suitability. In general, the process includes placing the hearing aids in the patient's ears, measuring their gain and frequency response in the ear canal, adjusting the parameters to meet targets, and then asking the patient to make a perceptual assessment of the quality of the hearing experience with the aids.

Real-Ear Verification

The methods used to verify the electroacoustic output of the hearing aids are generally designed to assess whether the targeted gains are achieved across the frequency range for a given input to the hearing aids. The procedures used to achieve this involve some form of real-ear testing, most commonly probe-microphone measurements (for a review, see Mueller et al., 1992; Revit, 2000).

Real-ear gain is the amount of gain delivered to the ear as opposed to a coupler; it is measured with a probe microphone or by functional gain assessment.

Probe-microphone measurements are made to assess **real-ear gain** characteristics. Figure 14-4 shows a photograph of a probe-microphone system. The system is a sophisticated spectrum analyzer that permits the delivery of various types of signals to a



FIGURE 14-4 **Photograph of a real-ear measurement system.** (Photograph courtesy of Audioscan®)

loudspeaker that is placed in proximity to a patient's ears. A tube is inserted into the ear canal down close to the tympanic membrane. The other end of the tube is attached to a sensitive microphone. This is shown schematically in Figure 14-5. The strategy here is to make a measurement that accounts for all of the acoustic alterations that occur due to the resonances of a patient's concha and ear canal and, once the hearing aid is in place, the effect of the aid or earmold.

To make a real-ear measurement, speech or speech-like sounds are presented through the loudspeaker at a given intensity level,

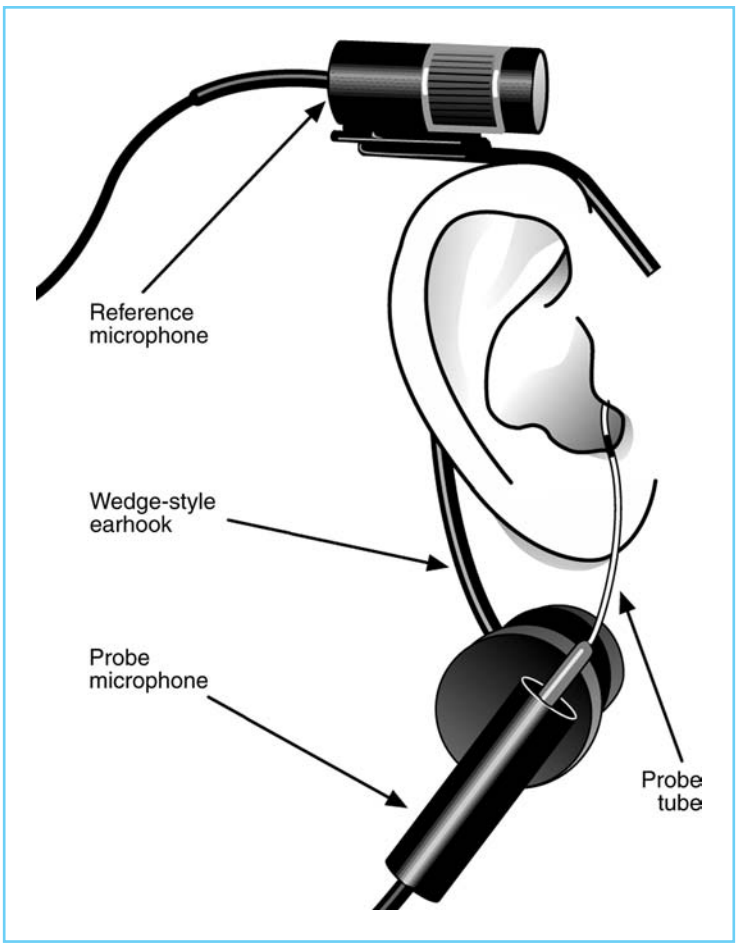


FIGURE 14-5 A probe-microphone system. (Drawing courtesy of Frye Electronics, Inc. Tigard, OR.)

and measurements are made of sound in the ear canal without a hearing aid. The resultant measurement is known as the real-ear unaided response or gain (REUR/G). The patient's hearing aid is then placed on the ear and activated, and the same sounds are presented. The resultant response from the probe-microphone is the real-ear aided response or gain (REAR/G). The difference between the unaided response and the aided response (REAG-REUG) is the real-ear insertion gain (REIG), or the amount that the hearing aid adds to the sound measured near the tympanic membrane.

Strategies for the verification process are numerous. One successful approach is delineated in the accompanying clinical note. The basic idea, though, is the same regardless of the nuances of technique. The hearing aid is programmed to amplify sound in a manner that is intended to match a target based on the patient's audiometric results. As mentioned earlier in this chapter, modern targets are derived from formulas such as NAL-NL1 (Byrne et al., 2001) and DSL[i/o] (Cornelisse et al., 1995). Speech or speech-like sounds are played through the hearing aid, and the real-ear gain is measured. Usually a low-intensity sound is delivered to the hearing aid, and the response is compared to the prescriptive target. If the response does not match the target, the hearing aid is adjusted until the target is approximated. The process is then repeated with average-level signals and high-intensity signals. In each case, adjustments are made to the hearing aid, if necessary, to achieve the prescriptive target.

Clinical Note

Speech Mapping

One clinical approach that combines probe-microphone measurement with hearing aid programmability is known as *speech mapping*. Here are the essentials of the speech mapping process:

- The patient is seated in front of the real-ear measurement computer screen, wearing hearing aids, which are coupled to their programming computer, with probe microphones placed in both ear canals.
- Ongoing speech is presented via the probe-microphone system at a fixed intensity level, usually starting with low-intensity speech.
- The output of the probe microphones is displayed on the screen as the spectrum of the ongoing speech.
- Also displayed on the screen are the patient's audiogram, loudness discomfort levels, prescriptive targets, and perhaps even a display of the speech spectrum at a typical conversational level.

continues

continued

- With the ongoing amplified speech displayed, the audiologist adjusts the appropriate hearing aid parameters until the speech map approximates the prescriptive targets.
- The process is then repeated for a high-intensity level of speech and any necessary adjustments are made.

The advantages of this type of approach are numerous (Moore, 2006). The result is that the response of the hearing aids, as measured at the patient's eardrum, are in close approximation to targeted responses for real speech input.

Clinical Note

This process results in the verification that the amplified signal being delivered to a patient's tympanic membrane meets prescriptive targets for different input levels. If the targets are correct, then when the patient is wearing the hearing aids, soft sounds should be audible, average sounds should be comfortable, and loud sounds should be tolerable.

Behavioral Verification

Once the electroacoustic characteristics of the hearing aids are verified in the ear canal, the actual quality of the amplified sound is assessed with some form of quality or intelligibility judgment procedure. This is done simply to verify that the targets achieved electroacoustically in the ear canal are, in fact, meeting expectations perceptually. Perceptual verification is done in a number of ways, both informally and formally. Strategies include speech perception judgments, loudness judgment ratings, functional gain measurement , and speech-recognition measures.

Speech Perceptual Judgments. Once the parameters of the hearing aids have been set to meet gain and prescriptive targets, the patient is often asked to make perceptual judgments about the nature of the amplified speech sound. Judgments are usually made along the perceptual dimensions of quality or intelligibility. For quality judgments, the patient is presented different speech signals and makes judgments about whether the speech sounds natural,

clear, harsh, and so on. The hearing aids are then adjusted until the quality of speech is judged to be maximal. For intelligibility judgments, the patient is presented different speech signals, often in quiet and in noise, and makes judgments about the intelligibility of speech. The hearing aids are then adjusted until the intelligibility of speech is judged to be acceptable.

Loudness Judgment Ratings. Another behavioral verification strategy that can be used is the determination of loudness judgments as a means for ensuring that speech is packaged appropriately within a patient's dynamic range. The goal of loudness judgment ratings is to ensure that low-intensity sounds are audible and that high-intensity sounds are not uncomfortable. Typically, the patient is asked to judge loudness for speech or speech-like sounds. The signals are presented at various intensity levels, and the patient is asked to rate the loudness at each level. For example, a speech signal presented at 45 to 50 dB SPL should be judged as soft, a speech signal presented at 60 to 65 dB SPL should be judged as comfortable, and speech signal presented at 80 to 85 dB SPL should be judged as loud but not uncomfortable. The hearing aids can then be adjusted until appropriate aided loudness judgments are obtained for all three presentation levels of the speech signal.

Functional Gain Measurement. One of the oldest behavioral verification strategies measures the hearing aids' response to soft sounds and is known as functional gain. This measurement is made by presenting frequency-specific signals via loudspeaker to the patient. The patient is tested in both unaided and aided conditions in the soundfield. The difference between aided and unaided thresholds is functional gain. These gain values are then compared to prescriptive target values. The hearing aids are then adjusted until the functional gain approximates the prescriptive target. Although fraught with measurement and conceptual problems, functional gain can occasionally be useful in the absence of other measures if interpreted carefully.

Speech-Recognition Measurements. Another technique that has been used for verification over the years is speech-recognition measurement. Here, the patient is presented with one of several types of speech materials, such as sentences or monosyllabic words, and performance scores are obtained. Testing is

usually done in the presence of one or multiple levels of noise or competition.

The goal of evaluating speech recognition is to ensure that the patient is hearing and understanding speech in a manner that meets expectations of performance. Performance in absolute terms is usually measured against expectations related to a patient's degree and configuration of hearing loss. Performance in relative terms is usually measured against unaided ability or as a comparison of monaural to binaural ability.

A number of strategies have been used over the years to assess aided speech-recognition performance. A common approach is to present speech signals at a fixed intensity level from a loudspeaker placed in front of a patient, with background competition of some kind delivered from a speaker above or behind. Performance in recognizing the speech targets is then measured, and the intensity level of the competition is varied to assess ability at various target-to-competition ratios.

Figure 14-6 provides an example of results from this type of speech-recognition testing. Performance in the monaural aided condition

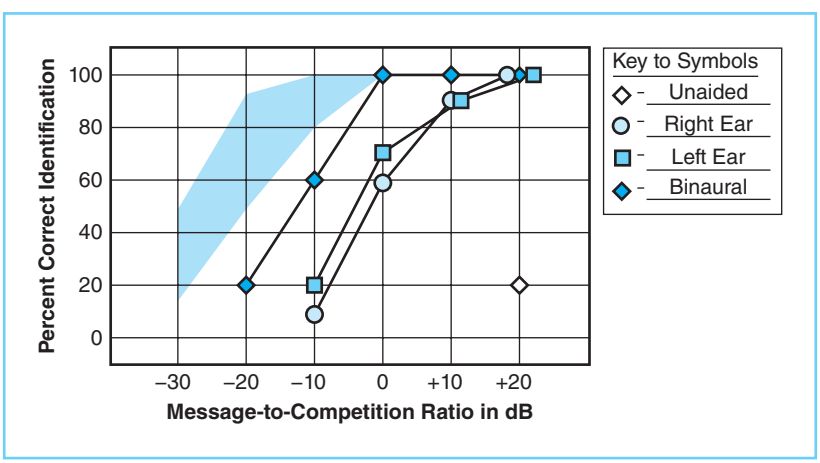


FIGURE 14-6 Results of aided speech-recognition testing. Speech targets are presented at a fixed intensity level from a loudspeaker placed in front of a patient, with background competition presented from a loudspeaker located above or behind. Percent correct identification of target sentences is plotted as a function of message-to-competition ratio for three aided conditions: right, left, and binaural.

is compared to the binaural aided condition, and all are compared to normal performance. If speech-recognition performance meets expectations, then the fitting is considered to be successful. If not, then the hearing aids can be adjusted or alternative amplification methods pursued.

Although once a widely used technique, speech-recognition testing is seldom used routinely today with a couple of exceptions. One remaining benefit of speech-recognition testing is that performance of monaural hearing aid fitting can be compared to binaural fitting, and the ears can be compared to each other. This can be important in older patients, who may show marked asymmetry in their ability to use hearing aids. Verification with other strategies will not reveal this problem. Another exception is the use of speech-recognition measures for assessing performance with cochlear implants. Numerous tests have been developed for evaluating these patients, and speech-recognition testing is carried out routinely for verification purposes. In addition, speech-recognition measures are used by some audiologists in pediatric settings.

ORIENTATION, COUNSELING, AND FOLLOW-UP

Following the completion of hearing aid fitting and verification, a hearing aid orientation program is implemented. An orientation program consists of informational counseling for both the patient and the patient's family. Topic areas include of the nature of hearing and hearing impairment, the components and function of the hearing aids, and care and maintenance of the hearing aids. One of the most critical aspects of the hearing aid orientation is a discussion of reasonable expectations of hearing aid use and strategies for adapting to different listening environments. The hearing aid orientation program also provides an opportunity to discuss and demonstrate other assistive devices that might be of benefit to the patient.

In some settings, groups of patients with hearing impairment are brought together for orientation. Such groups serve at least two important functions. First, they provide a forum for expanded dissemination of information to patients and their families. Second, they provide a support group that can be very important for

sharing experiences and solutions to problems. Regardless of the approach that is used, an effective orientation program will result in a higher likelihood of successful hearing aid use and fewer hearing aid returns (Kochkin, 1999).

The orientation process involves the dissemination of information on a number of topics and details about the hearing aid, its function, and its use. Topics that should be covered during the orientation period include:

- features and components,
- insertion/removal,
- care and cleaning,
- storage,
- battery management,
- telephone use,
- feedback, and
- warranty information.

It is important for the audiologist to recognize the likely novelty of this information and provide the patient with as much in the way of handout material as possible. In addition to the manufacturer's manual for the hearing aids, the audiologists should provide written instructions on use and routine maintenance, including troubleshooting guidelines.

The orientation also provides an excellent opportunity to educate the patient and family about successful communication strategies for those with hearing impairment. Information about manipulation of the acoustic environment for favorable listening and information about how to speak clearly and effectively to those with hearing impairment will be invaluable to both patient and family.

During the orientation, the patient should also be familiarized with other assistive devices that might be valuable for his or her communication needs. Familiarity with telephone amplifiers and remote microphone systems will provide patients with a perspective on the options that are available to them beyond their hearing aids. It is also a good opportunity to inform patients about the public facilities that may be available to them such as group

amplification for theaters and churches. Patients will also benefit from an understanding of any community resources that might be accessible to them.

The patient should also be counseled that the ultimate benefit they will receive from the hearing aids might not be immediately apparent. The patient is likely to experience some beneficial adaptation to the hearing aids following a period of adjustment (Horowitz & Turner, 1997).

Perhaps one of the most valuable discussions to have with the patient is about reasonable expectations regarding the hearing aids. Actually, the setting of expectations is an ongoing process. It should begin the moment that the patient is being told that he or she is a candidate for hearing aids and continue throughout the entire hearing aid process.

If a patient expects hearing aids to restore hearing to normal similar to the way that eyeglasses restore vision to normal, then that patient may be disappointed with the hearing aids that you have worked so hard to get just right. Hearing aids amplify sound. Some hearing aids amplify sounds extremely well. Regardless, the sound is being delivered to an ear that is impaired, and amplified sound cannot correct the impairment. If a patient has a reasonable understanding of that, and his or her expectations are in line with that understanding, then the prognosis for successful hearing aid use is good. Conversely, if patient expectations are unreasonable, the prognosis is guarded at best.

Patients should have the following expectations from hearing aid amplification:

- acceptable hearing in most listening environments,
- communication to improve but not be perfect,
- environmental sounds to not be uncomfortably loud,
- feedback-free amplification,
- that hearing aids are visible to some degree,
- reasonable physical comfort but not tactile transparency,
- more benefit in quiet than in noise, and
- that background noise will be amplified.

These expectations should be reviewed at the time of follow-up. If they are not being met, the hearing aids probably need to be adjusted. If they are being met and the patient accepts them as reasonable, the likelihood is that the patient will be a satisfied hearing aid wearer.

At the end of the orientation and counseling session, patients are scheduled for a follow-up visit, usually within 30 days of the hearing aid fitting. At the follow-up appointment, the audiologist and patient review benefit from and satisfaction with the hearing aids and make any necessary adjustments to them. It is often at this follow-up that the outcome measures are made to ensure that the patient's communication needs are being met and to help in the planning of any additional rehabilitative services.

ASSESSING OUTCOMES

Outcome validation is important in the provision of any aspect of health care. Hearing aid treatment is no exception. It is common practice to evaluate the success of hearing aid fitting at some point after the patient has had an opportunity to wear and adjust to the use of his or her hearing devices.

Validating the outcome of hearing aid fitting means asking if the treatment, in this case hearing aid use, is doing what it is supposed to do. To an extent, we have already provided some validation in the verification process by ensuring that the hearing aid is producing the type of acoustic response that it is supposed to produce. But that is really only part of the story.

The goal of the hearing treatment process is to reduce the communication disorder imposed by a hearing loss. We generally define success at reaching this goal in terms of whether the patient understands speech better with the hearing aids and whether the hearing aids help to reduce the handicapping influence of hearing impairment. The best way to understand if this success has been achieved is to ask the patient.

Outcome measures are designed to assess the impact of hearing aid amplification on self-perception of communication success. Results from self-assessment scales administered after amplification

use can be compared to pretreatment results to assess whether the hearing aids have had an impact on communication ability. Similarly, assessment can be done by spouses or others to verify the success of the treatment approach.

In Chapter 12, you learned about the self-assessment measures aimed at defining communication needs. Measures such as the Hearing Handicap Inventory for the Elderly (HHIE) (Ventry & Weinstein, 1982), the Abbreviated Profile of Hearing Aid Benefit (APHAB) (Cox & Alexander, 1995), and the Client Oriented Scale of Improvement (COSI) (Dillon et al., 1997) seek to define patients' perceptions of their own hearing ability and challenges in various listening situations. If these measures are given prior to hearing aid fitting and then again at follow-up, results can be used as validation of treatment success. Figure 14-7 shows results from a patient on the APHAB. Here, pre- and post-fitting results show a significant improvement in hearing in three of four measurement categories.

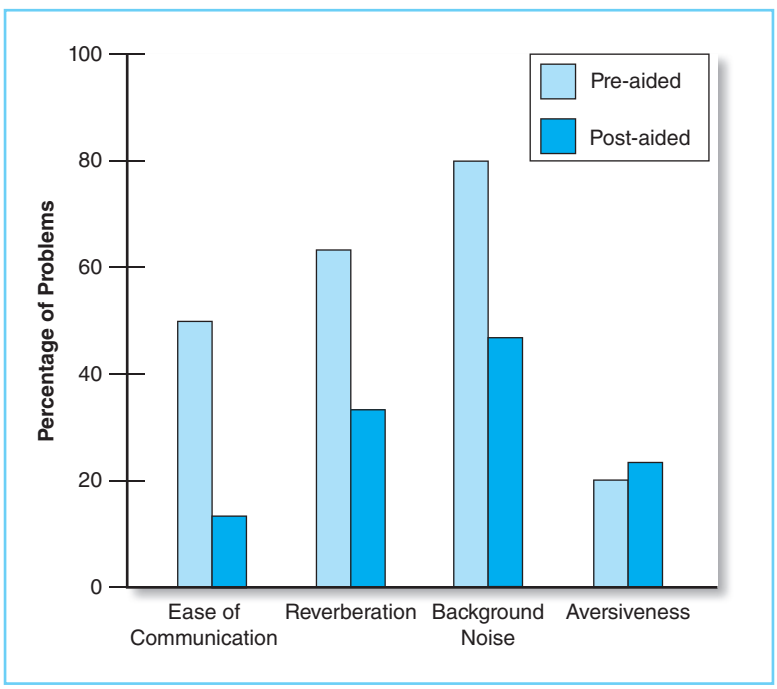


FIGURE 14-7 Results on the APHAB self-assessment scale in a patient before and after hearing aid use.

They also show that in one category, aversiveness, the patient does not perceive improvement. The audiologist will work with the patient and the hearing aids to address this listening situation.

In addition to these self-assessment measures of communication needs, it is often useful to measure quality-of-life issues to determine how the addition of hearing aid amplification is impacting overall well-being. Measures such as the Glasgow Hearing Aid Benefit Profile (GHABP) (Gatehouse, 1999) and the International Outcome Inventory – Hearing Aids (IOI-HA) (Cox & Alexander, 2002) can help to measure the impact of audiologic treatment on quality of life.

Self-assessment validation of treatment outcome is a valuable way to measure success in the audiologic management process. Once these measures have been made and discussed with the patient, the audiologist then evaluates the need for any additional rehabilitative services for the patient.

POST-FITTING REHABILITATION

For many adult patients, the proper fitting of appropriate hearing aid amplification, accompanied by effective orientation and follow-up, constitutes enough management to sufficiently ameliorate their communication disorders. For others, however, hearing aid fitting represents only the beginning of the process (for a comprehensive overview, see Tye-Murray, 2004).

Post-fitting rehabilitation for adults may involve auditory training to maximize the use of residual hearing and speechreading training to maximize use of the visual channel to assist in the communication process. Post-fitting rehabilitation for children is usually much more protracted. It often involves language stimulation, speech therapy, auditory training, and extensive educational programming.

Auditory Training and Speechreading

Auditory training and speechreading are treatment methods that are sometimes used following the dispensing of hearing aids. Auditory training programs are designed to bring awareness to the hearing task and to improve listening skills. Extensive focus is placed on maximizing the use of residual auditory function. Auditory training

programs typically include structured exercises in speech detection, discrimination, identification, and comprehension.

Speechreading programs are designed to enhance the skills of patients in supplementing auditory input with information that can be gained from lip movements and facial expressions.

Auditory training and speechreading services are provided in several different ways. Individual therapy sessions are a common first step in the process. Group training has also proven to be valuable and gives patients the extra benefit of supportive camaraderie. In addition to these approaches, computer-based home training programs have been developed for self-paced learning (Sweetow, 2005).

Educational Programming

The goal of any treatment program for children is to ensure optimal acquisition of speech and language. In children with mild hearing sensitivity losses, such a goal can be accomplished with careful fitting of hearing aids, good orientation of parents to hearing loss and hearing aids, and very careful attention to speech and language stimulation during the formative years. For more severe hearing losses the task is more difficult, and the decisions are more challenging.

The **oral approach** is a method of communication that involves the use of verbal communication and residual hearing.

The **manual approach** is a method of communication that involves the use of fingerspelling and sign language.

The **total approach** is a method of communication that incorporates both the oral and manual approaches.

For many years there has been controversy about the best method of communication development training for children with severe and profound hearing losses. One school of thought champions the **oral approach**, in which the child is fitted with hearing aids or a cochlear implant and undergoes very intensive training in oral/aural communication. The goal is to help the child to develop oral skills that will allow for a mainstreamed education and lifestyle. Another school of thought champions the **manual approach**. The manual approach teaches the child sign language as the method of communication. The goal is to help the child develop language through a sensory system that is not impaired. Yet another school of thought champions the idea of combining oral and manual communication in a **total approach**. The total approach emphasizes language development without regard to the sensory system. This approach seeks to maximize both language learning and oral communication.

Although the topic of education of the children with deafness has always been controversial, the tone of the discussion has changed in recent years with the advent of cochlear implantation. Implants are proving to be a successful alternative to conventional hearing aid use, particularly in terms of ease of learning language.

Regardless of the habilitation strategy, the most important component of a rehabilitation program is early identification and early intervention. The sooner a child is identified, the sooner the channels of communication required for language development can be opened.

Summary

- Hearing aids are selected and fitted based on an individual's communication needs, degree of hearing loss, audiometric configuration, and loudness discomfort levels.
- The fitting process usually begins with making impressions of the outer ear and external auditory meatus. These impressions are used by the manufacturer to create custom-fitted earmolds or in-the-ear hearing aids.
- When hearing aids are received from the manufacturer, they should be inspected immediately for the quality of appearance and tested for function.
- The first step in the fitting process with the patient is to assess the physical qualities of the devices, including their fit in the ears, the patient's perception of their appearance, and the patient's ease in manipulating the devices.
- The general strategy of fitting and verification is one of assessing the gain and frequency parameters, making adjustments, verifying that the responses meet targets, and verifying that the aids meet some defined perceptual expectations.
- Verification of the frequency response is usually made by probe-microphone measurement. A small microphone is placed near the tympanic membrane, and the responses of the hearing aids to sounds of various frequencies and intensities are determined.
- Following verification, a hearing aid orientation program is implemented, which consists of informational counseling about

the nature of hearing and hearing impairment, the components and function of the hearing aids, and care and maintenance of the hearing aids.

- One of the most critical aspects of the hearing aid orientation is a discussion of reasonable expectations of hearing aid use and strategies for adapting to different listening environments.
- It is common practice to evaluate the success of hearing aid fitting after the patient has had an opportunity to wear and adjust to the use of the devices.
- Success is usually defined by whether hearing aids are satisfactory in terms of fit and function and whether they provide communication benefit and enhance quality of life.
- Post-fitting rehabilitation for adults involves auditory training and speechreading training.
- Post-fitting rehabilitation for children involves language stimulation, speech therapy, auditory training, and extensive educational programming.

Short Answer Questions

1. The _____ _____ of a hearing aid is the amount of gain that a hearing aid should provide, based on the individual's hearing loss.
2. A _____-based prescriptive method specifies the frequency gain characteristics that will amplify average conversational speech to a comfortable or preferred listening level. One commonly used method is the _____ _____ Laboratory (NAL) method.
3. Other prescriptive methods are based on both threshold and _____ levels. The _____ _____ _____ (DSL) formula is an example of this type of method.
4. Additional considerations for determining prescriptive gain targets include the type of hearing loss, whether there is a _____ component to the hearing loss, and whether _____ or monaural hearing aids are used.
5. One decision to be made regarding hearing aid selection is the _____ of the hearing aid. This choice may be

limited based on degree and configuration of the hearing loss, patient dexterity, and patient preference.

6. Another decision to be made regarding hearing aid selection is the _____ level of the hearing aid. These choices of technology options offered to patients are often divided into basic, _____, and advanced levels of technology, which provide progressively greater features for the hearing aid user.
7. An _____ _____ is taken for a patient to create custom-made hearing aids or earmolds. This is accomplished by placing a foam or cotton _____ into a visually clear ear canal. Impression material is then injected into the ear canal and allowed to set. The impression is then sent to the manufacturer.
8. Upon receipt of a hearing aid from a manufacturer, _____ _____ is often performed to determine appropriate output from the hearing aid.
9. Hearing instrument _____ is accomplished using computer software that is proprietary for each manufacturer.
10. In addition to prescriptive gain, programming includes manipulation of factors, including _____ organization, telecoil preference, use of _____-on delay, and use of manual controls.
11. The use of _____-_____ measures allows for electroacoustic assessment of the characteristics of a hearing aid at or near the tympanic membrane using a probe microphone.
12. The _____-_____ _____ _____ is the output of the hearing aid in the ear canal without the hearing aid.
13. The _____-_____ _____ _____ is the output of the hearing aid in the ear canal with the hearing aid in place.
14. The _____-_____ _____ _____ is the difference between the real-ear aided response and the real-ear unaided response.
15. The goal of _____ judgment ratings is to ensure that low-intensity sounds are audible and that high-intensity sounds are not uncomfortable.

16. The _____ _____ of a hearing aid is the difference between aided and unaided responses to frequency-specific sounds presented through a loudspeaker in soundfield.
17. The goal of aided _____-_____ testing is to ensure that the patient is hearing and understanding speech in a manner that meets expectations of performance.
18. Hearing aid orientations are sometimes accomplished in a _____ session, which provides opportunities for support and sharing of experiences and solutions.
19. Appropriate _____ for hearing aid use contributes to good prognosis for successful hearing aid use.
20. Measures designed to assess the impact of hearing aid amplification on self-perception of communication success are known as _____ measures.
21. The _____ approach to educational training emphasizes verbal communication and the use of residual hearing.
22. The _____ approach to educational training emphasizes sign language as the primary mode of communication.
23. The _____ approach to educational training combines both aural and manual communication.

Discussion Questions

1. Describe the major components of the hearing aid selection and fitting process.
2. List and describe the factors that contribute to the selection of the appropriate hearing aid for a patient.
3. Explain the process of creating an ear impression for a patient.
4. How is the output of a hearing aid verified? Why is this important?
5. Describe the components of a hearing aid delivery orientation.
6. What should patients expect from their hearing aids? Discuss the importance of setting appropriate expectations for hearing aid use.

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15

DIFFERENT TREATMENT APPROACHES FOR DIFFERENT POPULATIONS

Learning Objectives

Adult Populations
- Adult Sensorineural Hearing Loss
- Geriatric Sensorineural Hearing Loss

Pediatric Populations
- Pediatric Sensorineural Hearing Loss
- Auditory Processing Disorder

Other Populations
- Conductive Hearing Loss
- Severe and Profound Sensorineural Hearing Loss

Summary

Short Answer Questions

Discussion Questions

Resources

LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- Explain how goals for and approaches to treatment are related to patient factors such as age, type of hearing disorder, and patient need.
- Describe treatment goals and strategies for adults with sensorineural hearing loss.
- Describe treatment goals and strategies for older individuals with sensorineural hearing loss.
- Describe treatment goals and strategies for children with hearing loss.
- Describe treatment goals and strategies for children with auditory processing disorder.
- Describe treatment goals and strategies for individuals with conductive hearing loss.
- Describe treatment goals and strategies for individuals with profound hearing loss.

ALTHOUGH the overall goal of any audiologic treatment strategy is to reduce hearing impairment by maximizing the auditory system's access to sound, the approach used to reach that goal can vary across patients. The approach chosen to evaluate and fit hearing aids and/or other devices is sometimes related to patient factors such as age, sometimes to type of hearing disorder, and other times to communication needs. For example, the strategy used for an adult patient with a sensorineural hearing impairment is considerably different from that used for a child with auditory processing disorder. In the former, emphasis is placed on matching gain targets; in the latter, emphasis is placed on remote-microphone strategies. Within these broad categories, the approach may also vary depending on a patient's age. For example, achieving hearing aid success in a geriatric patient may require a different approach than that used in a 20-year-old. Finally, there are patients with severe and profound hearing loss who benefit from cochlear implantation, which requires an altogether different approach to fitting.

Although audiologic treatment must be adapted to the needs and expectations of individual patients, several broad categories of patients present common challenges that can be approached in a similar clinical manner. These categories include adults with sensorineural hearing loss, aging patients, children with sensorineural hearing loss, children with APD, patients with conductive hearing loss, and patients with severe to profound hearing loss.

ADULT POPULATIONS

Adult Sensorineural Hearing Loss

Treatment Goals

The challenges of fitting hearing aids to adults with sensorineural hearing impairment are, of course, related to the difficulties that sensorineural hearing losses cause. To review, sensorineural hearing loss results in the following problems, to a greater or lesser extent:

- loss of hearing sensitivity, so that soft sounds need to be amplified to become audible;
- sensitivity loss that varies with frequency and is generally greater in the higher frequencies;
- reduced dynamic range from the threshold of sensitivity to the threshold of discomfort;
- nonlinearity of loudness growth;
- diminished speech-recognition ability, usually proportionate to the degree and configuration of the sensitivity loss; and
- reduced ability to hear speech in background noise.

Hearing aid amplification, then, is targeted at these manifestations of sensorineural hearing loss. A hearing aid must amplify soft sounds to a level of audibility; must "package" the range of sound so that soft sounds are audible and loud sounds are not uncomfortable; must limit the maximum output to avoid discomfort; must reproduce sound faithfully, without distortion, to ensure adequate speech perception; and must do so in a manner that maintains or enhances the relation of the signal to the background noise.

Treatment Strategies

Adult patients with sensorineural hearing impairment tend to be both easy and challenging in terms of hearing aid selection and fitting—easy because they are cooperative and can provide insightful feedback throughout the fitting process and challenging because there is not much to limit the audiologist's options.

Following are general guidelines for fitting adults. The most important variables in this population are the degree and configuration of hearing loss.

Hearing Aid Selection. The adult patient should be fitted with binaural hearing aids, unless contraindicated clinically or because of some substantial ear asymmetries. Most adults who are new to hearing aids believe that they prefer custom in-the-ear devices. When they are introduced to modern behind-the-ear technology, many are surprised by the style and appearance of newer devices. This seems especially true of newer open-canal BTEs. Although most features are available in most styles of hearing aids, BTE hearing aids are the choice of many audiologists due to issues pertaining to feedback and especially to maintenance and durability. Most patients with sensorineural hearing loss will benefit from sophisticated compression strategies. Occasionally, long-term hearing aid users will crave more gain that is linear in nature. Except with deep CIC fittings, patients will likely benefit from adding back some directionality that is lost due to relocating the microphone from the tympanic membrane.

Hearing Aid Fitting and Verification. Gain targets should be matched and verified with probe-microphone measurements. Loudness judgments can be obtained reliably in adults and can be used to verify that soft sounds are audible and loud sounds not uncomfortable. Finally, verification can be confirmed in adult patients with sensorineural hearing loss with speech quality or speech intelligibility judgments.

Outcome Measurement. Self-assessment scales will be useful in pre- and post-fitting assessment of communication abilities and needs. It is often helpful to address issues related to both hearing ability and quality of life when measuring outcomes.

Rehabilitation Treatment Plan. The treatment plan is usually uncomplicated in adult patients and consists of thorough orientation and follow-up to fine tune the hearing aid's functioning. Some patients, especially those with significant hearing loss and communication demands, will benefit from hearing assistive technology, including the use of telephone amplifiers and personal FM systems.

Illustrative Case

Illustrative Case 15-1 is a patient with a long-standing sensorineural hearing impairment. The patient is a 54-year-old man with bilateral sensorineural hearing loss that has progressed slowly over the past 20 years. He has a positive history of noise exposure, first during military service and then at his workplace. The patient reports that he has used hearing protection on occasion in the past but has not done so on a consistent basis. In addition, there is a family history of hearing loss occurring in middle age. He was having his hearing tested at the urging of family members who were having increasing difficulty communicating with him.

An audiologic assessment revealed normal middle-ear function, a bilateral, fairly symmetric, high-frequency sensorineural hearing loss, and speech-recognition ability consistent with the degree of hearing loss.

A treatment assessment showed that the patient has significant communication needs at work. Results of a communication needs assessment showed that he has communication problems a significant proportion of the time that he spends in certain listening environments, especially those involving background noise. He has no motoric and other physical disabilities and is financially able to pursue hearing aid use. The patient expressed a preference for the "computerized hearing aids that are invisible in the ear."

Based on the patient's audiogram, it was determined that completely in-the-canal hearing aids should be appropriate for his degree and configuration of hearing loss. His hearing loss is good enough in the high frequencies that sufficient gain should be achievable without feedback issues. His hearing loss is bad enough in the low frequencies that he will benefit from low-frequency gain and not require any sort of open-fit strategy. Figure 15-1A shows the audiogram from each ear superimposed on the fitting range of the hearing aid that was selected. Other than his preference for CICs, he had no real interest in advanced technology and was fairly price conscious about the devices. A basic feature/technology level was chosen as a starting point. Ear impressions were made, and the hearing aids were ordered.

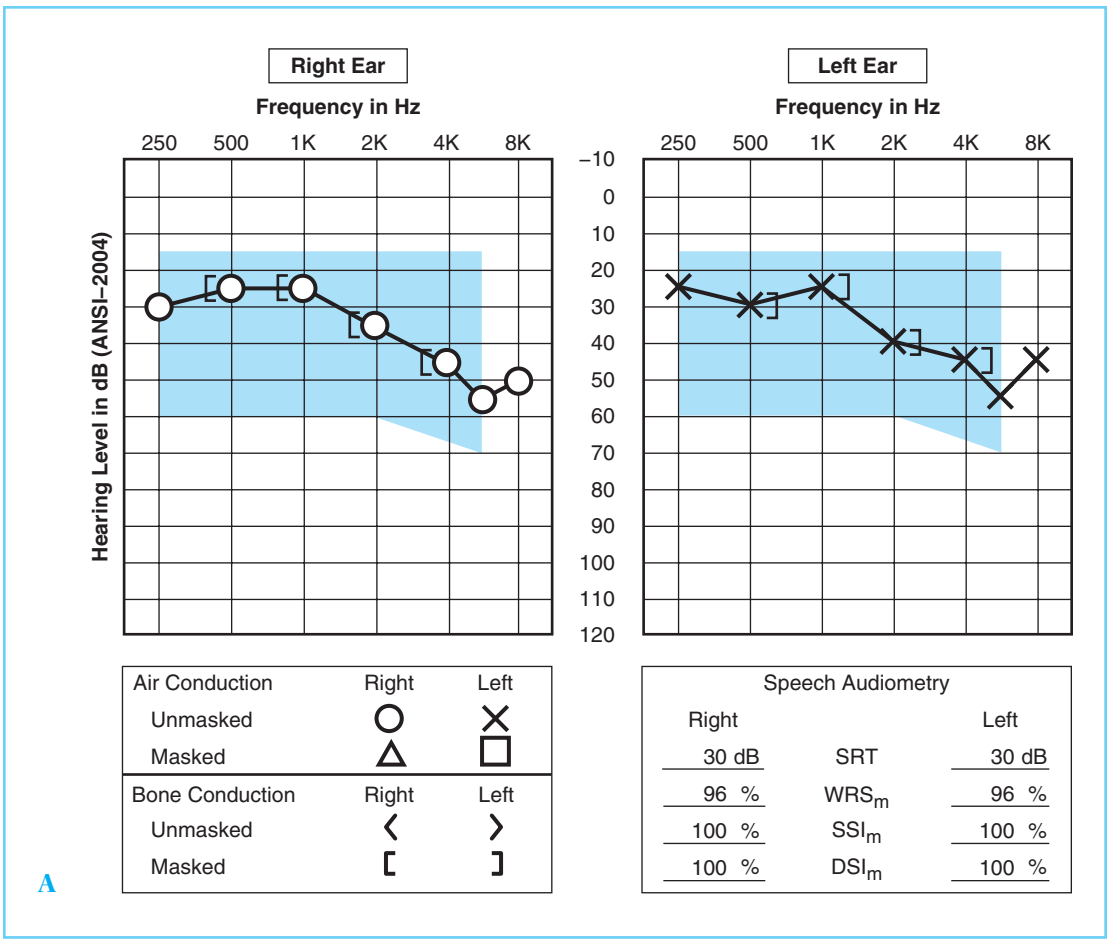
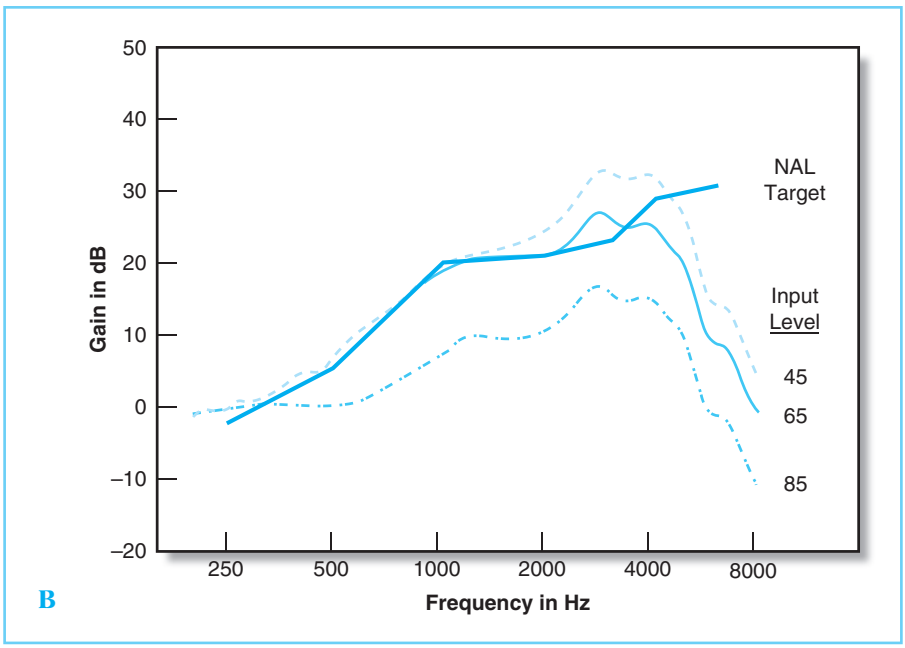


FIGURE 15-1 Hearing and hearing-aid consultation results in a 54-year-old man with bilateral sensorineural hearing loss. Pure-tone thresholds (A) are superimposed on the fitting range of the selected hearing aids. Probe-microphone measurements (B) from the right ear are compared to the targeted frequency gain.

After the hearing aids were programmed, real-ear assessment of the output of the hearing aid was made with probe-microphone measurements. Figure 15-1B shows the responses of the right-ear hearing aid to three levels of input signals and how they compare to a targeted frequency gain. Verification of the fitting was made by asking the patient to judge the loudness of speech presented at 45, 65, and 85 dB SPL. Adjustments were made to ensure that the patient heard the speech as soft, moderate, and loud, but not too loud.



Outcome measurements were made after 1 month of hearing aid use. The self-assessment scale that was given at the time of the initial treatment assessment was readministered. Results were compared to the earlier evaluation and showed that communication problems were reduced for him in most listening environments with the hearing aids.

Geriatric Sensorineural Hearing Loss

Treatment Goals

Hearing loss that occurs with aging is not necessarily different than that which occurs in younger adults. In some older patients, however, the sensitivity loss is confounded by changes in central auditory nervous system function. As a consequence, in addition to the problems described above, hearing impairment may result in:

- significant reduction in ability to hear speech in background noise;
- diminished ability to use two ears for sound localization and for separation of signals from noise; and
- reduced **temporal processing** of auditory information.

The ability of the auditory system to deal with timing aspects of sound is called **temporal processing**.

Hearing aid amplification, then, must be targeted either to overcome these problems or to reduce the impact of their influence. When fitting hearing aids on older patients, the audiologist must remember that sound emanating from the hearing devices needs to be processed by the auditory nervous system. When the nervous system is intact, the hearing devices need to overcome the peripheral cochlear deficit. However, as people age, so too do their auditory nervous systems, and this aging process is not without consequences. Audiologists are often confronted in the clinic with the impact of the aging auditory nervous system on hearing ability in general and on conventional hearing device use in particular. It appears that patients with demonstrable deficits from **senescent** changes in the auditory nervous system do not benefit as much from conventional hearing devices as their younger counterparts (for a review, see Stach, 2000).

Senescent changes are changes that occur due to the aging process.

Treatment Strategies

Clinical experience with older people suggests that the more that can be done to ease the burden of listening in background noise, whether by sophisticated directional microphones and noise-reduction processing in an ear-level hearing device or by use of a remote microphone, the more likely the patient will benefit from hearing-device amplification. Another important challenge in fitting hearing aids in older individuals is the difficulty involved in the physical manipulation of the device.

Hearing Aid Selection. The technical advances designed to enhance signal-to-noise ratio are, of course, no different for the elderly than for younger patients, but their application is probably more important. The use of binaural hearing aids, directional microphones, and advanced signal processing appear to be key elements in successful fitting. Gain and output characteristics should be similar to those prescribed for younger adults.

Choice of the style of hearing aids can be influenced by dexterity issues. For some older patients, ITE hearing aids are easier to insert and extract than BTE hearing aids with a custom earmold. On the other hand, the smaller the ITE device and its battery, the harder it is for some older patients to manipulate. Most ITE devices can be ordered with an extraction handle, which can be quite helpful to a patient with limited fine-motor control.

Remote controls can be quite useful to some older patients with poor dexterity but a burden to others who are not technologically oriented or who have difficulty remembering where they place things.

Although binaural hearing aids are indicated in most cases, some older individuals have significant ear asymmetries in speech perception and cannot successfully wear two hearing aids. In fact, in some rare cases, fitting a hearing aid on the poorly functioning ear can make binaural ability with hearing aids poorer than the best monaural performance.

Hearing Aid Fitting and Verification. As in younger adults, gain targets should be verified with probe-microphone measurements. Loudness judgments can be obtained reliably in most older patients and can be used to verify that soft sounds are audible and loud sounds not uncomfortable. Finally, verification can be confirmed in many older adult patients with sensorineural hearing loss with speech quality or speech intelligibility judgments. However, this can be a difficult perceptual task for some older listeners, who may have difficulty assigning a quality or intelligibility ranking.

Aided speech-recognition testing may also be helpful in some older patients to help determine if both ears can be aided effectively. Here a comparison should be made of right monaural, left monaural, and binaural speech-recognition ability. If binaural ability is poorer than the best monaural ability, then consideration should be given to fitting only one hearing aid. This, however, will be the exception rather than the rule.

Outcome Measurement. A self-assessment scale should prove useful in pre- and post-fitting assessment of communication abilities and need. Assessment by a spouse or significant other can also be quite useful in this age range.

Rehabilitation Treatment Plan. Despite all of the technical advances in conventional hearing aids, some older people cannot make use of conventional hearing aids. In such cases, the use of remote-microphone technology for the enhancement of the signal-to-noise ratio has been a successful approach. Many audiologists believe that it is good practice to familiarize older patients

with personal FM systems and other ALDs during the orientation process so that if hearing aid benefit declines, they will be aware of an alternative solution to their hearing problems.

Older patients may also benefit from various forms of group or individual aural rehabilitation and speechreading classes. They may also find value in the home programs developed to help them address their communication needs.

Illustrative Case

Illustrative Case 15-2 is an older patient with a long-standing sensorineural hearing loss. The patient is a 70-year-old woman with bilateral sensorineural hearing impairment that has progressed slowly over the last 10 years.

An audiological assessment revealed normal middle-ear function and a bilateral, symmetric, sloping, sensorineural hearing loss.

Speech recognition ability is reduced in comparison to that which would be expected from the hearing loss. Word recognition in quiet was predictable, with maximum scores of 80% on the right ear and 76% on the left, but hearing in competition was reduced. Maximum scores for a measure of sentences in competition are only 50% on the right ear and 40% on the left ear. In addition, her dichotic performance showed a mild deficit with scores of 70% on the left ear and 100% on the right. These results are not unusual for someone who is 70 years old and may contribute as much to her hearing difficulties as the sensitivity loss.

A treatment assessment revealed that this was a very active older woman who participated in a number of activities in her life that created significant communication demands. She served on the volunteer boards of a number of civic and charitable organizations. She was seen often on the society page of the newspaper at charity functions. She was a patron of the arts, with a particular fondness for the orchestra. She was beginning to feel embarrassed about her hearing loss and having to ask people to repeat themselves. She felt as if she were missing a lot of conversations at dinners. She also felt as if her hearing loss was making her appear old, a condition in which she had no interest. She felt as if she was

able to hear well in quiet but had communication problems a significant proportion of the time in noisy environments. She did not have financial concerns over the costs of technology.

The first step in the selection process was to demonstrate to her how inconspicuous BTE hearing aids could be with her current hairstyle. Once that barrier was crossed, binaural hearing aids were chosen at the highest feature/technology level. Figure 15-2 shows the audiogram from each ear superimposed on the fitting range

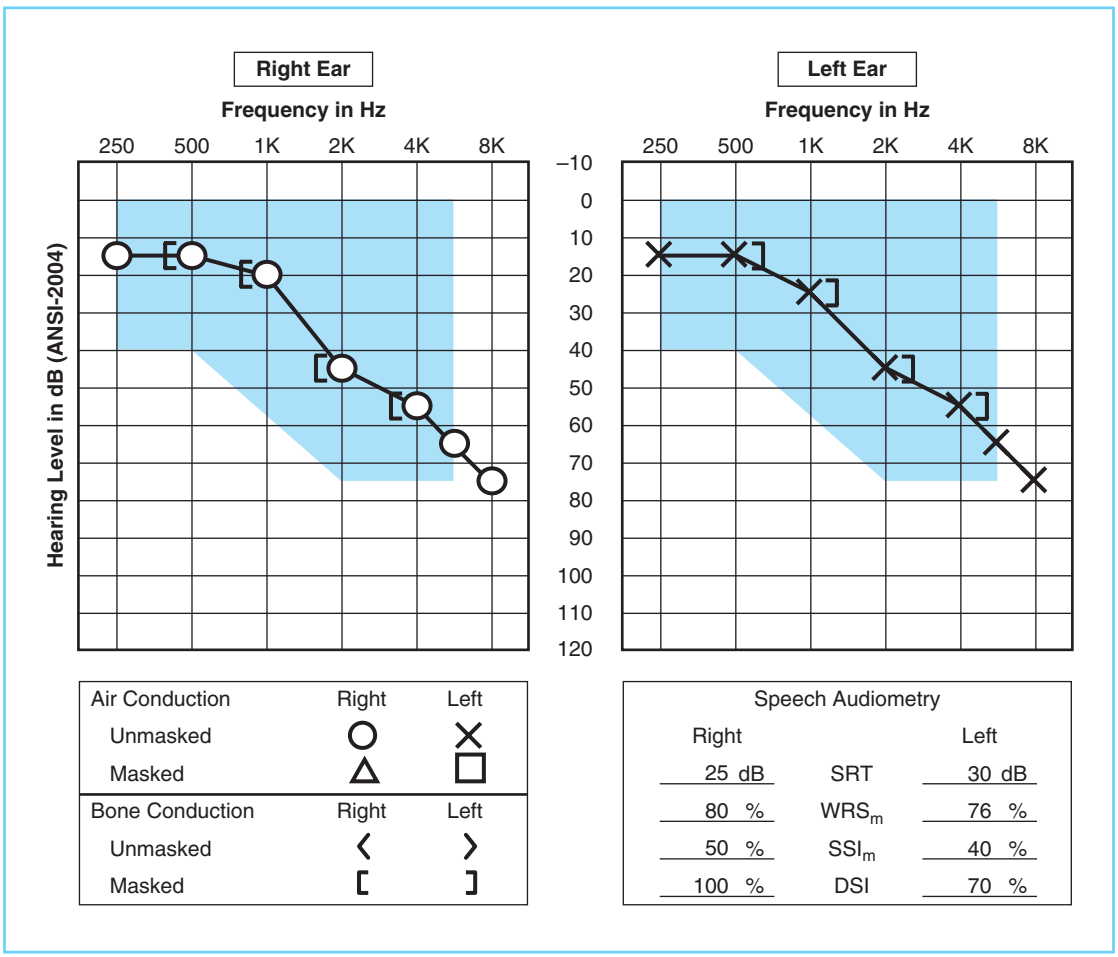


FIGURE 15-2 Hearing consultation results in a 70-year-old woman with bilateral sensorineural hearing loss. Pure-tone thresholds are superimposed on the fitting range of the selected hearing aids.

of the hearing aids that were selected. The hearing aids included a wireless technology solution that allowed the instruments to communicate with each other and with other electronic devices, such as mobile phones, computers, and personal music players. The binaural communication technology is designed to improve spatial hearing and to deliver high fidelity sound in a realistic way.

Following programming of the devices, frequency gain was adjusted by measuring real-ear responses with a probe microphone to targets for soft and loud sounds. Loudness, quality, and intelligibility ratings were then made of speech signals and the gain adjusted slightly. Because of her dichotic deficit, speech recognition was measured in the soundfield. Sentences were presented from a speaker in front and speech competition from behind. Results showed a slightly reduced performance on the left monaural condition, but a slight enhancement binaurally. These results suggested that the left ear was not interfering with her binaural ability.

Because of the wireless capability of the hearing aids, the patient was introduced to the ways her hearing aids could be connected to external electronic signals and to remote microphone technology. The patient seemed to enjoy the gadgetry and thought she might have the perfect purse for the remote microphone.

Outcome measures were given after one month of hearing aid use by re-administering the self-assessment scale that was given at the time of her hearing aid selection. Results showed that her communication problems, particularly those in noise, were reduced significantly. She reported using her hearing aids without the remote microphone a significant portion of the time but that she would use the microphone discretely in certain listening environments. She also thought that the interface to her car navigation system was particularly useful.

PEDIATRIC POPULATIONS

Pediatric Sensorineural Hearing Loss

Treatment Goals

The rehabilitative goal for young children is to maximize the auditory system's access to sound to ensure the best possible hearing for the development of oral language and speech. The specific

aims are to provide the best amplification possible, supplemented with hearing assistive technology when indicated, and to provide maximum exposure to language stimulation opportunities.

Hearing impairment in children results in the following problems:

- loss of hearing sensitivity, so that soft sounds need to be amplified to become audible;
- degree of sensitivity loss that varies with frequency and is generally greater in the higher frequencies;
- reduced dynamic range from the threshold of sensitivity to the threshold of discomfort; and
- nonlinearity of loudness growth.

You will notice immediately that these are the same problems faced by adults. Thus, in meeting the specific aim related to hearing aids, the actual hearing loss challenges are not different than those of adults. That is, sensorineural hearing loss in young children is essentially the same as sensorineural hearing loss in adults. That may well be where the similarity ends.

Treatment Strategies

Hearing aid selection and fitting in children with sensorineural hearing impairment is a challenging business for various reasons (for a review, see Lewis, 2000). What makes children different? Well, for one, they are smaller and, for two, their smallness changes. The size of their ear canals results in a smaller volume of space between the end of the earmold or hearing aid and the tympanic membrane. This results in higher sound pressure levels than in adults. Children also have different resonance characteristics. These physical factors must be accounted for as they change over time.

Another thing that makes children different is that the information we have about their hearing loss and ability may be known only generally at the beginning of the fitting process. Audiograms may simply be estimates of degree and configuration of the loss based on auditory evoked potential results. And we are unlikely to have any sense of discomfort levels through the first few years of life. Children are also less likely or able to participate in the selection and fitting process.

Regarding the actual hearing devices, there are at least three factors that must be considered. First, children probably need undistorted auditory input more than anyone because they are learning speech and language. Whereas adult knowledge of speech and language can fill in for missing or distorted input, children learning language through the auditory system have no linguistic basis for doing so. Second, children cannot manipulate their hearing aids in the same way that adults can, and they can't control their listening environment. Third, hearing may be more variable in young children due to progression or to fluctuation secondary to otitis media.

All of these factors must be considered in the approach taken to hearing aid amplification in children. Following are general guidelines for fitting children.

Hearing Aid Selection. Children should always be fitted with binaural hearing aids unless contraindicated by medical factors or extreme hearing asymmetries. The goal is to maximize residual hearing, and two ears will accomplish that better than one.

Because the auricle and ear canal grow in size, the custom part of the hearing aid will need to be changed frequently while the child is young. As a result, most audiologists choose to fit BTE hearing aids and change the earmolds as indicated rather than having an ITE case changed. Soft materials should be used for earmolds, and the earmolds should be connected to pediatric earhooks for proper fitting.

Flexibility in the fitting range of hearing devices is necessary for young children for at least three reasons. First, the degree and configuration of hearing loss may be known only generally at the beginning of the fitting process. The final frequency gain characteristics may only resemble those tried initially. Second, hearing is likely to fluctuate if the child has bouts of otitis media with effusion, and flexibility again will be required. Third, hearing loss can be progressive in children, and the more flexible the fitting range, the more likely the hearing aids can be adjusted to some extent to keep up with the changes.

Gain and output characteristics should be similar to those in adults, but targets may be more difficult to determine because of

limited audiometric data. Fortunately, algorithms have been developed to predict targets for frequency-specific gain to low-level and high-level input from audiometric data of children.

Another consideration for selecting hearing devices for children is the capacity for access to the devices from remote microphones and other sources. Direct audio input, telecoils, and other wireless techniques are important for classroom and other listening environments.

One other consideration is the use of directional microphones. Because children are normally fitted with BTE hearing aids, they necessarily lose some of their natural directionality when the microphone is moved from the tympanic membrane to the side of the head. Although directional microphone use in children has been controversial over the years, it seems intuitively appealing to want to give them back some of the lost directionality.

Hearing Aid Fitting and Verification. Fitting challenges start with the making of earmold impressions. The audiologist who is thinking ahead will make ear impressions while the child is undergoing ABR verification of hearing loss and is sleeping or sedated. Otherwise, the making of ear impressions in young children can be as much a matter of will as of technical ability.

Prescriptive targets have been developed for children. An example is the DSL[i/o] approach described in the previous chapter. Just as in adults, these targets can be verified by probe-microphone measurements. The case can easily be made that such measures are even more critical in children due to their ear canal size and variability. Again, the challenge here is usually not the measurement, but maintaining the child's cooperative spirit during the procedure.

It is not uncommon in pediatric fitting to verify with functional gain measures. Functional gain targets for children have been estimated from threshold data and can be used to serve as a guideline for fitting verification. As children get older, comfort levels can be estimated similarly.

It is also not uncommon to measure speech recognition with the hearing aids. The procedure is not unlike that used in adults,

wherein speech targets can be presented in the presence of background competition and the child attempts to identify the speech, usually through a picture pointing task. Aided results can be compared to unaided results and to expectations for normal hearing ability under similar circumstances.

Outcome Measures. Validation of the success of hearing aid fitting depends on directed observation of hearing ability by parents, teachers, therapists, and audiologists. Outcome measurement scales have been developed for assessing hearing aid success in children (for a complete review, see Johnson & Danhauer, 2002). Examples include the Family Expectation Worksheet (Palmer & Mormer, 1997) and Children's Outcome Worksheets (COWs). These measures identify children's communication needs and are administered before hearing aid fitting and periodically thereafter as a method of validating the amplification success.

Rehabilitation Treatment Plan. Once the hearing aid has been fitted, treatment begins. Depending on the degree of hearing loss, intensive auditory training, language stimulation, and speech therapy are introduced in an effort to maximize language development (for an overview, see Clark, 2007; Cole & Flexer, 2007).

Children are likely to use remote-microphone systems in classrooms at school, and proper fitting and orientation are imperative. Many parents find that supplemental use of an FM system at home can greatly enhance the language stimulation opportunities as well.

Illustrative Case

Illustrative Case 15-3 is a young child with a fluctuating, mild-to-severe sensorineural hearing loss bilaterally. The patient is a 4-year-old girl. She is enrolled in speech-language therapy for receptive language delay and articulation disorder. The hearing impairment appears to be caused by CMV or cytomegalic inclusion disease, a viral infection usually transmitted in utero. There is no family history of hearing loss and no other significant medical history.

An audiological evaluation shows normal middle-ear function; a bilateral, mild-to-severe, sensorineural hearing loss; and

speech-recognition ability that is congruous with the degree and configuration of hearing loss. Results are shown in Figure 15-3A.

The child's age and the fluctuating nature of the hearing loss were two major factors in the decision about type of amplification device to use. The decision was made to fit the child with binaural hearing aids, because nothing about her ears or hearing loss contraindicated the use of two devices. BTEs were chosen based on

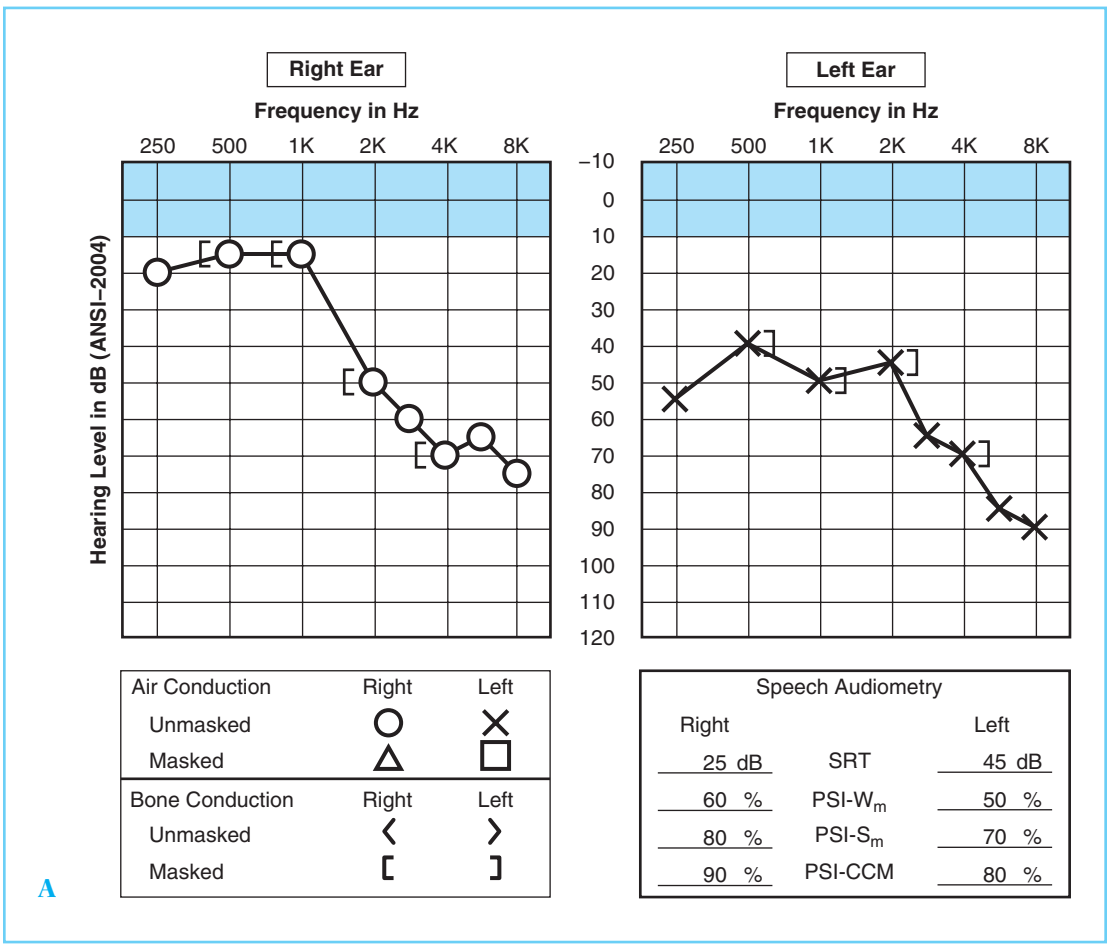
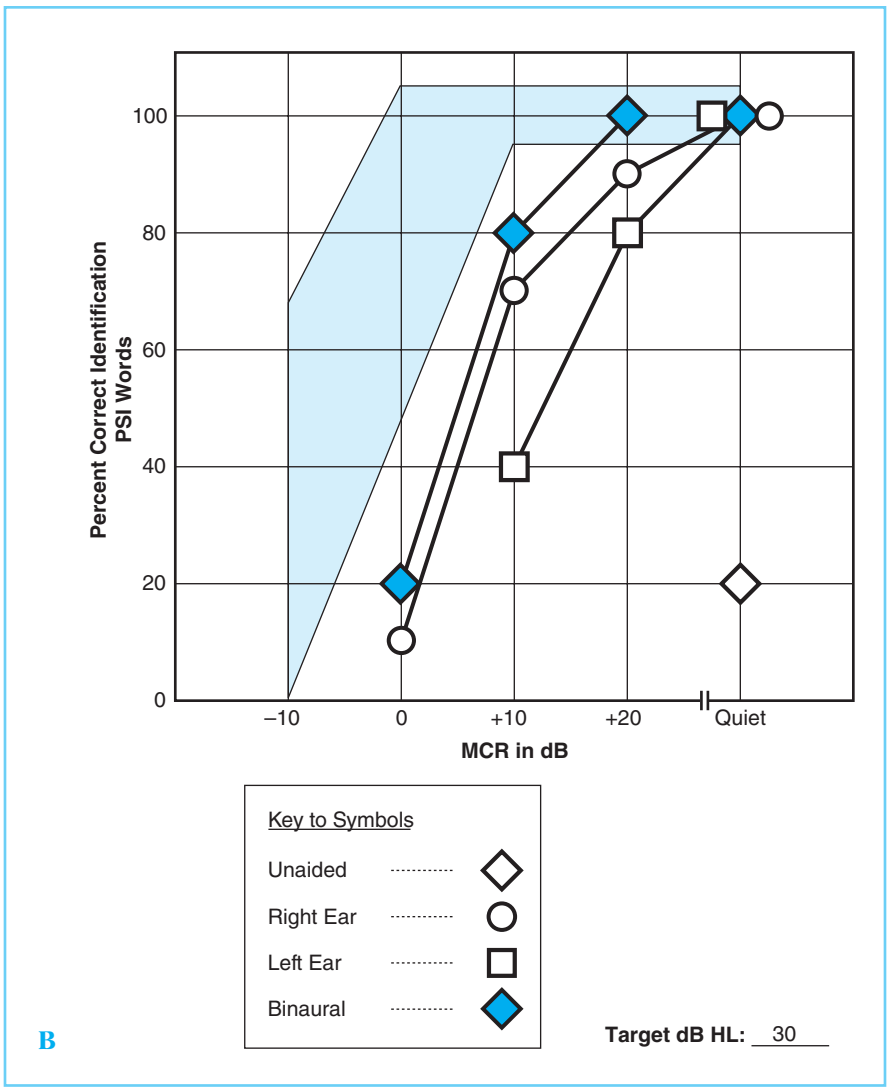


FIGURE 15-3 Hearing and hearing-aid consultation results in a 4-year-old child with hearing loss secondary to CMV infection. Pure-tone and speech audiometric results (A) show bilateral mild-to-severe sensorineural hearing loss and speech-recognition ability consistent with the loss. Aided speech-recognition results (B) show appropriate aided performance.



B

the practicality of replacing earmolds as her ears grow. Devices were chosen that have a wide fitting range to permit changes in case her hearing loss continues to fluctuate or progress.

With regard to the other characteristics of the hearing aid, a decision was made to use directional microphones in an effort to enhance the signal-to-noise ratio of sounds emanating from the front of the child. The hearing aids also included telecoils for use with neck-loop receivers of remote-microphone systems.

Fortunately for a 4-year-old child, real-ear assessment of the output of the hearing aids could be made with probe-microphone measurements. Responses of both hearing aids to low and high input signals were compared to the targeted frequency gains based on the DSL[i/o] formula and adjusted to approximate them. Adjustments were also made to ensure that the patient was not provided with too much output for her comfort.

Aided speech-recognition ability was also assessed at the time of initial fitting. The patient's speech-recognition performance with the hearing aids is shown in Figure 15-3B. Here, materials were used that were age-appropriate for the child. Results show very good speech-recognition performance in the aided conditions.

Outcome assessment was also made as part of an ongoing follow-up process to ensure that the child was receiving adequate aided gain and to assess the impact of any hearing fluctuation on performance with the hearing aids. When this child enters school, the use of classroom amplification will become important. Her hearing aids have t-coils built in to be used with a neck loop on a remote-microphone system for classroom use.

This patient had normal speech and oral language development prior to the initial reduction in her hearing. However, she is now at risk for developing speech and academic-achievement problems and needs to be monitored carefully.

Auditory Processing Disorder

Treatment Goals

APD is an auditory disorder that has as one of its main components difficulty in understanding speech in background noise. Treatment goals that focus on this component are often effective in forestalling academic achievement problems that may be related to the presence of APD (for a review, see Chermak & Musiek, 2007).

Intervention strategies directed toward enhancement of signal-to-noise ratio have proven successful in the treatment of children with APD. There are at least two approaches to this type of intervention. The first approach is to alter the acoustic environment to enhance the listening situation. Environmental alterations

include practical approaches such as preferential seating in the classroom and manipulation of the home environment so that the child is placed in more favorable listening situations. Alterations may also include equipping the classroom with soundfield speakers to provide amplification of the teacher's speech.

It is not uncommon in children with APD for the diagnosis itself to serve as the treatment. That is, once parents and teachers become aware of the nature of the child's problem and that the solution is one of enhancement of the signal-to-noise ratio, they manipulate the environment so that the problem situations are eliminated, and the child's auditory processing difficulties become inconsequential.

In other cases, however, when severity of the auditory processing disorder is greater, the use of remote-microphone technology may be indicated.

Treatment Strategies

The main challenge in treating children with APD is to assist them in overcoming their difficulties in understanding speech in background noise. The main focus of their problems is the classroom setting. In some areas, classrooms have amplification systems that can be used to overcome these problems. If not, the child may benefit from amplification designed to enhance the signal-to-noise ratio.

Hearing Aid Selection. Conventional hearing aids do not appear to be indicated for children with APD. Even mild gain amplification with sophisticated signal processing and noise reduction circuitry may be insufficient to reduce background noise to the extent necessary for children with APD. Here the selection process is focused on finding the right remote-microphone configuration for the child. Generally that means the use of a personal FM system. These systems can be designed to provide a flat frequency response with minimal gain delivered to the ear and low maximum output levels to protect the normal hearing ear from damaging noise levels.

The amplified signal can be delivered to the ear through headphones or through an ear-level receiver.

Hearing Aid Fitting and Verification. Probe microphone measurements can be made of the output of the remote-microphone device to ensure minimal gain and low maximum output.

Speech-recognition testing can also be used to verify that the child can take advantage of enhanced signal-to-noise ratios. A common approach is to present speech signals at a fixed intensity level from a loudspeaker placed in front of a patient, with background competition of some kind delivered from a speaker above or behind. Performance in recognizing the speech targets is then measured, and the competition intensity level is varied to assess ability at various signal-to-noise ratios. Testing is carried out without a device and with the remote microphone in close proximity to the loudspeaker from which the targets are being presented. Performance should increase substantially with the remote-microphone device.

Outcome Measurement. Validation of success with this fitting strategy is made with teacher and parental questionnaires designed to assess the benefit of device use in the classroom and at home. Appropriate questionnaires include assessment of listening skills, general behavior, apparent hearing ability, and general academic achievement before and after implementation of device usage. The questionnaire also addresses the emotional impact of device use in the classroom.

Rehabilitation Treatment Plan. Children with APD may also benefit from auditory-training therapy directed toward enhancement of the ability to process auditory information and toward development of compensatory skills (see Geffner & Ross-Swain, 2007).

Because children with APD often have **concomitant deficits** in speech, language, attention, learning, and cognition, comprehensive approaches to treatment are recommended. Treatment for memory, vocabulary, comprehension, listening, reading, and spelling are often necessary in children with multiple involvement.

Concomitant deficits are those that occur together.

Illustrative Case

Illustrative Case 15-4 is a young child with auditory processing disorder. The patient is a 6-year-old girl with a history of chronic otitis

media. Although her parents have always suspected that she had a hearing problem, pure-tone screenings in the past revealed hearing sensitivity within normal limits. Tympanometric screenings revealed type B tympanograms during periods of otitis media and normal tympanograms during times of remission from otitis media.

An audiological evaluation showed normal middle-ear function, normal hearing sensitivity, abnormal speech-recognition ability, and abnormal auditory evoked potentials. Results are summarized in Figure 15-4A.

Speech audiometric results show two indicators of APD. On the right ear, performance on measures of words and sentences in competition show rollover of the performance-intensity function; performance actually worsens as intensity is increased. On the left ear, performance on a measure of word recognition in competition is significantly poorer than sentence recognition.

A treatment assessment showed that this child has substantial difficulty hearing in noisy and distracting environments. She is likely to be at risk for academic achievement problems if her learning environment is not structured to be a quiet one.

Initially, the parents were provided with information about the nature of the disorder and the strategies that can be used to alter listening environments in ways that might be useful to this child.

The parents found this information to be quite useful and to go a long way in solving the patient's communication needs in the home environment. However, once the child entered school, the hearing problem resurfaced.

A re-evaluation showed little change in the patient's processing ability. Consultation with the parents and teacher led to a decision to try the use of a personal FM system in the classroom.

Personal FM systems for use with those who have normal hearing sensitivity generally provide a flat frequency response with very little gain across the frequency range. The input-output is generally linear. Output limiting is of little concern because of the minimal gain characteristics. A set of contemporary ear inserts were used, a solution that tends to be acceptable if not enviable in today's classroom.

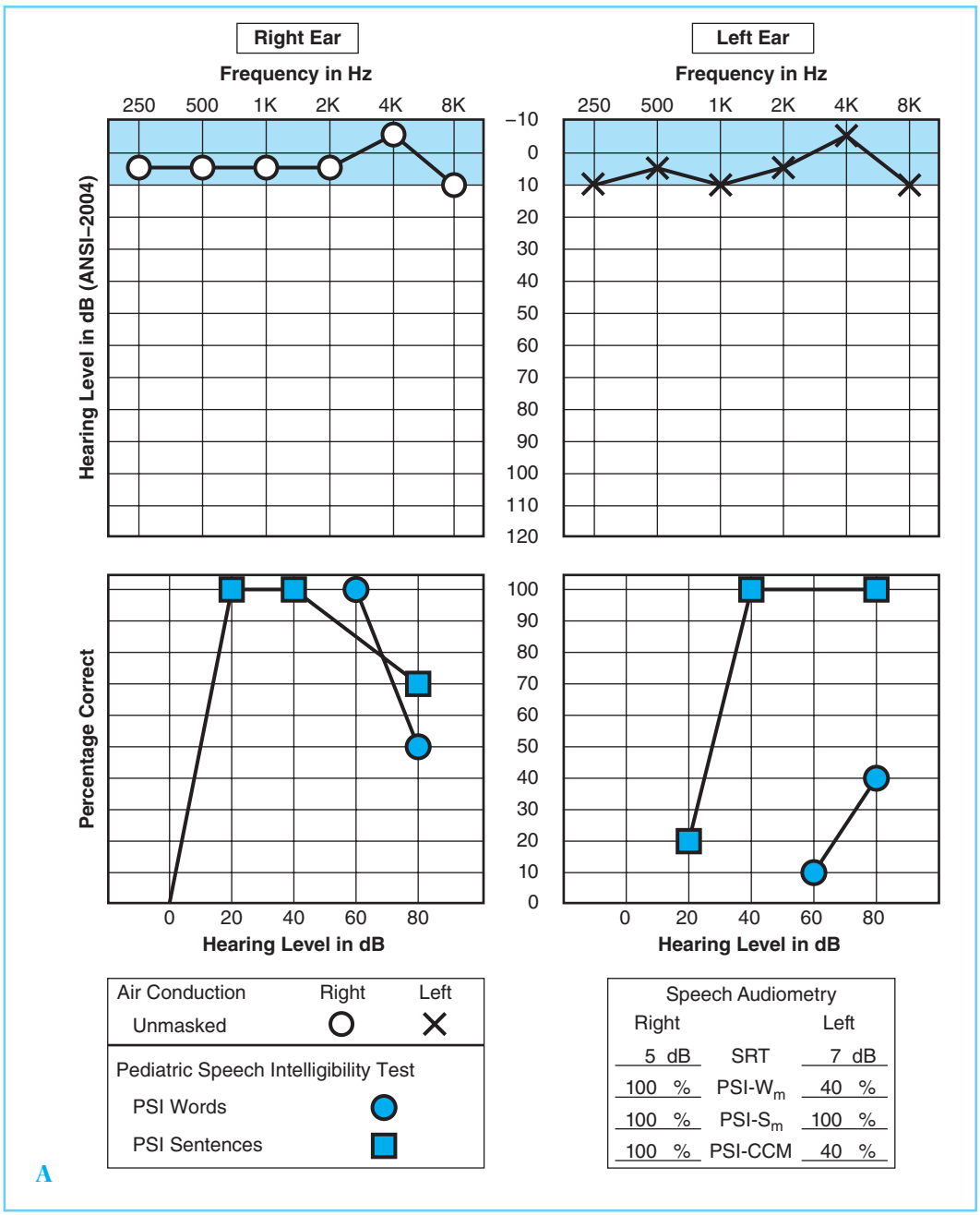
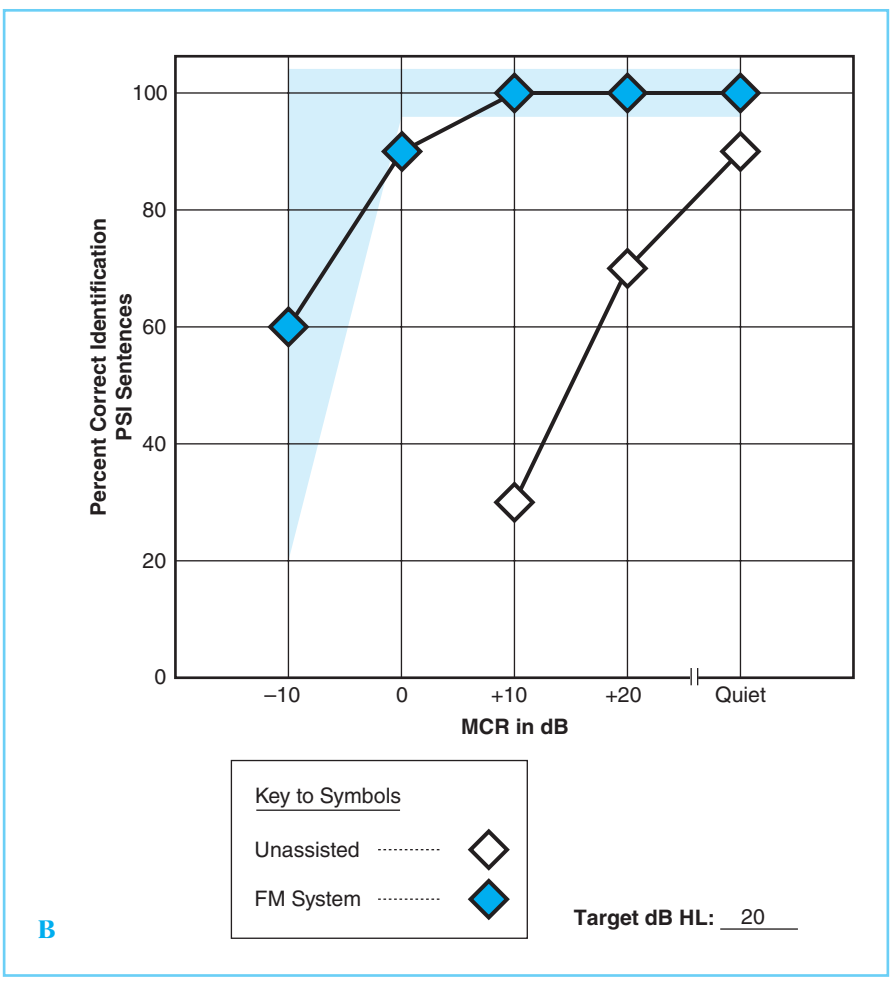


FIGURE 15-4 Hearing consultation results in a 6-year-old child with auditory processing disorder. Pure-tone and speech audiometric results (A) show normal hearing sensitivity and abnormal speech-recognition ability. Aided results (B) show good speech-recognition performance with an FM system in a soundfield.

Performance with the FM system was assessed by measuring speech-recognition in the sound field with the microphone located at the child's ear and in proximity to the loudspeaker from which the target emanated. Results are shown in Figure 15-4B. As expected, the patient enjoys substantial benefit from the enhancement of signal-to-noise ratio.

The child uses the FM system in the classroom and under certain circumstances at home. Parent and teacher reports substantiate the benefits of an enhanced listening environment for this child.



B

OTHER POPULATIONS

Conductive Hearing Loss

Treatment Goals

Conductive hearing loss results from disorders of the outer or middle ears. In most cases, these disorders can be treated medically or surgically, and little residual hearing impairment remains. In a small percentage of patients, however, the disorder cannot be treated. For example, a patient who has experienced multiple surgical procedures for protracted otitis media and **mastoiditis** might end up with middle-ear disorder that is beyond surgical repair. In such cases, a hearing device might be the only realistic form of rehabilitation. As another example, patients with **congenital atresia** have hearing loss due to lack of an external auditory meatus. Although this condition is surgically treatable, it is usually not carried out in children until they are older. In such cases, hearing aid use will be necessary during the presurgical years.

Inflammation of the bony process behind the auricle is called **mastoiditis**.

Congenital atresia is the absence at birth of the opening of the external auditory meatus.

The goal in the treatment of intractable conductive hearing loss is to maximize the auditory system's access to sound with some form of amplification. A conductive hearing loss acts as a sound attenuator, with little reduction in suprathreshold hearing once sound is made audible. Hearing aid amplification, then, is targeted at this primary manifestation of conductive hearing impairment.

Treatment Strategies

Overcoming the attenuating effects of conductive hearing loss is relatively simple from a signal processing strategy. The challenge in this population is more often related to providing a satisfactory physical fit for the amplification device or deciding on the surgical solution of a bone-anchored hearing aid.

Recall from Chapter 13 that a BAHA consists of a titanium screw that is surgically placed into the mastoid bone. An external amplifier that is essentially a bone vibrator is snapped into the screw and sends vibratory energy to the screw, which in turn stimulates the cochlea via bone conduction. So at some point in the process, a patient needs to decide whether to pursue conventional hearing aid use or the use of a BAHA. Advantages of the BAHA include

ease and comfort of use, no feedback, and excellent sound quality delivered to the cochlea. Advantages of conventional hearing aids include considerably less cost than the BAHA, better directional hearing, and better binaural hearing.

Hearing-Device Selection. Patients with permanent conductive hearing loss in both ears should be fitted with binaural hearing aids unless otherwise indicated.

A permanent conductive loss is usually flat in configuration, requiring a broad, flat frequency gain response. Loudness growth in a conductive hearing loss is equivalent to that of a normal ear. Therefore, the device should be programmed to resemble linear gain. Also, because the conductive loss acts as an attenuator, the hearing aid should be programmed to provide additional gain on the order of 25% of the air-bone gap at a given frequency. There are few concerns regarding output limitation, because the attenuation effect of the conductive hearing loss serves as a protective measure.

The style of hearing aid depends on the nature of the disorder causing the conductive hearing loss. For example, permanent conductive hearing loss secondary to chronically draining ears requires a BTE hearing aid with sufficient venting due to the drainage. Because a conductive hearing loss requires more gain than a sensorineural hearing loss, this venting must be done carefully to avoid feedback problems.

As another example, bilateral atresia requires the use of a bone-conduction hearing aid or a BAHA. In a bone-conduction hearing aid, the normal receiver is replaced with a bone vibrator that is designed to stimulate the cochlea directly, bypassing the closed ear canal.

Hearing Aid Fitting and Verification. The frequency gain and maximum output characteristics are programmed to meet target gain estimates. Fitting of a conventional device can then be done with probe-microphone measures, depending on the physical status of the ear canal. Often there is some sensorineural component to the loss, and assessment of discomfort levels and speech perception may add value to the verification process.

Fitting of BAHA and bone-conduction hearing aids requires functional gain measurement for output verification. The output of the hearing aid can be adjusted until targeted functional gain levels are met.

Outcome Measurement. As with any hearing device, a self-assessment scale will prove useful in pre- and post-fitting assessment of communication abilities and needs.

Rehabilitation Treatment Plan. Other rehabilitation needs are often unnecessary for those with permanent conductive hearing loss. The exception is the child with congenital, bilateral atresia, who, until proven otherwise, will need all of the intensive hearing and language stimulation training of children with sensorineural hearing impairment. The efficiency with which such training can be accomplished is likely to be better in the child with atresia because of normal cochlear function.

Illustrative Case

Illustrative Case 15-5 is a young patient with bilateral conductive hearing loss due to long-standing untreated middle-ear disorder. The patient is a 19-year-old woman. As a child, she experienced chronic otitis media with effusion that was not treated because of restricted access to appropriate health care. As a result of the chronic nature of the disease process, her middle-ear structures eroded to a point that surgical attempts to reconstruct the middle ears failed. Although there was no longer any active disease process, the conductive hearing loss remained. She had used binaural BTE hearing aids for the last several years but wanted to see if she was a candidate for a bone-anchored hearing aid.

An audiological assessment revealed a bilateral, symmetric, flat conductive hearing loss and good suprathreshold speech-recognition ability. Results are shown in Figure 15-5A.

A treatment assessment showed the patient to benefit significantly from her BTE hearing aids. She was asked to compete a self-assessment of her communication with and without use of the devices, and the contrast was substantial in terms of ease of communication. However, she didn't enjoy wearing BTE hearing

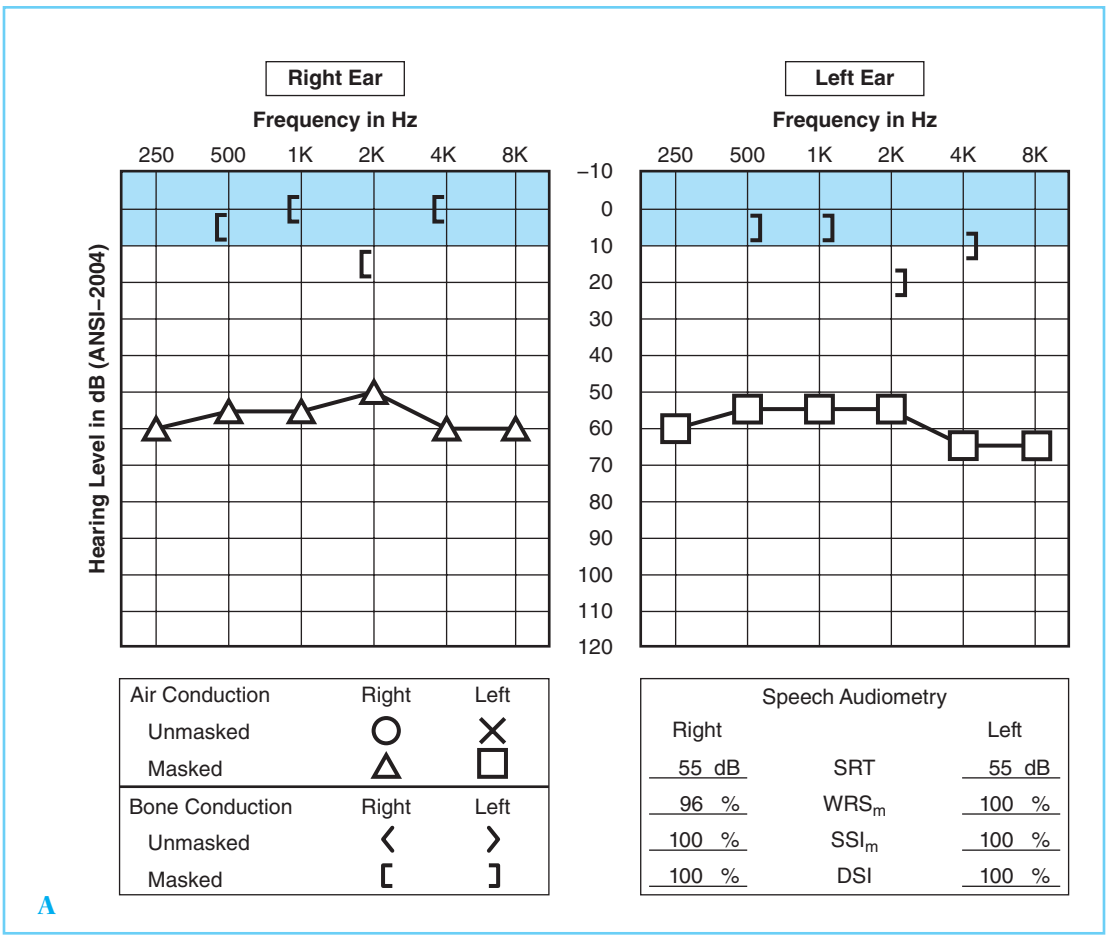
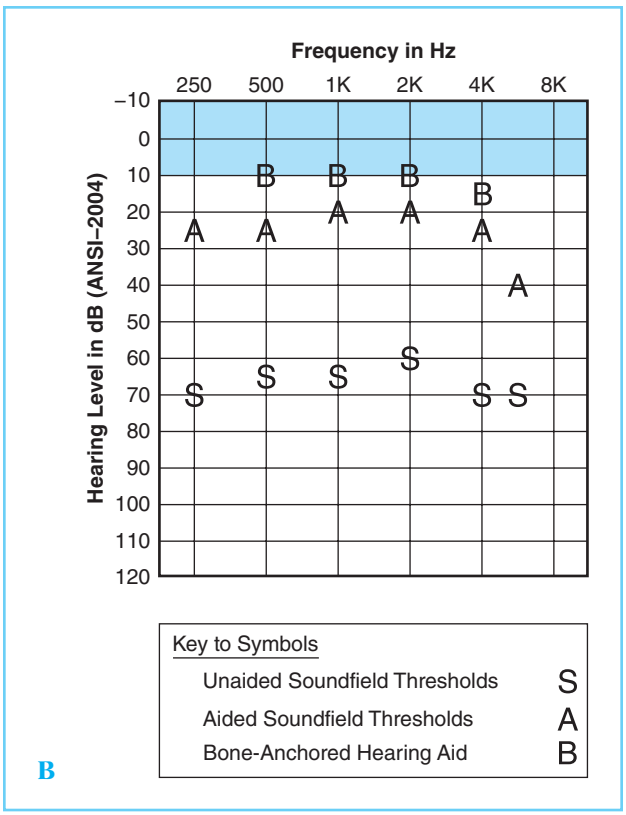


FIGURE 15-5 Hearing consultation results in a 19-year-old woman with intractable middle-ear disorder. Pure-tone and speech audiometric results (A) show flat conductive hearing loss and good suprathreshold speech-recognition ability bilaterally. Soundfield thresholds (B) show appropriate real-ear gain for both conventional hearing aids and a BAHA device.

aids, mostly from an appearance perspective. Her hearing aids were evaluated electroacoustically and shown to be functioning appropriately. Functional gain measures were made and are shown in Figure 15-5B. Results show that she was receiving appropriate gain from the devices.

The otolaryngology consult showed that there was nothing to contraindicate the use of a BAHA nor to contraindicate surgery.



B

The surgery was performed as an outpatient minor procedure and was deemed successful. Following a brief waiting period for healing, she returned for fitting of the device.

The BAHA fitting is relatively straightforward, providing essentially linear gain. Functional gain measures were again made to ensure adequacy across the frequency range. Results showed slightly better functional gain than conventional hearing aids, as shown in Figure 15-5B. Quality and speech perception judgments suggested enhanced benefit over her conventional hearing aids.

After one month of BAHA use, the self-assessment scale that was given at the time of the initial treatment assessment was re-administered. Results were compared to the earlier evaluation and showed that the patient's communication problems were reduced in most environments with the BAHA. Results compared favorably with those of conventional hearing aid use. She reported that

she was very pleased with the quality of sound and the ease of use of the BAHA. At first, she had a difficult time adjusting to a reduction in spatial hearing, but she reported that she was becoming increasingly accustomed to the change and that she perceived the problem to be somewhat minor in comparison to the benefits. She also reported that she still uses her conventional hearing aids on occasion, particularly in noisy environments.

Severe and Profound Sensorineural Hearing Loss

Treatment Goals

Severe and profound hearing impairment in children or adults can substantially limit the use of the auditory channel for communication purposes. Even with very powerful hearing aids, auditory function may be limited to awareness of environmental sounds.

In young children, the prognosis for learning speech and oral language can be quite low. Most children born with profound hearing loss communicate in sign language and have little or no verbal communication ability without audiologic treatment and rehabilitation.

In adults with adventitious severe to profound hearing impairment, reception of verbal communication can be limited, and speech skills can erode due to an inability to monitor vocal output.

The most common first step in hearing treatment in this population is trial use of conventional amplification, followed by cochlear implantation. The treatment goal is the same: maximize access to sound in an effort to ameliorate the communication disorder caused by the hearing loss.

Treatment Strategies

Cochlear implantation is the primary hearing treatment strategy for patients with severe to profound hearing loss. In children under 2 years of age, candidacy for cochlear implantation includes the following criteria:

- profound bilateral sensorineural hearing loss,
- little or no benefit from hearing aid amplification,
- no medical contraindications,

- educational placement in a program that emphasizes audition,
- family support, and
- appropriate expectations.

In children older than 2 years of age, candidacy includes the following criteria:

- severe to profound bilateral sensorineural hearing loss,
- minimal benefit from hearing aid amplification,
- no medical contraindications,
- educational placement in a program that emphasizes audition,
- family support, and
- appropriate expectations.

In adults, candidacy is generally based more on speech perception than on the audiogram. Criteria include:

- severe to profound bilateral sensorineural hearing loss,
- limited benefit from hearing aids, defined as scores of 50% or less on open-set sentence recognition measures on the ear to be implanted and 60% or less on the nonimplanted ear,
- no medical contraindications, and
- appropriate expectations.

Figure 15-6 shows four audiograms from ears that have been successfully implanted to give you a framework for the range of fitting. It is important to emphasize that the criteria have shifted over the years, very appropriately, from those based on thresholds to those based on suprathreshold outcomes. If a patient with severe-to-profound hearing loss is not getting speech perception benefit from appropriately fitted conventional hearing aids, he or she is now considered a candidate for implantation.

Patients with severe to profound hearing loss who are not candidates for cochlear implantation benefit from powerful conventional hearing aids. The selection and fitting strategies for power hearing aids are challenging but straightforward. Binaural hearing aids are used to provide the most gain possible. Hearing aids are

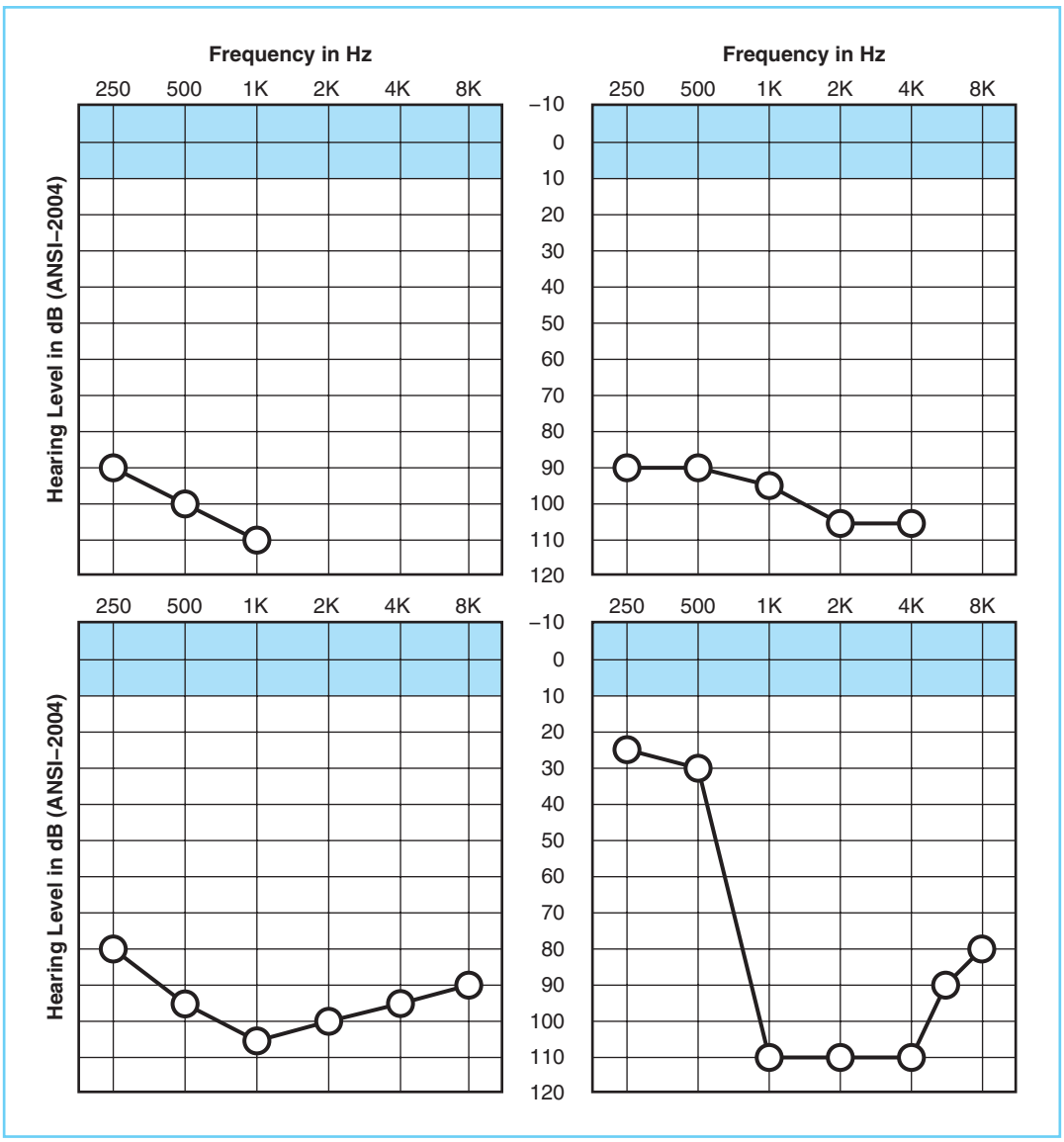


FIGURE 15-6 Audiometric configurations from four individual ears that have been successfully treated by cochlear implantation.

BTE devices with tight-fitting earmolds. Dynamic range is usually quite limited, and maximum output must be carefully adjusted. Because access to sound is limited to begin with, it is imperative to maximize it with features including directionality, noise reduction, and wireless connectivity for remote microphone use.

The remainder of this section will address cochlear implantation as the strategy for hearing treatment of this population.

Cochlear Implant Selection. Once candidacy has been determined, decisions related to strategy are limited mostly to which ear to implant and which brand of device to implant. The former decision is an important one. In general, there is a tendency to implant the better ear if there is a difference in function between ears, assuming that prognosis will be best for successful neural stimulation in that ear.

Most of the selection process is completed once this decision is made. Different manufacturers use different processing strategies, most of which have been implemented with equivalent success.

Device Fitting and Verification. Programming of the cochlear implant processor varies by manufacturer and by processing strategy, but some generalizations can be made. One of the first steps is to determine if activation of a given electrode in the implanted array results in the perception of hearing. If so, then the threshold and dynamic range of that electrode are determined. Once this is done for the entire array, a "map" of these values is created across electrodes. From these basic data, determination is made of which electrodes are to receive frequency and intensity information, depending on the processing strategy that is chosen.

This process of "mapping" the electrodes is an ongoing one that can take several sessions to complete in adults and can take months to complete in young children.

Verification of the map is usually accomplished with the use of soundfield thresholds and speech-recognition testing. Several batteries of tests have been developed for both children and adults to assess performance with the implant devices (for a review, see Zwolan, 2002).

Outcome Measurement. The self-assessment scales of communication abilities and needs that are used for assessing outcomes with conventional hearing aids are appropriate for cochlear implants as well. Similarly, parental and teacher assessment scales designed for hearing aid outcomes in children are also appropriate for cochlear implants.

Rehabilitation Treatment Plan. Rehabilitation treatment planning is similar to that described for conventional hearing devices. Adults may benefit from supplemental use of remote-microphone input and other assistive devices. They might also benefit from courses in speechreading. For young children, implantation simply marks the beginning of the process of speech and language stimulation (see Clark, 2007; Cole & Flexer, 2007).

Illustrative Cases

Illustrative Case 15-6. Case 6 is an adult patient with profound bilateral sensorineural hearing impairment that has progressed over the last 10 years. The patient is a 44-year-old woman. Based on familial history, her hearing impairment is thought to be caused by dominant progressive hereditary hearing loss. She is an accountant in a large insurance firm and, although much of her work is computer based, she feels that she is being left behind professionally and socially because of her substantial hearing impairment.

Figure 15-7A shows the audiogram from each ear. Speech-recognition ability is poor, consistent with the degree of loss. Performance with binaural hearing aids shows some achievable gain, but virtually no benefit in speech-recognition ability. Unaided and aided scores were 0% for both CNC words and Hearing in Noise Test (HINT) sentences presented in quiet.

A treatment assessment showed the patient to be an excellent candidate for implantation. She was in good health and has strong support from her family, friends, and employer. She judges her communication needs and her communication disorder to be substantial.

After evaluation of her unaided and aided performance, a decision was made to pursue the use of a cochlear implant. A device was selected and implanted in her right ear.

Approximately 4 weeks following implantation, the device was activated through the speech processor, and the processor was programmed to stimulate the electrodes that were considered distinctly usable. Programming was accomplished by setting

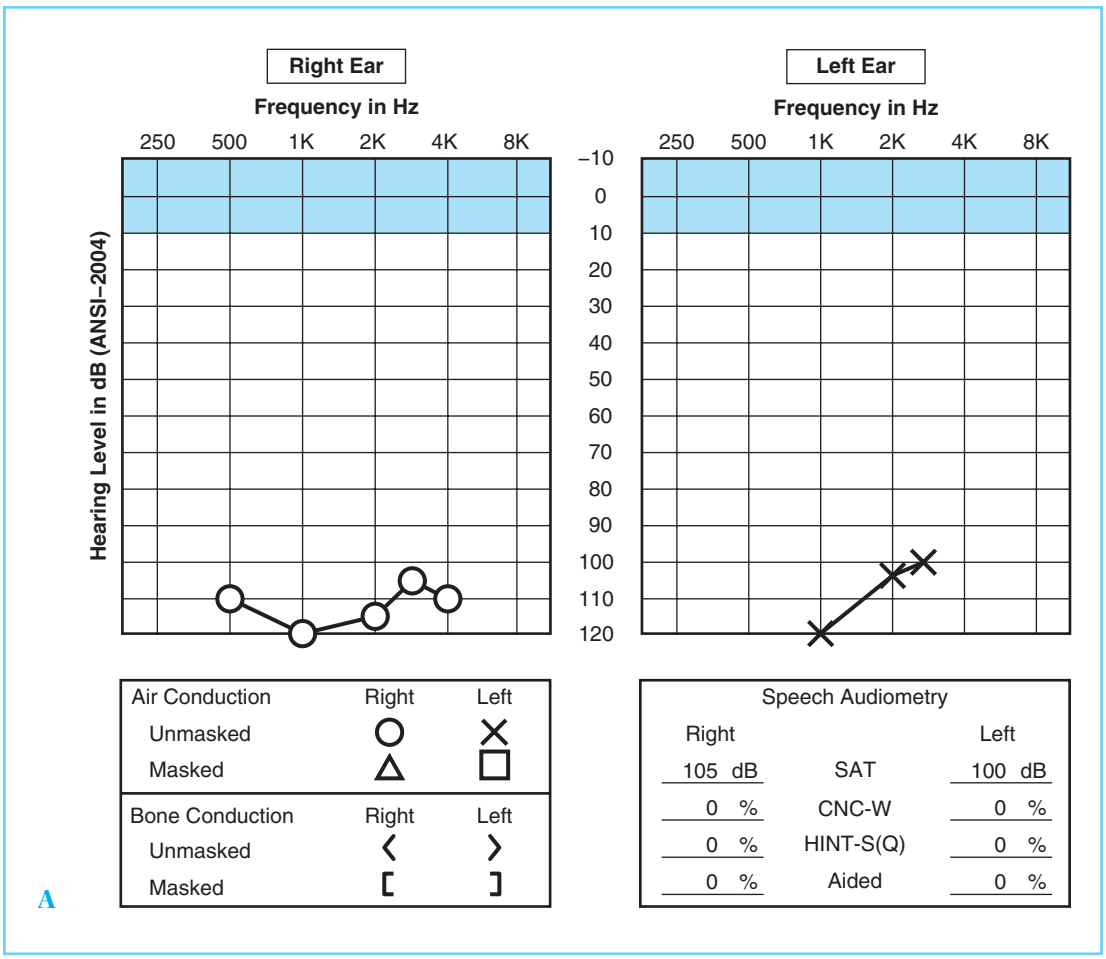


FIGURE 15-7 Hearing consultation results in a 44-year-old woman with profound sensorineural hearing loss. Pure-tone and speech audiometric results (A) show bilateral hearing loss and poor speech-recognition ability with or without conventional hearing aids. Pre- and post-implant results (B) show substantial improvements in audibility and in performance on selected speech-recognition measures.

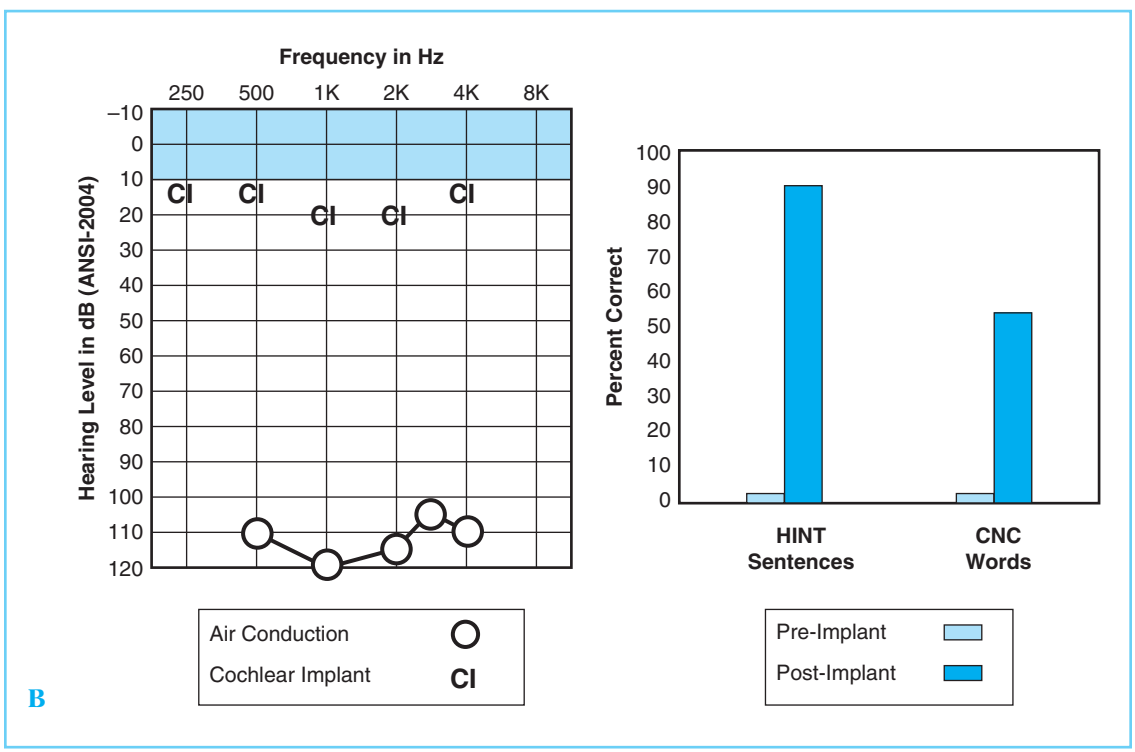
thresholds of detectability of electrical currents delivered to each electrode. Comfort levels were also set for each electrode or group of electrodes. The exact processing strategy was determined from the proprietary strategies available for the specific implant that was chosen.

Performance with the device was assessed by soundfield threshold measures and by comparing pre- and post-implant performance

on a range of speech-recognition measures. Results of the threshold measures and on several selected speech-recognition tests are shown in Figures 15-7B. Results indicated that the cochlear implant was providing very good hearing sensitivity thresholds and substantial improvement in speech-recognition over aided performance.

A self-assessment scale showed that the patient is receiving substantial benefit from the cochlear implant and that, with the implant, her communication problems are reduced in most listening environments.

Illustrative Case 15-7. Case 7 is a young boy with progressive bilateral sensorineural hearing impairment, secondary to a bout of meningitis at age 12 months. The child passed a routine newborn hearing screening at birth, and the parents had no reason to suspect a hearing loss prior to the meningitis.



B

An audiologic evaluation was carried out shortly after his recovery from the medical aspects of meningitis, and he was found to have a moderate sensorineural hearing loss. If his loss had been profound or had there been evidence of cochlear ossification, trial hearing aid use could have been skipped and implantation carried out immediately. Fortunately in this case, there was no evidence of ossification, and his hearing loss was only moderate in degree. He was fitted with binaural BTE hearing aids shortly thereafter and enrolled in an auditory habilitation program aimed at enhancing oral language development. The severity of his hearing loss progressed to moderately severe by 3 years of age and again to severe by 5 years of age. Although he was participating in mainstream education, by 6 years of age he was struggling, and his parents were interested in understanding his alternatives regarding implantation.

An audiological assessment shows severe to profound, primarily sensorineural hearing loss bilaterally. An audiogram is shown in Figure 15-8A. Speech awareness thresholds were in agreement with pure-tone thresholds.

Without hearing aids, speech-recognition was negligible. Aided speech-recognition testing was carried out with the Lexical Neighborhood Test (LNT) (Kirk et al., 1995) and the Multi-Lexical Neighborhood Test (MLNT) (Kirk et al., 1995). Results showed poor aided performance, with scores of 8% on the LNT and 4% on the MLNT.

After careful consideration, the parents decided that the child should receive a cochlear implant. Following recovery from surgery, the speech processor was programmed and reprogrammed in an effort to achieve the best speech and sound recognition ability available from the device. The programming efforts took approximately 3 months to complete.

During the programming period, the child showed substantial improvement in his ability to function with the implants. Speech recognition results at 6 months post-implant are shown in Figure 15-8B. Substantial improvements were noted between the child's ability to recognize speech with the cochlear implant over conventional hearing aid amplification.

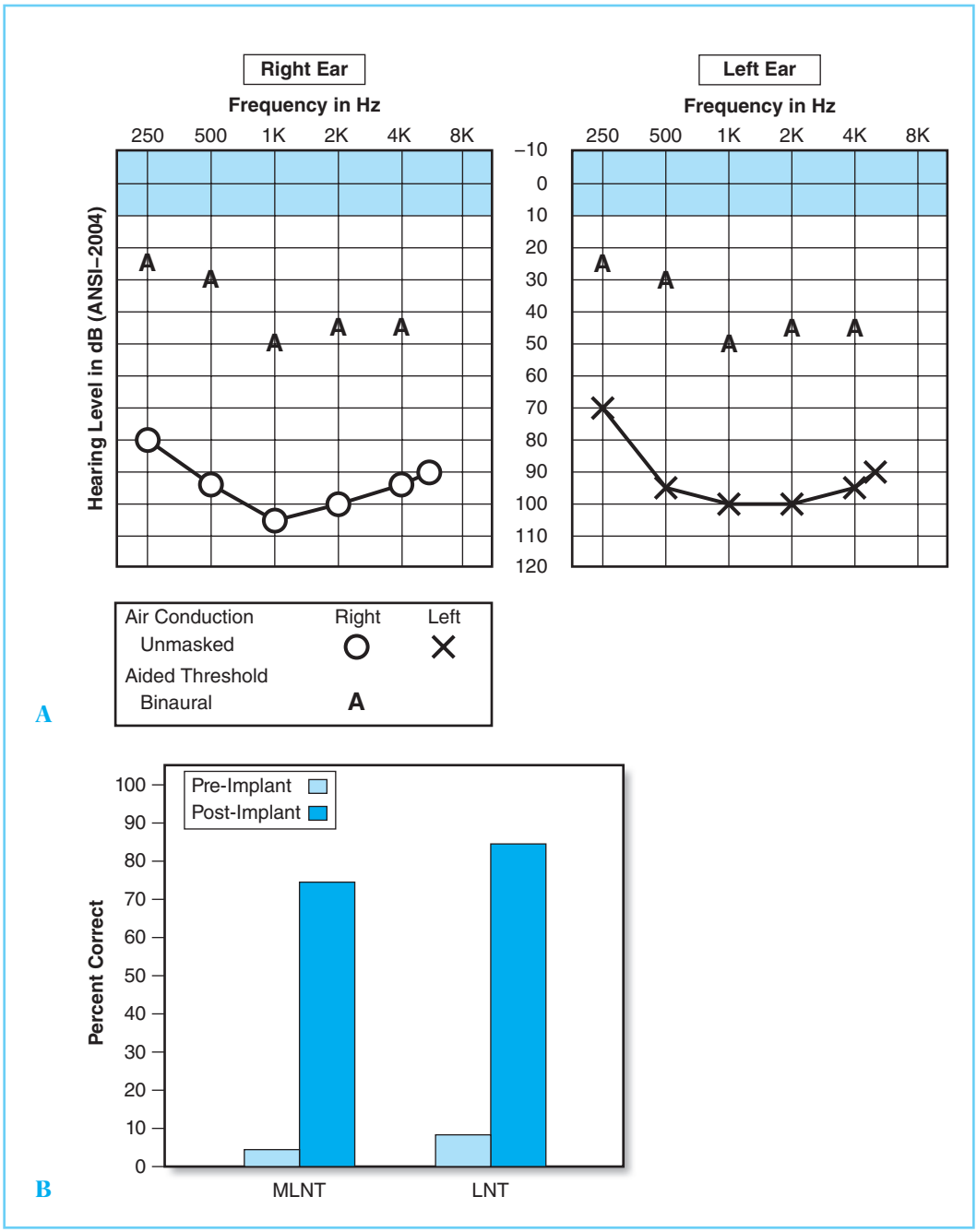


FIGURE 15-8 Hearing consultation results in a 6-year-old child with severe-to-profound sensorineural hearing loss. Pure-tone audiometric results (A) show bilateral hearing loss. Aided thresholds are with binaural hearing aids. Pre- and post-implant results (B) show substantial improvement and in performance on selected speech-recognition measures.

The child is now 9 years old. His standard scores on vocabulary and language measures are within normal limits for his age. He remains in mainstream education and is doing very well in school.

Summary

- Although the overall goal of any hearing treatment strategy is to reduce hearing impairment by maximizing access to sound, the approach used to reach that goal can vary across patients.
- The approach chosen to evaluate and fit hearing aids can vary with patient factors such as age, type of hearing disorder, and patient need.
- Adult patients with sensorineural hearing loss tend to be both easy and challenging in terms of hearing aid selection and fitting—easy because they are cooperative and can provide insightful feedback throughout the fitting process and challenging because there is not much to limit the audiologist's options.
- With older individuals, the more that can be done to ease the burden of listening in background noise, whether by sophisticated signal processing in ear-level hearing devices or by use of a remote microphone, the more likely the patient will benefit from hearing-device amplification.
- Another important challenge in fitting hearing aids in older individuals is the difficulty involved in the physical manipulation of the device.
- Hearing aid selection and fitting in children with sensorineural hearing impairment is a challenging business for various reasons. One is that audiometric levels may be known only generally at the beginning of the fitting process.
- Another is that children are less likely or able to participate in the selection and fitting process.
- Still another is that hearing may be more variable in young children due to progression or to fluctuation secondary to otitis media.
- The main challenge in treating children with APD is to assist them in overcoming their difficulties in understanding speech in background noise.

- A child with APD may benefit from amplification designed to enhance the signal-to-noise ratio.
- Overcoming the attenuating effects of conductive hearing loss is relatively simple from a signal processing strategy. The challenge in this population is more often related to deciding on the most appropriate transducer.
- Cochlear implantation is the primary hearing treatment strategy for patients with profound deafness.

Short Answer Questions

1. A major problem resulting from sensorineural hearing loss includes loss of hearing _____, typically in the _____ frequencies.
2. Individuals with sensorineural hearing loss of cochlear origin also tend to have a reduced _____ range and _____ growth of loudness.
3. In the case of sensorineural hearing loss, _____ recognition and ability to hear speech in _____ _____ is typically diminished.
4. A goal for treating sensorineural hearing loss is to amplify soft sounds so that they are _____, and ensure that loud sounds are not _____.
5. For most populations, _____ amplification is recommended unless clinically contraindicated because of the numerous advantages to hearing with both ears.
6. Nonlinear signal processing strategies using a _____ circuit are helpful for fitting the output of the hearing aid into the reduced dynamic range of the individual with sensorineural hearing loss.
7. The use of _____ microphones helps to increase the signal-to-noise ratio. This is done to increase speech perception in _____.
8. Hearing aid fittings are typically verified using _____-microphone measurements, subjective _____ judgments to determine that loud sounds are comfortable, and subjective _____ quality or intelligibility judgments.

9. Outcome measurements are typically made using _____-_____ scales that are completed both pre- and post-fitting. Comparison of these measures is thought to reflect changes due to hearing aid benefit.
10. Patients with sensorineural hearing loss should be provided information about other _____ _____ technology, such as amplified telephones, smoke alarms, and other specialized alerting devices.
11. One consideration for hearing aid style for older individuals is the _____ of the patient. It is necessary for patients to be able to manipulate both the hearing aid and the battery for the hearing aid.
12. Auditory rehabilitation plans may include _____ training and/or speechreading training.
13. The goal of audiologic treatment for the pediatric population is to ensure the best possible hearing for development of oral _____ and _____.
14. The smaller ear canals of children results in a higher _____ _____ _____ of the signal delivered to the tympanic membrane. In addition, the ear canals of children have different _____ characteristics than found in adult ears.
15. The use of _____-_____ measurements is essential for pediatric patients because they are less able to provide information about hearing sensitivity and suprathreshold perception.
16. Unless contraindicated, binaural amplification with _____-_____-_____ hearing aids is recommended for pediatric patients. Earmolds made of a soft material, such as _____ are typically used.
17. The _____ prescriptive formula is most typically used for programming hearing aids in pediatric patients.
18. Outcomes measurements specifically used for pediatric patients include the _____ _____ Worksheet and the Children's _____ Worksheets.
19. A rehabilitation treatment plan for a pediatric patient typically includes auditory training, _____ stimulation, and speech _____.

20. A remote _____ system is often used in cases of auditory _____ disorder, to provide a higher signal-to-noise ratio in the classroom environment.
21. Bone-anchored hearing aids are often a solution for _____ hearing loss.
22. A hearing aid used for a conductive hearing loss typically requires an additional gain equal to _____ % of the air-bone gap.
23. Both powerful conventional hearing aids and _____ _____ are common treatment solutions for profound hearing loss.

Discussion Questions

1. How does nonlinearity of loudness growth complicate fitting of hearing aids? What technology can be used to cope with this complication?
2. For an older patient with good speech recognition in one ear and poor speech recognition in the other ear, should binaural amplification be used?
3. Why are probe-microphone measures especially important for children?
4. Describe treatment options that are appropriate for children with auditory processing disorder.
5. What are the comparative advantages of binaural conventional hearing aids and a bone-anchored hearing aid?
6. Describe candidacy for cochlear implantation.

Resources

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Appendix A

AUDIOLOGY SCOPE OF PRACTICE: AAA

Following is an excerpt from Audiology: Scope of Practice 2004, according to the American Academy of Audiology (reprinted with permission).

Introduction

The Scope of Practice document describes the range of interests, capabilities and professional activities of audiologists. It defines audiologists as independent practitioners and provides examples of settings in which they are engaged. It is not intended to exclude the participation in activities outside of those delineated in the document. The overriding principle is that members of the Academy will provide only those services for which they are adequately prepared through their academic and clinical training and their experience, and that their practice is consistent with the Code of Ethics of the American Academy of Audiology.

I. Purpose

The purpose of this document is to define the profession of audiology by its scope of practice. This document outlines those activities that are within the expertise of members of the profession. This Scope of Practice statement is intended for use by audiologists, allied professionals, consumers of audiologic services, and the general public. It serves as a reference for issues of service delivery, third-party reimbursement, legislation, consumer education, regulatory action, state and professional licensure, and inter-professional relations. The document is not intended to be an exhaustive list of activities in which audiologists engage. Rather, it is a broad statement of professional practice. Periodic updating of any scope of practice statement is necessary as technologies and perspectives change.

II. Definition of an Audiologist

An audiologist is a person who, by virtue of academic degree, clinical training, and license to practice and/or professional credential, is uniquely qualified to provide a comprehensive array of professional services related to the prevention of hearing loss and the audiologic identification, assessment, diagnosis, and treatment of persons with impairment of auditory and vestibular function, and

to the prevention of impairments associated with them. Audiologists serve in a number of roles including clinician, therapist, teacher, consultant, researcher and administrator. The supervising audiologist maintains legal and ethical responsibility for all assigned audiology activities provided by audiology assistants and audiology students.

The central focus of the profession of audiology is concerned with all auditory impairments and their relationship to disorders of communication. Audiologists identify, assess, diagnose, and treat individuals with impairment of either peripheral or central auditory and/or vestibular function, and strive to prevent such impairments.

Audiologists provide clinical and academic training to students in audiology. Audiologists teach physicians, medical students, residents, and fellows about the auditory and vestibular system. Specifically, they provide instruction about identification, assessment, diagnosis, prevention, and treatment of persons with hearing and/or vestibular impairment. They provide information and training on all aspects of hearing and balance to other professions including psychology, counseling, rehabilitation, and education. Audiologists provide information on hearing and balance, hearing loss and disability, prevention of hearing loss, and treatment to business and industry. They develop and oversee hearing conservation programs in industry. Further, audiologists serve as expert witnesses within the boundaries of forensic audiology.

The audiologist is an independent practitioner who provides services in hospitals, clinics, schools, private practices and other settings in which audiologic services are relevant.

III. Scope of Practice

The scope of practice of audiologists is defined by the training and knowledge base of professionals who are licensed and/or credentialed to practice as audiologists. Areas of practice include the audiologic identification, assessment, diagnosis and treatment of individuals with impairment of auditory and vestibular function, prevention of hearing loss, and research in normal and disordered auditory and vestibular function. The practice of audiology includes:

A. Identification

Audiologists develop and oversee hearing screening programs for persons of all ages to detect individuals with hearing loss. Audiologists may perform speech or language screening, or other screening measures, for the purpose of initial identification and referral of persons with other communication disorders.

B. Assessment and Diagnosis

Assessment of hearing includes the administration and interpretation of behavioral, physioacoustic, and electrophysiologic measures of the peripheral and central auditory systems. Assessment of the vestibular system includes administration and interpretation of behavioral and electrophysiologic tests of equilibrium. Assessment is accomplished using standardized testing procedures

and appropriately calibrated instrumentation and leads to the diagnosis of hearing and/or vestibular abnormality.

C. Treatment

The audiologist is the professional who provides the full range of audiologic treatment services for persons with impairment of hearing and vestibular function. The audiologist is responsible for the evaluation, fitting, and verification of amplification devices, including assistive listening devices. The audiologist determines the appropriateness of amplification systems for persons with hearing impairment, evaluates benefit, and provides counseling and training regarding their use. Audiologists conduct otoscopic examinations, clean ear canals and remove cerumen, take ear canal impressions, select, fit, evaluate, and dispense hearing aids and other amplification systems. Audiologists assess and provide audiologic treatment for persons with tinnitus using techniques that include, but are not limited to, biofeedback, masking, hearing aids, education, and counseling.

1. Audiologists also are involved in the treatment of persons with vestibular disorders. They participate as full members of balance treatment teams to recommend and carry out treatment and rehabilitation of impairments of vestibular function.
2. Audiologists provide audiologic treatment services for infants and children with hearing impairment and their families. These services may include clinical treatment, home intervention, family support, and case management.
3. The audiologist is the member of the implant team (e.g., cochlear implants, middle-ear implantable hearing aids, fully implantable hearing aids, bone anchored hearing aids, and all other amplification/signal processing devices) who determines audiologic candidacy based on hearing and communication information. The audiologist provides pre and post surgical assessment, counseling, and all aspects of audiologic treatment including auditory training, rehabilitation, implant programming, and maintenance of implant hardware and software.

The audiologist provides audiologic treatment to persons with hearing impairment, and is a source of information for family members, other professionals and the general public. Counseling regarding hearing loss, the use of amplification systems and strategies for improving speech recognition is within the expertise of the audiologist. Additionally, the audiologist provides counseling regarding the effects of hearing loss on communication and psycho-social status in personal, social, and vocational arenas.

The audiologist administers audiologic identification, assessment, diagnosis, and treatment programs to children of all ages with hearing impairment from birth and preschool through school age. The audiologist is an integral part of the team within the school system that manages students with hearing impairments and students with central auditory processing disorders. The audiologist participates in the development of Individual Family Service Plans (IFSPs) and Individualized Educational Programs (IEPs), serves as a consultant in matters pertaining to classroom acoustics, assistive listening systems, hearing aids, communication,

and psycho-social effects of hearing loss, and maintains both classroom assistive systems as well as students' personal hearing aids. The audiologist administers hearing screening programs in schools, and trains and supervises nonaudiologists performing hearing screening in the educational setting.

D. Hearing Conservation

The audiologist designs, implements and coordinates industrial and community hearing conservation programs. This includes identification and amelioration of noise-hazardous conditions, identification of hearing loss, recommendation and counseling on use of hearing protection, employee education, and the training and supervision of nonaudiologists performing hearing screening in the industrial setting.

E. Intraoperative Neurophysiologic Monitoring

Audiologists administer and interpret electrophysiologic measurements of neural function including, but not limited to, sensory and motor evoked potentials, tests of nerve conduction velocity, and electromyography. These measurements are used in differential diagnosis, pre- and post-operative evaluation of neural function, and neurophysiologic intraoperative monitoring of central nervous system, spinal cord, and cranial nerve function.

F. Research

Audiologists design, implement, analyze and interpret the results of research related to auditory and balance systems.

G. Additional Expertise

Some audiologists, by virtue of education, experience, and personal choice choose to specialize in an area of practice not otherwise defined in this document. Nothing in this document shall be construed to limit individual freedom of choice in this regard provided that the activity is consistent with the American Academy of Audiology Code of Ethics.

Appendix B

AUDIOLOGY SCOPE OF PRACTICE: ASHA

Following is an excerpt from the Scope of Practice in Audiology, according to the American Speech-Language-Hearing Association (reprinted with permission from Scope of Practice in Audiology. Available from the Website of the American Speech-Language-Hearing Association: www.asha.org. All rights reserved.)

Statement of Purpose

The purpose of this document is to define the scope of practice in audiology in order to (a) describe the services offered by qualified audiologists as primary service providers, case managers, and/or members of multidisciplinary and interdisciplinary teams; (b) serve as a reference for health care, education, and other professionals, and for consumers, members of the general public, and policy makers concerned with legislation, regulation, licensure, and third party reimbursement; and (c) inform members of ASHA, certificate holders, and students of the activities for which certification in audiology is required in accordance with the ASHA Code of Ethics.

Audiologists provide comprehensive diagnostic and treatment/rehabilitative services for auditory, vestibular, and related impairments. These services are provided to individuals across the entire age span from birth through adulthood; to individuals from diverse language, ethnic, cultural, and socioeconomic backgrounds; and to individuals who have multiple disabilities. This position statement is not intended to be exhaustive; however, the activities described reflect current practice within the profession. Practice activities related to emerging clinical, technological, and scientific developments are not precluded from consideration as part of the scope of practice of an audiologist. Such innovations and advances will result in the periodic revision and updating of this document. It is also recognized that specialty areas identified within the scope of practice will vary among the individual providers. ASHA also recognizes that credentialed professionals in related fields may have knowledge, skills, and experience that could be applied to some areas within the scope of audiology practice. Defining the scope of practice of audiologists is not meant to exclude other appropriately credentialed postgraduate professionals from rendering services in common practice areas.

Audiologists serve diverse populations. The patient/client population includes persons of different race, age, gender, religion, national origin, and sexual orientation.

Audiologists' caseloads include individuals from diverse ethnic, cultural, or linguistic backgrounds, and persons with disabilities. Although audiologists are prohibited from discriminating in the provision of professional services based on these factors, in some cases such factors may be relevant to the development of an appropriate treatment plan. These factors may be considered in treatment plans only when firmly grounded in scientific and professional knowledge.

This scope of practice does not supersede existing state licensure laws or affect the interpretation or implementation of such laws. It may serve, however, as a model for the development or modification of licensure laws.

Framework for Practice

The practice of audiology includes both the prevention of and assessment of auditory, vestibular, and related impairments as well as the habilitation/rehabilitation and maintenance of persons with these impairments. The overall goal of the provision of audiology services should be to optimize and enhance the ability of an individual to hear, as well as to communicate in his/her everyday or natural environment. In addition, audiologists provide comprehensive services to individuals with normal hearing who interact with persons with a hearing impairment. The overall goal of audiologic services is to improve the quality of life for all of these individuals.

Definition of an Audiologist

Audiologists are professionals engaged in autonomous practice to promote healthy hearing, communication competency, and quality of life for persons of all ages through the prevention, identification, assessment, and rehabilitation of hearing, auditory function, balance, and other related systems. They facilitate prevention through the fitting of hearing protective devices, education programs for industry and the public, hearing screening/conservation programs, and research. The audiologist is the professional responsible for the identification of impairments and dysfunction of the auditory, balance, and other related systems. Their unique education and training provides them with the skills to assess and diagnose dysfunction in hearing, auditory function, balance, and related disorders. The delivery of audiologic (re)habilitation services includes not only the selecting, fitting, and dispensing of hearing aids and other hearing assistive devices, but also the assessment and follow-up services for persons with cochlear implants. The audiologist providing audiologic (re)habilitation does so through a comprehensive program of therapeutic services, devices, counseling, and other management strategies. Functional diagnosis of vestibular disorders and management of balance rehabilitation is another aspect of the professional responsibilities of the audiologist. Audiologists engage in research pertinent to all of these domains.

Professional Roles and Activities

Audiologists serve a diverse population and may function in one or more of a variety of activities. The practice of audiology includes:

A. Prevention

1. Promotion of hearing wellness, as well as the prevention of hearing loss and protection of hearing function by designing, implementing, and coordinating occupational, school, and community hearing conservation and identification programs;
2. Participation in noise measurements of the acoustic environment to improve accessibility and to promote hearing wellness.

B. Identification

1. Activities that identify dysfunction in hearing, balance, and other auditory-related systems;
2. Supervision, implementation, and follow-up of newborn and school hearing screening programs;
3. Screening for speech, orofacial myofunctional disorders, language, cognitive communication disorders, and/or preferred communication modalities that may affect education, health, development or communication and may result in recommendations for rescreening or comprehensive speech-language pathology assessment or in referral for other examinations or services;
4. Identification of populations and individuals with or at risk for hearing loss and other auditory dysfunction, balance impairments, tinnitus, and associated communication impairments as well as of those with normal hearing;
5. In collaboration with speech-language pathologists, identification of populations and individuals at risk for developing speech-language impairments.

C. Assessment

1. The conduct and interpretation of behavioral, electroacoustic, and/or electrophysiologic methods to assess hearing, auditory function, balance, and related systems;
2. Measurement and interpretation of sensory and motor evoked potentials, electromyography, and other electrodiagnostic tests for purposes of neurophysiologic intraoperative monitoring and cranial nerve assessment;
3. Evaluation and management of children and adults with auditory-related processing disorders;
4. Performance of otoscopy for appropriate audiological management or to provide a basis for medical referral;
5. Cerumen management to prevent obstruction of the external ear canal and of amplification devices;
6. Preparation of a report including interpreting data, summarizing findings, generating recommendations and developing an audiologic treatment/management plan;
7. Referrals to other professions, agencies, and/or consumer organizations.

D. Rehabilitation

1. As part of the comprehensive audiologic (re)habilitation program, evaluates, selects, fits and dispenses hearing assistive technology devices to include hearing aids;
2. Assessment of candidacy of persons with hearing loss for cochlear implants and provision of fitting, mapping, and audiologic rehabilitation to optimize device use;

3. Development of a culturally appropriate, audiologic rehabilitative management plan including, when appropriate:
   a. Recommendations for fitting and dispensing, and educating the consumer and family/caregivers in the use of and adjustment to sensory aids, hearing assistive devices, alerting systems, and captioning devices;
   b. Availability of counseling relating to psychosocial aspects of hearing loss, and other auditory dysfunction, and processes to enhance communication competence;
   c. Skills training and consultation concerning environmental modifications to facilitate development of receptive and expressive communication;
   d. Evaluation and modification of the audiologic management plan.
4. Provision of comprehensive audiologic rehabilitation services, including management procedures for speech and language habilitation and/or rehabilitation for persons with hearing loss or other auditory dysfunction, including but not exclusive to speechreading, auditory training, communication strategies, manual communication and counseling for psychosocial adjustment for persons with hearing loss or other auditory dysfunction and their families/caregivers;
5. Consultation and provision of vestibular and balance rehabilitation therapy to persons with vestibular and balance impairments;
6. Assessment and non-medical management of tinnitus using biofeedback, behavioral management, masking, hearing aids, education, and counseling;
7. Provision of training for professionals of related and/or allied services when needed;
8. Participation in the development of an Individual Education Program (IEP) for school-age children or an Individual Family Service Plan (IFSP) for children from birth to 36 months old;
9. Provision of in-service programs for school personnel, and advising school districts in planning educational programs and accessibility for students with hearing loss and other auditory dysfunction;
10. Measurement of noise levels and provision of recommendations for environmental modifications in order to reduce the noise level;
11. Management of the selection, purchase, installation, and evaluation of large-area amplification systems.

E. Advocacy/Consultation

1. Advocacy for communication needs of all individuals that may include advocating for the rights/funding of services for those with hearing loss, auditory, or vestibular disorders;
2. Advocacy for issues (i.e., acoustic accessibility) that affect the rights of individuals with normal hearing;
3. Consultation with professionals of related and/or allied services when needed;
4. Consultation in development of an Individual Education Program (IEP) for school-age children or an Individual Family Service Plan (IFSP) for children from birth to 36 months old;
5. Consultation to educators as members of interdisciplinary teams about communication management, educational implications of hearing loss

and other auditory dysfunction, educational programming, classroom acoustics, and large-area amplification systems for children with hearing loss and other auditory dysfunction;
6. Consultation about accessibility for persons with hearing loss and other auditory dysfunction in public and private buildings, programs, and services;
7. Consultation to individuals, public and private agencies, and governmental bodies, or as an expert witness regarding legal interpretations of audiology findings, effects of hearing loss and other auditory dysfunction, balance system impairments, and relevant noise-related considerations;
8. Case management and service as a liaison for the consumer, family, and agencies in order to monitor audiologic status and management and to make recommendations about educational and vocational programming;
9. Consultation to industry on the development of products and instrumentation related to the measurement and management of auditory or balance function.

F. Education/Research/Administration

1. Education, supervision, and administration for audiology graduate and other professional education programs;
2. Measurement of functional outcomes, consumer satisfaction, efficacy, effectiveness, and efficiency of practices and programs to maintain and improve the quality of audiologic services;
3. Design and conduct of basic and applied audiologic research to increase the knowledge base, to develop new methods and programs, and to determine the efficacy, effectiveness, and efficiency of assessment and treatment paradigms; disseminate research findings to other professionals and to the public;
4. Participation in the development of professional and technical standards;
5. Participation in quality improvement programs;
6. Program administration and supervision of professionals as well as support personnel.

Practice Settings

Audiologists provide services in private practice; medical settings such as hospitals and physicians' offices; community and university hearing and speech centers; managed care systems; industry; the military; various state agencies; home health, subacute rehabilitation, long-term care, and intermediate-care facilities; and school systems. Audiologists provide academic education to students and practitioners in universities, to medical and surgical students and residents, and to other related professionals. Such education pertains to the identification, functional diagnosis/assessment, and non-medical treatment/management of auditory, vestibular, balance, and related impairments.

Appendix C

ANSWERS TO SHORT ANSWER AND DISCUSSION QUESTIONS

CHAPTER 1

Answers to Short Answer Questions

1. evaluation; impairment
2. diagnosis; communication
3. clinical; licensure
4. degree; extent
5. treatment
6. forensic
7. conservation
8. multimodality
9. autonomous
10. otolaryngology; otology; hearing loss
11. speech-language pathologists
12. AuD
13. certification
14. licensure
15. audiometer; audiogram

Answers to Discussion Questions

1. An autonomous profession is one that is independent. It does not rely on the oversight of other professions in order to engage in professional activities. Because the profession of audiology is an autonomous profession, it is necessary for audiologists to thoroughly understand the scope of practice and the code of ethics for the profession.

   The scope of practice defines the roles and activities of audiology. Those roles and activities defined in the scope of practice are typically well established and understood within the professional community. Performing activities outside of the scope of practice puts the professional at risk for making errors of judgment by utilizing a knowledge base outside of that provided by the academic and clinical education established for the training of professionals. In addition, performing activities outside of the scope of practice creates confusion in understanding what separates one profession from another. As a profession that is not governed by outside professionals, audiologists as a group must be self-governed and establish their own boundaries for professional practice. It is incumbent upon members of the profession to understand and practice within the boundaries established by their peers when referring to themselves as audiologists.

   Autonomous professionals collectively develop an ethical code of conduct to govern the behaviors of the practitioners representing their profession. Because other professionals do not oversee the activities of audiologists, audiologists are responsible for the activities that they perform. As such, it is necessary for audiologists to have a thorough understanding of what constitutes ethical practice for the safety and concern of patients, as well as for professional protection.
2. The scope of practice for a profession is developed by members of the profession. This is typically accomplished in the context of professional organizations, which are developed for the purpose of representing the interests of professionals and patients treated by such professionals. In addition, governmental licensing bodies also participate in defining the scope of practice by delineating the activities that professionals are legally permitted to practice within a given state. Often, however, licensing bodies adopt much of the scope of practice for a given profession from that defined by those professional organizations representing the profession.

   In the United States, the scope of practice of Audiology is defined by two major organizations representing the practice of audiology: The American Academy of Audiology (AAA) and the American Speech-Language-Hearing Association (ASHA). Both organizations have drafted documents to provide specific information concerning the professional role and activities of audiologists.
3. Certification is the process by which a nongovernment agency or association grants recognition to an individual meeting qualifications specified by that institution. Certification is a voluntary credential that is ordinarily not legally mandatory for practice of a profession.

Certification is typically granted by professional organizations, which specify certain criteria that individuals must demonstrate in order to present themselves as possessing the knowledge and skills to perform certain activities. For the profession of audiology, the Certificate of Clinical Competence in Audiology (CCC-A) from the American Speech-Language-Hearing Association (ASHA) and certification from the American Board of Audiology (ABA) can be attained.

Licensure is the process by which a government agency grants permission to engage in a specified profession. Licensure provides a professional with the legal right to practice. Like the process of certification, the ability to obtain a license to practice audiology depends on the demonstration by an individual that he or she has obtained the necessary academic education and clinical skills necessary to be a competent practitioner. Licensing boards for government institutions are largely composed of individuals who represent the professions in question. As such, these boards typically develop requirements for licensure that are very similar to those required for earning the Au.D. degree.

Historically, many state governments did not require licensure to practice the profession of audiology. Therefore, credentialing via certification provided the best available means to identify those who completed requirements to carry out the activities in which audiologists engage. In recent years, licensure has largely replaced need for entry-level certification in audiology. This means that it is not necessary for audiologists to obtain certification in order to demonstrate competence to practice because the right to practice is conferred by the state government. However, many audiologists choose to obtain or maintain their certification for professional reasons, such as to demonstration of support for their professional organizations.

In addition, some audiologists may choose to pursue certifications beyond those required for entry-level practice. Such certifications may be useful in providing evidence of proficiency in particular specialized areas of audiology, such as in the area of cochlear implants.

4. Technological advancements have contributed to expanding the scope of practice for audiologists. Over the last several decades, new technologies that allow evaluation of the auditory and vestibular systems have been adopted by the profession of audiology for use in diagnosis and assessment of hearing and vestibular disorders. Examples of such technologies include the use of auditory brainstem responses (ABR) for evaluation of the integrity of the auditory nerve when suspicious of space-occupying lesions in the brain, contributing to the expansion of the scope of audiology to include certain neurodiagnostic testing procedures.

   The development of objective measures such as the ABR, otoacoustic emissions, and auditory steady-state responses have provided audiologists with the ability to assess the auditory status of infants and newborns. These technologies have led to newborn infant hearing screening as an extremely important component of the scope of audiology practice and to an even greater emphasis on the identification and treatment of infant hearing loss. Vestibular testing advances, such as the use of electronystagmography, and more recently, videonystagmography, have placed the audiologist in an important role in the assessment of vestibular function.

   The scope of audiology treatment has also expanded with the introduction of new technologies. Advancements in hearing aids in recent years expanded the number of patients who utilize personal hearing instruments. This has increased the amount of time audiologists spend with hearing aid treatment activities. In addition, the advent of cochlear implantation and expansion of candidacy for implantation have added another dimension of treatment activities to the scope of practice in audiology.

   The introduction of electrophysiological techniques necessary for monitoring of motor and sensory nerves has allowed audiologists to use multimodal sensory evoked potentials in surgical monitoring.

5. Events and forces of the past dictate, to a large extent, the manner in which audiology is practiced today. This knowledge is helpful in determining future goals for audiology as a profession.

   A major contribution to the field of audiology was the invention of the clinical audiometer by C. C. Bunch and the introduction of the pure-tone audiogram. The behavioral techniques developed by the profession of audiology at its inception are among the most important used today.

   The development of programs devoted to aural rehabilitation had their genesis in Army hospitals following World War II. To this day, the military and the Veterans Administration are among the largest employers of audiologists in the United States.

   Controversies of the past, such as the ethical nature of hearing aid dispensation and sales, continue to provide topics for consideration in current refinement of ethical guidelines crafted by professional organizations representing audiologists.

   The academic roots of audiology in the discipline of communication sciences and disorders continues today in many university training programs, despite the continued progress toward differentiation of the professions of speech-language pathology and audiology. Expansions of the scope of practice in audiology

and the necessity for autonomy in the profession have been major contributors in the emergence of the entry-level degree for audiology, the Au.D.

Issues of reimbursement for clinical services are deeply entrenched in historical notions of audiological services and audiologists as service providers. Current efforts in the field of audiology are geared toward reimbursement concepts that are more closely aligned with the current notion of audiologists as autonomous professionals. In addition, efforts toward licensure for audiologists in all states has been pursued by professional organizations in an effort to promote greater autonomy of audiology as a profession, rather than using certification by professional organizations for demonstration of clinical proficiency.

CHAPTER 2

Answers to Short Answer Questions

1. pressure waves
2. mass; elasticity; work
3. condensation; rarefaction
4. simple harmonic motion
5. intensity; loudness; amplitude
6. frequency; pitch
7. phase
8. outer ear; middle ear; inner ear
9. auricle; external auditory meatus; tympanic membrane
10. ossicles; malleus; incus; stapes
11. cochlea
12. scala vestibuli; scala media; scala tympani
13. perilymph; endolymph
14. inner; outer
15. VIIIth
16. tonotopic
17. threshold
18. audiogram; intensity; frequency
19. sensorineural; conductive
20. vestibular; visual; somatosensory
21. macula; utricle; saccule
22. crista

Answers to Discussion Questions

1. When a force is applied to a sound source, energy is transferred through the medium of air (or any other medium that has the properties of mass and elasticity) via a sound pressure wave. The pressure wave propagates through the medium by the compression of air molecules (known as condensation) and the decrease in density of air molecules (known as rarefaction) that occurs as a result of elastic forces. The energy emanates through the medium until it reaches the level of the outer ear. The outer ear functions to collect and funnel sound to the tympanic membrane, enhancing the intensity of particular frequencies. The sound wave impinges on the tympanic membrane and the energy is transferred to this structure, where it is passed on to the structures of the middle and inner ear.
2. The Eustachian tube is a narrow passageway from the nasopharynx to the anterior wall of the middle ear. Muscles of the Eustachian tube contract and open the passageway during swallowing and yawning. Opening of this tube serves to equalize the pressure of the air-filled middle-ear space with atmospheric pressure. An individual on an airplane, who experiences rapid changes in atmospheric pressure during ascent and descent, may easily appreciate this function. The ears feel "plugged" until swallowing or yawning opens the Eustachian tube, and the pressure of the middle-ear space is equalized.

   When the Eustachian tube fails to function properly, the trapped air of the middle-ear space is gradually absorbed by the mucosa of the middle-ear space, creating a negative pressure in the middle ear, relative to atmospheric pressure. The vacuum created by this pressure differential is can result in an accumulation of fluid, secreted from the fluid in the mucosa, in the middle space. The presence of fluid in the middle-ear space contributes to an attenuation of sound passing through the middle-ear system because more energy is lost when sound travels through fluid than through air. This attenuation creates a conductive hearing loss.

   In addition, infectious material may spread to the middle-ear space from the area of the nasopharynx, via the Eustachian tube. In such cases, the fluid of the middle ear may become infected, leading to severe pain, as inflammation and fluid in the middle ear combine to create pressure on the tympanic membrane. The tympanic membrane may even rupture, given sufficient pressure. Toxins from the infectious process may ultimately invade the cochlea itself, causing a sensory component to hearing loss as well.
3. The sensitivity of the auditory system varies as a function of frequency. It is more common to measure sound in sound pressure level rather than sound intensity. However, both measures are expressed in units of decibels, and when describing sound, both properties are expressed as relative measures. The reference used for these measures is the lowest intensity or pressure that is capable of displacing individual air particles over a very small distance.

   The ratio of the absolute level to the reference level would be an extremely large range over the range between the softest and loudest sounds that humans can perceive. In order to reduce these levels into manageable numbers, the logarithm to the base ten of the ratio of the two intensities is used. This value is known as the Bel.

Although the Bel is an easier value to use than the ratio itself, the Bel is too large of a unit to adequately express the sensitivity of the auditory system capabilities. Therefore a fraction of the Bel, 1/10, known as the decibel (dB) is used for describing sound intensity and sound pressure levels. When describing sound intensity, the term dB IL (intensity level) is used, and the reference level for intensity is provided. When describing sound pressure level, the term dB SPL (sound pressure level) is used, and the reference level for sound pressure is provided.

Sound pressure level is the more commonly used measure when referring to auditory capabilities of humans. As mentioned before, the sound pressure levels to which humans are sensitive are not the same across frequencies. Humans are most sensitive to frequencies that are in the speech range (about 500–4000 Hz), and are less sensitive to higher and lower frequency sounds. Because of this, it would be rather difficult to understand an individual's relative level of difficulty hearing if their sensitivity was expressed in dB SPL as the level of "normal" would vary as a function of frequency.

In order to minimize confusion, the concept of dB HL (hearing level) was developed. A reference level was developed by determining the threshold levels of audiometric frequencies for a group of otologically healthy young adults (people with normal hearing). The sound pressure levels that were determined to be at threshold then became the reference levels for 0 dB HL. The audiometer, which provides signals for hearing testing, is calibrated to these levels. The use of dB HL allows for deviations from normal-hearing levels to be more clearly understood than if dB SPL was used.

4. The outer hair cells function as the cochlear amplifier. They work to increase the hearing sensitivity of the cochlea. The inner hair cells, which have afferent connections to the brain, respond to deflections of stereocilia, caused by change in the flow of cochlear fluid that occurs in response to movement of the basilar membrane in response to sound vibrations. The flow of fluid is only strong enough to cause stereocilia deflections in response to higher intensity sounds.

   The flow of cochlear fluid is influenced by the location of the tectorial membrane relative to the basilar membrane. Unlike the inner hair cells, the tips of the outer hair cells are embedded in the tectorial membrane, which overlies the basilar membrane. In response to softer intensity sounds, the outer hair cells contract, causing the tectorial membrane to change its location relative to the basilar membrane. This change in the relative location of the tectorial membrane to the basilar membrane changes the dynamics of the fluid flow in such a way that the stereocilia of the inner hair cells become stimulated at a lower intensity level than without the functioning of the outer hair cells.

5. There is a fluid known as endolymph contained within the membranous labyrinth of the semicircular canals of the vestibular system. When the head moves in a particular direction, the fluid moves in the opposite direction. The force of the flow of endolymph exerts pressure on the cupula in the semicircular canal, causing a deflection. The deflection of the cupula causes movement of the stereocilia embedded in the hair cells of the crista, the vestibular sensory organ. Movement of the stereocilia allows for chemical signaling of the hair cells to transduce the mechanical energy to electrical energy, which is then carried by the vestibular portion of the VIIIth cranial nerve to the brain. Depending on the direction of the head turn, the stereocilia are either deflected away from the kinocilium (the long protruding fiber from the hair cell), causing a decrease in baseline electrical activity, or toward the kinocilium resulting in an increase in baseline electrical activity. Because the semicircular canals are organized into functional pairs on each side of the head, movement in one direction will cause an increase in electrical firing activity on one side and a corresponding decrease in electrical firing activity in the related organ on the opposite side of the head. Incorporation of these changes in the rate of electrical activity received from both organs is made in the brain to allow for deduction of the angular acceleration of the head.

CHAPTER 3

Answers to Short Answer Questions

1. site; extent
2. sensitivity; suprathreshold
3. onset; congenital; acquired; adventitious
4. unilateral; less; bilateral
5. conductive; attenuation; air-bone
6. configuration; higher; lower
7. sensorineural; basilar membrane
8. sensitivity; frequency; dynamic range
9. mixed; conductive; sensorineural
10. suprathreshold; retrocochlear; auditory processing
11. background; redundancy; localize; lateralize; dichotic; temporal
12. functional; organic
13. onset; prelinguistic; postlinguistic
14. compensatory; speechreading; environmental
15. degree
16. configuration; flat; rising; sloping; precipitous
17. reverberation; distortion
18. fluctuating; inconsistent
19. sensorineural; frequency; dynamic
20. retrocochlear; decruitment; adaptation

Answers to Discussion Questions

1. Some believe that fluctuating conductive hearing losses can have a negative impact during the critical period of speech and language development, as a result of a prolonged period of inconsistent auditory stimulation. It is thought that because children learn speech and language through repeated exposure to the hearing modality, interruptions to the quality of this signal through repeated episodes of hearing loss might reduce the developing child's ability to utilize the auditory signal effectively during auditory development.

   Factors that may contribute to poorer outcomes with transient, fluctuating conductive losses are numerous. The frequency of hearing loss episodes is one such factor. More frequent episodes may result in greater negative impact because the auditory signal is more frequently degraded. The degree of hearing loss would be expected to have an impact because a greater degree of hearing loss results in a less audible signal. The duration of the hearing loss in the case of a transient hearing loss may be a factor. Some causes of conductive hearing loss, such as acute otitis media, may resolve over a short period of time or may evolve into longer lasting episodes, such as chronic otitis media. The longer the child is exposed to the degraded auditory signal, the greater the predicted consequences on speech and language development. The age and language development level of the child may have an impact on the consequences of transient hearing losses. If the hearing loss occurs at a particularly critical point in speech and language development, the negative effect of the loss could theoretically be greater. There are patient factors that may help to compensate for the effects of a hearing loss, such as high intelligence. A child without such compensating factors could suffer greater negative consequences from even a transient hearing loss. In fact, some children may be prone to conductive hearing losses as a component of a larger syndrome complex, such as Down's syndrome, in which other symptoms could conceivably compound the impact of the hearing loss for the child.
2. The consequences of auditory processing disorders in children can include: reduced ability to understand in background noise; reduced ability to understand speech of reduced redundancy, reduced ability to localize and lateralize sound; reduced ability to separate dichotic stimuli; and reduced ability to process normal or altered temporal cues. The reduced ability to perceive speech in a hostile acoustic environment, such as might be found in a classroom setting, might mimic the outcomes of a language impairment or learning disability, because a child is unable to utilize the speech signal as do children with normal hearing. Difficulties in classroom performance might result in frustration and diminished motivation on the part of the student. Children may be unable to follow directions and appear distractible. These factors could contribute to the impression of an attention deficit disorder.

   In addition, some children with auditory processing disorder may have concomitant disorders. Due to the presence of these disorders, the presence of an auditory processing disorder may fail to be considered by referral sources.
3. Common consequences of a sensorineural hearing loss include: a reduction in cochlear sensitivity; a reduction in frequency resolution; and a reduction in the dynamic range of the hearing sensitivity mechanism. A hearing aid will assist in the first of these consequences, by increasing the intensity of the auditory signal. An increased auditory signal will allow the cochlea to sense the auditory signal at levels that will be audible to the impaired system.

   A hearing aid will not provide assistance for the other common consequences of a sensorineural hearing loss. The reduction in frequency resolution that occurs in a sensorineural hearing loss results in the addition of distortion to the auditory signal. Distortion causes the auditory signal to be changed from its original source and reduces the intelligibility of the speech signal. An increase in the intensity of the signal, such as that provided by the output of a hearing aid, will merely increase the audibility of the distorted signal. Additional increases in intensity may even add distortion to the auditory signal. A hearing aid will not help to reduce distortion that occurs as a consequence of sensorineural hearing loss.

   The third common consequence of a sensorineural hearing loss, a reduction in the dynamic range of the hearing mechanism, impacts the ability to utilize a hearing aid to increase audibility. The abnormal growth of loudness provides a smaller "window" of usable hearing that can be conceivably amplified. When sounds are already perceived to be loud, which occurs at a low sensation level in the case of a reduced dynamic range, only a small range of intensity levels can be amplified. Sophisticated hearing aid technology is required to modify the speech signal so that soft intensity sounds are perceived as soft, medium sounds as medium, and loud sounds as loud , but not too loud.
4. The cause of a functional hearing loss is related to internal or external gain. An external gain provides reinforcement that is extrinsic to the individual, such as monetary gain. Internal gain provides reinforcement that is intrinsic to the individual, such as psychological benefits like attention.

The intent of a functional hearing loss exists on a continuum from intentional to unintentional. With an intentional functional hearing loss, the person is aware of the behavior and purposefully feigns or exaggerates a hearing loss. With an unintentional functional hearing loss, the person is unaware of the motivations and actions in feigning their hearing loss.

Gain and intent are typically both factors in the various motivations for functional hearing loss. In a case of malingering, the patient is intentionally feigning or exaggerating a hearing loss for external motivation. In the case of a factitious disorder, a person intentionally feigns or exaggerates a hearing loss to achieve an internal psychological benefit from the assumption of a sick role. In a conversion disorder, the symptoms of hearing loss occur unintentionally. This often occurs for psychological benefit following some form of distress.

5. Although a mild hearing loss would be unlikely to interfere with the audibility of most phonemes, patient factors may contribute to a significantly negative functional impact from this degree of hearing loss. The age of onset of the hearing loss may contribute to the effects of a mild hearing loss. A child who has developed a hearing loss prelingually may experience a greater impact from the mild hearing loss because the development of spoken language requires greater access to the auditory signal. A child may also be negatively impacted with a mild hearing loss in an acoustically challenging environment, such as a classroom setting. While FM systems or other assistive listening devices may assist in such settings, mild hearing losses are generally missed in hearing screenings.

   An individual with a mild hearing loss will be differentially affected depending on communication needs. An individual whose occupation depends on a high degree of communication ability is likely to be quite challenged by even a mild hearing loss, especially if working in an acoustically hostile environment.

   In addition, the type of hearing loss can impact the consequences of a mild hearing loss. A hearing loss that adds substantial distortion to the signal, such as may occur in some sensorineural hearing loss or a retrocochlear lesion in which speech recognition is substantively affected, may have considerable functional consequences.

CHAPTER 4

Answers to Short Answer Questions

1. dominant; recessive
2. teratogenic
3. acoustic
4. auditory neuropathy
5. idiopathic
6. atresia; microtia
7. conductive; stapes
8. cerumen; impaction; flat
9. perforation; infection
10. otitis media; effusion
11. Eustachian tube; negative
12. cholesteatoma; epithelial
13. congenital; inherited; acquired
14. endogenous; exogenous
15. temporal; vestibular aqueduct
16. nonsyndromic; progressive
17. noise-induced; temporary threshold shift; permanent threshold shift
18. ototoxic
19. presbycusis
20. multiple sclerosis
21. vertigo
22. benign paroxysmal positional vertigo; canalithiasis

Answers to Discussion Questions

1. Hearing loss can often be treated medically, depending on the underlying cause. Treatment includes medications, such as the use of antibiotics for the treatment of acute otitis media and immunosuppressant drugs for the treatment of autoimmune inner ear disorder. Other treatments may be used, such as surgical procedures for placement of pressure equalization tubes for management of chronic otitis media or replacement of the stapes with a prosthesis to treat stapes fixation. Understanding of the underlying cause of a hearing disorder is important in determining whether hearing loss can be treated.

   Knowing the underlying cause of a hearing disorder is also important in the management of the hearing loss. Progressive hearing loss is a characteristic of certain etiologies of hearing loss. Expecting that a hearing loss may continue to develop over time will be an important aspect of counseling patients and planning for follow-up. It may also be important to understand additional characteristics of a disorder that may impact treatment decisions for hearing loss. For example, progressive loss of vision is an expected outcome of Usher syndrome. Therefore, it may not be beneficial for a patient with Usher syndrome to utilize a manual communication system or to be counseled to rely very heavily on visual cues for speech perception given the expectation that visual acuity will decline over time.

   Additionally, in cases of hereditary hearing losses, families may be counseled to have appropriate expectations regarding future occurrences of hearing loss with additional offspring.

2. The Eustachian tube is a passageway between the middle-ear space and the nasopharynx. It is normally closed. The Eustachian tube opens in order to equalize

the pressure in the middle-ear space. It does so upon activities such as swallowing or yawning. When the Eustachian tube is not functioning properly, it fails to open appropriately. When this occurs, pressure in the middle-ear space does not become equalized with atmospheric pressure, leading to inflammation of the lining of the middle ear and negative middle-ear pressure. The relative negative pressure of the middle ear causes a vacuum and may result in effusion of fluid into the middle-ear space from the mucous membrane of the middle-ear cavity. This fluid builds up in the middle-ear space, ultimately impeding the normal functioning of the ossicles and tympanic membrane. Many times Eustachian tube dysfunction occurs as a result of upper respiratory infection. As the nasopharynx and related structures, such as the adenoids, become inflamed, the opening of the Eustachian tube into the nasopharynx may become blocked. In addition, if infected material enters the middle-ear space, this can cause the effusion to become infected.

Otitis media with effusion is more commonly found among children than adults. The main reasons for this are believed to be primarily structural: children have shorter Eustachian tubes, that are at a different angle plane than those of adults. Eustachian tubes of children are also more compliant and as such may not allow adequate ventilation. Lastly, children typically have greater occurrence of upper respiratory infections than adults, which may contribute to the relatively greater occurrence of otitis media in children.

3. Both syndromic and nonsyndromic disorders can be genetic, inherited from parents. In both cases, genetic inheritance can be autosomal dominant, autosomal recessive, or X-linked. Syndromic and nonsyndromic disorder can both be present at birth or occur later in life as a progressive hearing loss.

   Syndromic hearing disorders occur as a part of a larger set of disorders that occur together. Not all syndromic disorders are necessarily the result of genetic causes. Some may be influenced by environmental factors. A nonsyndromic hearing disorder is a genetic condition in which there is no significant feature other than hearing loss.

4. Presbyacusis is defined as a decline in hearing that occurs as a part of the aging process. It is clear, however, that over the course of a lifetime, individuals are likely to be exposed to numerous conditions and disease processes that can have a negative impact on hearing, including noise exposure, vascular and systemic disease, exposure to environmental toxins, and ototoxic medications. It is difficult, if not impossible, to control for these myriad effects when examining the hearing of individuals longitudinally. This means that hearing loss due a solely to the effects of aging cannot be precisely determined.

5. Given a particular frequency composition of a sound, the impact of that sound on the auditory system becomes a function of both the intensity and duration of the noise exposure. It is generally held that a substantial amount of noise-induced hearing loss is due to the effects of metabolic exhaustion and ischemic damage to the hair cells of the cochlea. During both exposure to high-intensity noise and excessive noise of long duration, the hair cells are forced to work beyond their typical capacity. At high intensities, the hair cells can only maintain this level for a certain period before damage occurs. For extremely high intensities, the amount of time before damage occurs is very limited. (Imagine how a runner doing a sprint can run for a short time at a very fast rate, but the runner could not maintain the same speed when running over a very long distance).

   Damage-risk criteria are guidelines that have been developed to define the maximum noise levels that individuals may be exposed to (particularly for an occupational environment) for a given period of time. In the United States, this amounts to a 5 dB doubling rate, meaning that for every 5 dB increase in intensity, the amount of time that would be safe to be exposed to decreases by half. For example, a 90 dBA sound would be considered safe for 8 hours, while a 95 dBA sound would be considered safe for only 4 hours. Beyond these levels, damage to the hearing mechanism is likely to occur for many individuals.

   In addition, there is evidence that individuals have different susceptibility to noise exposure than others. Some individuals may experience damage at lower levels than is typical for the larger population and may therefore require noise-protection in lower intensity sound environments. Unfortunately, individual susceptibility is typically not discovered until a certain amount of hearing damage has already occurred.

6. Many causes of hearing loss may be compounded by exposure to ototoxic medications. In cases of infections that cause hearing loss, an example being opportunistic infections that may occur with AIDS, the infection itself may contribute to hearing loss, and ototoxic aminoglycoside antibiotics may be administered to ward off infection, also contributing to hearing loss. A similar situation may occur in cases of perinatal illness or prematurity. Both have a high likelihood of hearing loss in and of themselves, but the hearing loss is further impacted by life-sustaining antibiotics medications typically administered.

   In other cases, ototoxic medications may work synergistically when administered together, having a greater affect on hearing loss than either medication would alone. For instance, if a patient with kidney

disease contracts an infection requiring amingoglycoside antibiotics, a synergistic affect can occur. This is because such a patient would likely also be exposed to loop diuretics for management of kidney disease.

7. Patients often report that they experience a sensation of "dizziness." This term is vague and does not provide enough information to unambiguously discern a diagnosis. More specific terms would include: balance disturbance, lightheadedness, loss of balance, etc. Vertigo, an abnormal sensation of movement, is likely to occur with vestibular disorders. Other types of "dizzy" sensations are likely to occur in response to central or systemic disorders.

   There are numerous disorders that can result in such a symptom, and many medications can also cause dizziness in patients. Often, the only way to determine the cause of dizziness is to provide treatment and evaluate the results of treatment, or to provide additional testing. Vestibular testing is useful for determining the presence or absence of disorders of the vestibular system.

CHAPTER 5

Answers to Short Answer Questions

1. nature; extent
2. case history
3. otoscopy; otoscope
4. cerumen; irrigation
5. immittance; static
6. negative; mass; stiffness; ossicular; disarticulation
7. threshold; pure-tone
8. audiogram
9. speech; 500; 1000; 2000
10. air-conduction; bone-conduction
11. air-bone gap
12. conductive; sensorineural; mixed
13. suprathreshold
14. recognition; monosyllabic
15. impairment; disability; handicap
16. screening
17. newborns; six months
18. universal; auditory brainstem; otoacoustic emission
19. school-age; behavioral
20. occupational

Answers to Discussion Questions

1. The goals of universal newborn hearing screening are to identify all children born with significant sensorineural hearing loss by the age of 3 months, for the purpose of providing appropriate intervention by the age of 6 months. Lack of financial resources may prohibit programs from providing universal newborn hearing screening because of the costs required to administer such a program. Even if a program has sufficient funds to provide universal newborn hearing screening, it may be deemed necessary to forgo hearing screening in favor of applying available resources to lifesaving measures or toward treatment. In addition, in cases where resources are scarce, personnel and/or funding may not be available to provide adequate treatment for children identified as having hearing loss. Without provision of appropriate intervention, identification of infants with hearing loss provides little or no benefit.

   Some professionals suggest that universal newborn hearing screening provides a false "sense of security" regarding the status of hearing in children. Hearing losses in children can occur later in life, due to acquired, late onset, and/or progressive hearing losses. It is felt by some that medical professionals and parents may believe that once a child passes a hearing screening at birth, there is no further need for vigilance in assessing hearing. The argument is made that children may be better served by educating medical professionals about risk factors and signs for hearing loss, as well as normal speech and language development, and to rely on referrals from medical personnel for audiologic assessment rather than on referrals from universal newborn hearing screening programs.

2. The characteristics of a hearing loss (degree, configuration, type) do not provide sufficient information for understanding the degree of impact that a hearing loss can have on an individual. While the ability to understand speech is generally poorer with greater degrees of hearing loss, the relationship between these factors is not complete. Some individuals experience significant impairment in their ability to communicate with others as a result of a given hearing loss, while others may experience relatively little impairment with the same degree of hearing loss. Factors such as speechreading ability, cognitive ability, language development, etc., can contribute to the ability to communicate effectively.

   The lifestyle of an individual plays a large role in how important effective communication is to a patient. A patient whose occupation and social activities rely heavily on the ability to perceive spoken communication is more likely to experience a significant negative effect from a hearing loss than an individual who does not rely as extensively on oral communication. The inability to participate in even a few activities as a result of hearing loss can result in significant self-perceived handicap for an individual, if the events are of great importance for quality of life for a patient.

   Knowledge of disability and handicap imposed by a hearing loss is important in determining goals and objectives for treatment of hearing loss. An individual who is significantly negatively impacted by a

hearing loss may be more motivated to utilize personal hearing instruments than an individual who is not. In order to provide services to patients, it is necessary to determine in what ways their hearing disorder impacts them personally.

3. Understanding why a patient is being evaluated is critical in tailoring the evaluation to ensure that the most important goals of a particular assessment are met. To do this in the most efficient and effective manner, it is necessary to understand how the information that the audiologist obtains will be utilized. Knowledge of the referral source is often helpful in elucidating the goals for assessment as well as information gleaned from the case history. Having an understanding of a patient's particular goals for hearing assessment are important in the counseling provided to a patient during and following testing procedures, and in selection and administration of appropriate audiologic tests. In addition, a level of vigilance regarding detection of functional hearing loss can be cued by the reason for referral.
4. The use of additional procedures to verify and/or supplement findings describes a cross-check. There is no perfect way to measure true hearing ability. Each assessment tool available for evaluation of hearing has its own particular accuracy as well as limitations. Therefore, multiple methods of assessing the integrity of the auditory system are often utilized. The overall impressions from these tests are then utilized to determine hearing ability. Examples of cross-checks include the use of speech recognition thresholds to verify the pure-tone average of the speech frequencies (500, 1000, and 2000 Hz); the use of tympanometry to support the presence of a conductive hearing loss; and the use of acoustic reflex thresholds to support suspicion of retrocochlear pathology.
5. Objective measures are useful for testing the functional integrity of particular structures of the auditory system. These types of measures are helpful in predicting auditory function in individuals who are incapable of, or uncooperative in providing behavioral responses to auditory stimuli. Certain measures, such as the auditory brainstem response, are also helpful in providing precise temporal information regarding the response of the auditory pathway, which can provide important clues about potential lesions in the auditory nervous system, such as cochleovestibular schwanomma.

   Hearing is a process of perception that is realized at the highest levels of the central nervous system, in the auditory cortex. While objectives measures provide information about the structures of the auditory system, they do not provide insight into the ultimate integration and interpretation of the sensory information received by the auditory system. The response of the central auditory nervous system to auditory stimuli is the essence of "hearing" ability. Without behavioral measures to inform the audiologist of this response, there can be only predictions of true hearing ability, without confirmation.

CHAPTER 6

Answers to Short Answer Questions

1. audiometer
2. transducer
3. electrical; acoustical/vibratory
4. air; bone
5. collapsing; masking; stability
6. American National Standards Institute
7. audiogram; intensity; frequency
8. threshold; 50
9. symbols
10. symmetry
11. type; conductive; sensorineural; mixed
12. conductive; external; middle ear
13. sensorineural; cochlea; auditory nerve
14. mixed; both
15. sound-treated; responses
16. otoscopic; cerumen
17. limits
18. vibrator; mastoid; forehead
19. crossover
20. masking
21. interaural attenuation; transducer
22. bone
23. plateau
24. undermasking; masking; overmasking
25. masking dilemma; air-bone gaps
26. tuning fork
27. Schwabach; conductive
28. Rinne; negative; conductive
29. Bing; conductive
30. Weber; sensorineural; poorer

Answers to Discussion Questions

1. The use of insert earphones is beneficial in preventing the occurrence of collapsing ear canals during hearing testing. Particularly in the older adult population, ear canal cartilage may be very pliable. The use of supra-aural headphones with such individuals often results in a collapse of the ear canal, which causes a conductive loss to occur during testing because sound cannot reach the tympanic membrane appropriately. Insert earphones, by nature of their placement in the ear canal itself, prevent this phenomenon from occurring.

   A second advantage of using insert earphones is the reduced need to mask. The need to mask is determined by the amount of interaural attenuation that occurs during presentation of a sound. The interaural

attenuation is the amount by which sound is dampened by the structures of the head before it reaches the opposite cochlea. The minimum values for interaural attenuation are high for insert earphones because of their small surface area, meaning that they require a large amount of intensity before they are sufficient to cause cross-hearing. This means that there is less need to mask because there can be a greater difference in hearing thresholds between the ears before one must be "kept busy."

A third advantage of using insert earphones is the greater likelihood of correct earphone placement, with greater stability once the earphone is in place. Soft, pliable foam inserts are typically used to house the end of the insert earphone so that the earphone will remain firmly in the ear canal once placed. Whereas misplacement of the insert earphone is unlikely to occur, the correct placement of the supra-aural headphone can sometimes be difficult to achieve. The transducer of the earphone in a supra-aural earphone must be placed directly over the ear canal opening in order for the appropriate signal intensity to reach the tympanic membrane.

The use of supra-aural earphones is preferred for patients who have a draining ear, as insert earphones cannot be placed in such an ear canal. For patients with stenotic (very small) ear canals or with atresia (absence of an ear canal), the use of insert earphones may not be possible.

2. The measurement used to quantify hearing sensitivity is the threshold of audibility. The intensity level at which threshold occurs is just barely audible. Many listeners tend to be overly responsive when listening for such sounds, providing positive responses when no stimulus has occurred. Other listeners tend to be more conservative, waiting until they are absolutely certain that they hear a sound before responding. This results in responses to levels that are higher than "just audible." It is necessary for patients to respond to sounds as closely as possible to their true threshold level. Therefore, for the sake of obtaining accurate measurements, it is necessary for patients be instructed regarding what they are listening for and how they are expected to respond.

   It is important to note that even though a patient may be properly instructed, misunderstanding of the required task may still occur. In such cases it may be necessary to re-instruct the patient on how to respond appropriately. It is important to remember that many individuals may not have participated in a hearing test before and are naïve test-takers.

3. One commonly used placement location for the bone oscillator is the mastoid bone behind the ear. This area provides for the lowest levels of thresholds. This may allow thresholds to be recorded for an ear with high thresholds, which might not be observable otherwise due to limitations of the bone vibrator output. A second advantage to mastoid placement is that there is some interaural attenuation for the higher frequencies typically tested. This allows for the ear to be somewhat isolated when testing, compared to the lower frequencies. If there is a relatively small asymmetry, placement of the bone oscillator on the mastoid of the poorer ear may result in thresholds that demonstrate a sensorineural hearing loss (lack of an air-bone gap) without the need to mask. A disadvantage of the mastoid placement is that in order to mask for both ears, it is necessary to switch the oscillator and earphones between the tests for each ear. This requires an additional trip into the sound booth, costing valuable time.

   Another placement location for the bone oscillator is the forehead. This area provides for a stable placement of the bone oscillator because it is relatively flat in comparison to the mastoid location. In forehead placement, earphones are kept in place for masking of each ear individually. Because neither ear is isolated, it is necessary to mask each of the ears. This is easily accomplished because earphones are kept in place over both ears during testing. With forehead placement, it is possible to have masked thresholds for each ear with only one trip into the sound booth, versus the two trips necessary with mastoid placement. A disadvantage to this placement location is that the measurement of thresholds with earphones in place will create an occlusion effect for the lower frequencies tested. This occlusion effect will need to be corrected for when determining accurate thresholds.

4. The first step in the plateau method is to find the unmasked bone conduction threshold. Next, masking noise is added to the nontest ear just above the threshold for air conduction in that ear. The bone-conduction signal is again presented to determine whether the threshold remains stable, or the intensity is raised to find the new threshold level. Additional intensity is then added to the masking noise, and the process is repeated.

   Initially, as the intensity of the masking noise is raised on each successive trial, in the case of a sensorineural hearing loss the threshold of the bone-conduction signal will begin to increase. This is because there is now an effective level of masking noise being presented to the nontest ear to begin to mask the nontest ear. The intensity range in which the bone-conduction threshold continues to be elevated is an area of undermasking.

   When there is sufficient intensity of masking noise in the nontest ear to completely mask the bone-conduction signal, the bone-conduction threshold

that is measured will represent the true threshold of the test ear. The bone-conduction threshold will remain stable over several increases in presentation intensity level. The range in which this true masking occurs is known as the plateau.

At a certain point, elevation of the masking noise begins, once again, to increase the level of the measured bone-conduction threshold. This occurs because the intensity of the masking noise is so high that it actually is cross-heard in the test ear. This cross-hearing in the test ear causes the bone-conduction signal to be masked in the test ear as well, which causes the threshold to be raised. At this point, overmasking is occurring.

The bone-conduction threshold that is found at the plateau level is the true bone-conduction threshold for the test ear.

5. A masking dilemma occurs when the difference between the bone-conduction threshold and the air-conduction threshold in the nontest ear is near the amount of interaural attenuation. In this case, the amount of masking that is required to be effective at masking the nontest ear is so high that it crosses over to the test ear and causes overmasking. The best way of coping with a masking dilemma is to use insert earphones, rather than supra-aural earphones. This is because there is a greater amount of interaural attenuation with insert earphones, making it less likely to cause overmasking. However, in some cases, even with insert earphones, a masking dilemma does occur. In these cases, it may not be possible to obtain valid air- or bone-conduction audiometric thresholds.
6. Tuning fork tests are still used quite often in clinical practice by audiologists and otologists. Typically, the tests are performed using a bone oscillator rather than a tuning fork when done by audiologists. These tests are helpful as a cross-check for the validity of bone-conduction audiometric results. They help to verify the presence or absence of conductive hearing disorders. In some instances, the immittance results for a patient may not "agree with" bone-conduction threshold measures. In such cases, it may be especially helpful to use tuning fork tests in order to determine whether a conductive hearing loss or possible middle-ear disorder exists.

CHAPTER 7

Answers to Short Answer Questions

1. speech audiometry
2. detection threshold; awareness threshold
3. lowest; recognized
4. pure-tone average
5. word-recognition score; suprathreshold
6. poorer
7. communicative; threshold; recognition; processes
8. monosyllables; recognition; phonetically balanced; conversational
9. spondees
10. predictability; low
11. competing; message; competition
12. synthetic; Identification; context
13. extrinsic; compression
14. dichotic
15. open; closed
16. detection; recognition
17. carrier
18. recorded; consistency
19. performance/intensity
20. rollover
21. Articulation (or Audibility) Index
22. count-the-dots; counseling
23. recruitment
24. cochlear
25. loudness adaptation

Answers to Discussion Questions

1. Speech awareness and speech threshold measures are used to determine the softest levels of speech that can be detected or recognized, respectively. The main purpose of these measures is to check the reliability of the pure-tone thresholds that are obtained. Speech awareness/detection measures will typically be 5–10 dB lower than speech-recognition threshold measures. This testing is typically performed using monitored-live-voice for the sake of efficiency. Speech threshold testing is typically performed using spondees — two-syllable words that have equal stress on each syllable. Speech awareness/detection and threshold measures are measured as the lowest level at which about 50% of the words are correctly identified or repeated. Because the purpose of these measures is to determine the lowest level at which person can hear, rather than how well a person understands speech, the materials used are common, easy-to-learn words, and the listener is familiarized with the materials prior to testing.

   Word-recognition testing is used to determine how well a person hears speech when it is made audible in an ideal listening situation. The main purposes of these measures are to understand the patient's suprathreshold hearing abilities and to use as a tool for identification in site-of-lesion testing. This testing is typically performed using recorded materials in order to be able to provide reliable measures over time and from tester to tester, and even from test to test with the same speaker. Monosyllabic words are used for word-recognition testing. The word lists utilized are phonetically or phonemically balanced, meaning the lists represent the occurrence of sounds or groups of

sounds in a spoken language. Word-recognition scores are measured as the percentage of words correct from the list presented. Performance at a given presentation level can provide clues as to whether a retrocochlear site of lesion may exist for a given patient. At particularly high presentation levels, the phenomenon of rollover can occur during speech testing in cases of retrocochlear lesions, where the patient performs better under lower intensity conditions.

Sensitized speech measures are used to determine the deficits resulting from disorder in the auditory pathways of the central nervous system. This testing is typically performed using recorded materials, which have been altered in a manner that reduces the extrinsic redundancy of the signal. The most successful use of sensitized speech measures has been the use of a speech signal with a competing message. Dichotic listening tests in which different speech signals are presented simultaneously to the two ears, are also used. Reduced performance in particular tests indicates deficits in particular areas of processing or lesions within particular areas of the central nervous system.

2. The task of identifying sounds that are "just audible" as is the case in pure-tone threshold testing can be difficult for some patients. Some patients are prone to overresponding or providing responses when sounds are not present. Other patients do not respond until they are certain that they have heard a sound, which leads to elevated thresholds. The task of responding to words, however, takes much of the guesswork out of deciding what a "real" stimulus is. Therefore, the speech-recognition threshold may in some cases be a more accurate measure of threshold of sound. If the thresholds measured for speech frequencies (500, 1000, and 2000 Hz) do not match the speech-recognition threshold, the patient may need re-instruction on the pure-tone threshold testing task.

   While some patients may have difficulty in understanding the pure-tone testing task, other patients may provide responses that are consistent with a functional hearing loss. In this case, because speech stimuli are perceived as louder than individual pure tones, most patients will have difficulty accurately judging the intensity of the speech signal compared to the pure-tone signals. This typically results in the speech-recognition threshold being significantly lower than the pure-tone average. Such a difference persisting after re-instruction of the patient should increase the suspicion of a functional hearing loss.
3. The advantage of using monitored-live-voice over recorded materials is that testing is faster. The advantages of using recorded testing materials outweigh this advantage in most situations. One use of the word-recognition score is to determine whether the results are consistent with the degree of hearing loss. This is an important question to answer because lack of consistency with the degree of hearing loss can be indicative of a retrocochlear disorder. In order to answer this question, the percentage of words correct is compared to what is expected based on normative data that has been determined empirically. These norms were developed using commercially recorded materials. Therefore, it is necessary to use recorded materials in testing in order to be able to compare results with the normative data.

   Another common use of the word-recognition score is to assess change in performance over time. Again, this can help to indicate problems such as retrocochlear disorder that may begin to demonstrate effects over time as an acoustic tumor grows in size. The ability to compare results from one test to the next depends on the use of recorded test materials because presentation of materials using monitored-live-voice has the potential to be dramatically different among clinics, among testers, and even with the same test on different occasions.
4. The central auditory nervous system has a great deal of redundancy inherent in the innervation patterns and anatomic makeup of the system. This allows for damage to occur in the central auditory nervous system without obvious effects on hearing sensitivity or speech perception abilities. However, when damage or developmental problems occur in the central auditory nervous system, there can be subtle effects on sound processing abilities.

   The speech signal itself that is used to measure processing ability is also highly redundant. This extrinsic redundancy is due to the wealth of information present in the phonetic, phonemic, syntactic, and semantic characteristics of the speech signal. So, even when an individual has deficits that are present in the central auditory system, the extrinsic redundancy of the signal can be used to facilitate speech understanding, thereby masking the deficit.

   By sensitizing the speech signal, the extrinsic redundancy is reduced in some way. This reduction of redundancy may be helpful in revealing the central nervous system deficit that would otherwise be masked by use of typical speech stimuli.
5. Speech audiometry materials can be open set, meaning that the response choice can be any of all available targets in a language, or closed set, where the response choice is from a limited set. The use of closed-set test materials tends to result in higher scores than would be found from open-set materials because the responses that the patient must decide on are limited in number.

In addition, some speech audiometry materials are designed specifically for use with particular populations, such as children. These materials are designed to account for the developing language abilities of children, so that the test score is reflective of hearing ability rather than language ability. A test that uses developmentally inappropriate materials would likely negatively impact test scores and give a false impression of hearing ability.

CHAPTER 8

Answers to Short Answer Questions

1. immittance; middle; retrocochlear
2. admittance; impedance; immittance
3. middle-ear
4. tympanometry; static; reflexes
5. tympanometry
6. tympanogram
7. shape; A; C
8. A; normal
9. B; fluid
10. C; Eustachian tube
11. Eustachian tube; ventilate
12. A_s; shallow; stiffness
13. A_d; disarticulation
14. tympanometric peak pressure
15. tympanometric width
16. 226; 1000
17. static immittance
18. equivalent volume
19. acoustic reflex
20. stapedius
21. binaural
22. uncrossed; crossed
23. afferent; efferent
24. acoustic reflex threshold
25. elevated; 70
26. Sensitivity Prediction; Acoustic Reflex

Answers to Discussion Questions

1. If all immittance measures are normal, then whatever hearing loss is determined by pure-tone audiometry is sensorineural in nature because immittance audiometry is significantly more sensitive to middle-ear disorder than the assessment of air-bone gaps. If an air-bone gap is found to exist on pure-tone testing, then either air-conduction or bone-conduction thresholds are likely not accurate.

   In addition, the knowledge that immittance measures are normal at the onset of pure-tone testing may be helpful as a time-saving tool because some audiologists may choose to forego bone-conduction testing, particularly in cases of normal air-conduction thresholds.

   In cases where it is known from immittance measures that there is likely middle-ear dysfunction, this can alert the audiologist to the likelihood of an air-bone gap occurring during pure-tone testing. This can be helpful when testing patients who are more difficult to test behaviorally, such as children.

   Another possible advantage of conducting immittance testing at the outset of the hearing test battery is that it can be shown to patients that objective measures can be made that provide important information regarding the functioning of the hearing mechanism. Such a demonstration may be advantageous in cases where an individual is attempting to feign or exaggerate a hearing loss. By demonstrating that information can be obtained without the cooperative behavioral responses of the patient, the patient who may be tempted to exaggerate or feign a hearing loss may be less likely to do so when immittance measures are performed first.
2. The goal of audiometric testing is to assess communication and hearing function. The first such question is whether a middle-ear disorder is present. This relates to treatment goals, because middle-ear disorders are, for the most part, medically treatable. The next question is whether the disorder is causing a conductive hearing loss. This question will be determined by air- and bone-conduction testing. Immittance testing provides the answer to the first question that is asked. It does so in a manner that is more sensitive than the presence of an air-bone gap on pure-tone testing.
3. A probe with a rubber tip is situated in the ear canal of the patient in order to obtain an air-tight seal for making measures of air pressure. The probe is connected to the immittance meter with several thin rubber tubes, through which sounds and air are delivered from the immittance meter where they are generated. The probe houses (1) small loudspeaker for the delivery of the probe-tone signal and the reflex signal, (2) a small microphone that records the acoustic signal in the ear canal, and (3) a tube through which air is delivered to the ear canal.

   The immittance meter houses the components that control the delivery of sound and air to the probe. A reflex signal generator controls and delivers reflex-eliciting signals to ipsilateral and contralateral loudspeakers. The probe-tone generator delivers a tone of a fixed frequency and SPL to the probe. The microphone recording and analysis device maintains the SPL in the ear canal at a constant level by measuring any changes and making adjustments to the sound generators. The air-pressure system consists of an air pump for generating controlled levels of air pressure and a manometer to measure the air pressure in the ear canal.

For making measures of contralateral acoustic reflexes, a second earphone is placed into the patient's other ear. This is typically an earphone that is coupled to the ear using either a foam insert (such as that used for insert earphones) or a rubber tip (the same as is used for the probe coupling). This earphone serves as the speaker for delivering the reflex signal to the ear.

4. The most typical middle-ear dysfunction seen in audiology practice is caused by the presence of fluid in the middle-ear space. The effect of fluid is to reduce the flow of energy through the middle-ear system, because energy does not flow as well through fluid as through air. In such a case, the admittance is decreased and the impedance is increased. Immittance measures will reflect these changes. Other examples of middle-ear dysfunction that decrease the admittance and increase impedance of energy flow through the system are negative pressure in the middle-ear space, masses in the middle-ear space that restrict movement of the ossicles, fusion of the ossicles, and otosclerosis.

   In other cases, energy flow through the middle-ear system is increased relative to normal. This will result in high admittance and low impedance in the system. An example of this would be an ossicular discontinuity.

   A tympanic membrane perforation has immittance results that reflect the presence of a very large volume of air. This is because the volume of air being measured reflects the air in the ear canal, as would normally be measured, and the volume of air in the middle-ear space, which is not normally measured. The hole in the tympanic membrane causes the measurement to be made of both cavities.

   The specific effects of the various disorders on immittance are a function of the probe tones that are used to make measurements. Typically, a 226 Hz probe tone is used for measurement of immittance in adults. The patterns of findings for middle-ear dysfunction described here are characteristic of the fact that a low-frequency probe tone is used. However, immittance meters exist that can also use different frequencies to make immittance measures. The findings using this type of multifrequency immittance measure can provide information regarding the characteristics of mass versus stiffness effects in the middle-ear system. However, given that the first question to be answered in the hearing test battery is whether or not there is middle-ear dysfunction present, the findings using the 226 Hz probe tone are often sufficient to answer this question. Because multifrequency immittance measures are often too sensitive to minor, nonpathologic conditions they are typically not used in clinical practice.

5. Type C tympanograms represent substantial negative pressure in the middle-ear space, relative to atmospheric pressure. Type B tympanograms represent increased mass in the middle-ear system, which is often the result of fluid in the middle-ear space. Both types of tympanogram results are often outcomes of Eustachian tube dysfunction.

   The Eustachian tube is a passageway between the middle-ear space and the nasopharynx. It is normally closed. The Eustachian tube opens in order to equalize the pressure in the middle-ear space. It does so upon activities such as swallowing or yawning. When the Eustachian tube is not functioning properly, it fails to open appropriately. When this occurs, pressure in the middle-ear space does not become equalized with atmospheric pressure, leading to inflammation of the lining of the middle ear and negative middle-ear pressure. Tympanometric measurement made at this stage of the dysfunctional process would result in type C tympanograms.

   The relative negative pressure of the middle ear causes a vacuum, followed by effusion of fluid into the middle-ear space from the mucous membrane of the middle ear cavity. This fluid builds up ultimately impeding the normal functioning of the ossicles and tympanic membrane. Tympanometric measurement made at this stage of the dysfunctional process would result in type B tympanograms.

6. The sound is initially transduced to mechanical energy in the middle-ear space where the ossicles are set into motion from movement of the tympanic membrane. Movement of the stapes in the oval window transduces the mechanical energy to hydraulic energy as the movement of fluid occurs. The inner hair cells of the cochlea transduce this hydraulic energy to electrical energy, and the electrical signal is sent from the cochlea along the VIIIth (vestibuloacoustic) cranial nerve.

   From the VIIIth cranial nerve, the electrical signal is sent to the ventral cochlear nucleus. It is then relayed to both the ipsilateral and contralateral superior olivary complex. This is the first level of the brain where afferent information is received bilaterally. From the superior olivary complex, the efferent arc of the response begins. The signal is relayed via the motor nucleus of the VIIth cranial (facial) nerve. The facial nerve innervates the stapedius muscle. The tendon of the stapedius muscle is attached to the neck of the stapes. Contraction of the stapedius muscle causes a pull on the stapes, resulting in the decrease of energy transmission to the cochlea by an increase in impedance of the middle-ear system.

   Disorders that occur at any level of this pathway can result in changes to the end result of the acoustic

reflex response. As such, the acoustic reflex response is a good way to measure the overall integrity of this pathway. However, because a number of disorders at any level of the pathway will result in the same outcome (elevated or absent acoustic reflex), information gleaned from the acoustic reflex response must be coupled with other sources of information (such as tympanometry and static immittance) to localize the site of the lesion.

CHAPTER 9

Answers to Short Answer Questions

1. auditory evoked potentials
2. electroencephalography
3. ground; reference; active
4. signal; noise
5. differential
6. amplified
7. filtered
8. signal averaging
9. compound action potential
10. summating potential
11. cochlear microphonic
12. near-field; far-field
13. auditory brainstem response
14. five
15. distal; VIIIth cranial nerve; proximal; cochlear nucleus; superior olivary complex
16. middle latency response; Pa; Pb;
17. late latency response; N1; P2; greatly
18. auditory steady-state response
19. auditory brainstem response; auditory steady-state response
20. auditory brainstem response
21. outer hair cells
22. present; absent
23. spontaneous; evoked
24. click; transient
25. distortion product
26. ototoxic

Answers to Discussion Questions

1. The purpose of signal averaging is to reduce the amount of background noise from a recorded signal to permit visualization and extraction of the desired signal. Signal averaging is the averaging of samples of ongoing electroencephalogram (EEG) activity in order to reduce the background activity and enhance the evoked response. Multiple samples are recorded over a fixed time base. The response is time-locked to the stimuli, and is recorded in a specified time window. The activity that is present in this time window is averaged over multiple presentations of the stimulus. The activity that is "background noise" will be random electrical activity with respect to the stimulus. Over repeated presentations, the random activity, which has no fixed pattern, becomes closer to a value of 0 as it is averaged. However, the time-locked activity continues to occur with every presentation. As the responses are averaged over and over again, the time-locked response becomes more enhanced, relative to the disappearing, random background activity. In this way, the extremely small electrical signal, which could not be viewed in ongoing EEG activity, becomes robust and easily recognized.
2. Evoked potential testing is often used for surgical monitoring in cases where hearing preservation is attempted during the removal of an acoustic tumor. During the course of tumor extraction, function of the nerve may be influenced by physical manipulation, thereby affecting the evoked potentials. By monitoring the response of the auditory nerve to sounds presented to the cochlea, the surgeon can be alerted to the diminished or absent response and can take measures to prevent further damage from occurring. In addition, the nerve may sometimes be intertwined with the acoustic tumor to a certain extent. By monitoring the responsiveness of the nerve to sound, the surgeon can be alerted to damage occurring following tumor removal.
3. The use of the auditory brainstem response is considered the best method for infant hearing screening. This method is valuable because of its objectivity, its specificity and sensitivity, and its ease of administration. Prior to the use of evoked potentials and otoacoustic emissions, behavioral testing was the only available method for screening the hearing of infants. As can be imagined, the responses obtained with behavioral methods were difficult to interpret for many infants due to their unreliable responses. In addition, behavioral responses by infants to sound stimuli were not reliable at near-threshold levels. With the advent of objective measures, such as evoked potentials, information could be obtained regarding the functional integrity of the auditory system, without the need for behavioral responses from the infant.

   Compared to other measures of auditory function, the ABR has a great deal of specificity. In cases where otoacoustic emissions are used as a screening tool for infants, there is a high number of false positive results. This means that many infants are referred for further testing who do not have hearing loss. The reason that this occurs so often with the use of otoacoustic emissions is that newborns often have residual fluid and debris remaining in the outer-ear system following the birth process. These materials interfere with the recording of the evoked otoacoustic emissions, which lose a great deal of energy in

traveling from the cochlea to the external auditory canal. However, it must also be realized that the ABR may be absent or abnormal in some infants due to neuromaturational delay, which would again cause a failure of the hearing screening, even though hearing itself may be normal.

The ABR has an advantage over evoked OAEs in detection of hearing disorder in the special case of auditory neuropathy. In some children, the ABR may be abnormal due to a problem with the cochlear inner hair cells or the VIIIth nerve. However, the evoked OAEs may be perfectly normal. By screening hearing using only evoked OAEs, children with this type of anomaly will be incorrectly categorized as having normal hearing.

Ease of administration is another advantage to testing using ABR. Although evoked OAEs are also easily administered, the use of automated ABR has greatly improved the efficiency of newborn hearing screening. The automated ABR compares recordings made from infants to templates that represent expected results. If the recordings are sufficiently like the expected results, the infant passes the screening. This system is very useful because individuals with minimal skills and training can administer testing. In addition, both evoked OAEs and ABR testing are insensitive to patient state, so they are easily administered to sleeping infants.

4. Compared to imaging studies, the auditory brainstem response (ABR) test is less sensitive to detection of small acoustic tumors. However, the auditory symptoms that may indicate the presence of a tumor are often quite subtle or absent in some individuals. Therefore, based on financial considerations and patient and physician preference, the ABR may first be used as a screening tool to determine whether further imaging studies are warranted for a given patient. In addition, the ABR is often useful in indicating other VIIIth nerve or auditory brainstem disorders such as neuritis, multiple sclerosis, or brainstem neoplasms.
5. Evoked OAEs are valuable as a cross-check for behavioral thresholds in children. The pediatric population can be difficult to test behaviorally. When results are obtained, the reliability as judged by the examiner may not be sufficient to proceed with treatment or discharge from follow-up. While immittance measures provide valuable information regarding middle-ear function, this alone is insufficient to characterize the hearing of the child. Evoked OAEs provide a valuable, objective measure of cochlear function that helps to support or refute behavioral responses. Auditory brainstem response (ABR) testing may be performed once a hearing disorder is detected by from evoked OAE responses. Although the ABR or ASSR would provide frequency-specific, objective information about the children's hearing threshold, they may not be attainable in pediatric assessment. This is because these measures require minimal movement on the part of the patient, necessitating sedation in young children in order to obtain interpretable responses. As such, they are reserved for testing in children only when necessary.
6. Evoked OAEs are commonly used to monitor cochlear function in individuals undergoing treatment with medications that are likely to be ototoxic (poisonous to the ear). There are many such life-sustaining drugs that are used. They include medications such as chemotherapy drugs and antibiotics used to control infection. The first effects that are seen from such drugs are typically on the outer hair cells of the cochlea. They typically affect the higher frequencies first. By measuring outer hair cell function with distortion product otoacoustic emissions (DPOAEs), the effects of these drugs can be monitored. If the DPOAE results indicate that cochlear function has begun to deteriorate, dosages may be able to be adjusted to minimize the ototoxic effects of the drug.

CHAPTER 10

Answers to Short Answer Questions

1. goals; strategies
2. nature; sensitivity
3. middle-ear
4. immittance; mass; stiffness; perforation; negative
5. pure-tone; air-bone
6. recognition thresholds
7. sensitivity prediction; acoustic reflexes; broad-band noise
8. symmetry
9. stability
10. recognition; retrocochlear; rollover
11. handicap
12. identify; audiologic; delayed; progressive
13. family; syndrome; cytomegalovirus
14. automated
15. otoacoustic emissions
16. 1000; 226
17. Behavioral observation

Answers to Discussion Questions

1. The primary goals for evaluation of a patient seeking otologic care include the determination of the degree of hearing loss and the site of disorder. This relates to the consequence that a disorder has on the function of the outer- and middle-ear structures. The primary goals for evaluation of a patient seeking audiologic care include determination of the degree of impairment and the prognosis for successful hearing aid use.

These goals relate to the impact of the impairment on the patient and how audiologic intervention may be used to facilitate more successful communication.

2. The main goals for audiologic evaluation of adult patients are to assess degree and type of hearing loss and to assess the impact of the hearing loss on communicative function. These goals are similar for both younger and older adult populations. However, with older adults additional considerations must be made for the changes in function of the cochlea and central auditory nervous system that occur with aging.

   Due to the decreased abilities of many older adults to hear rapid speech and speech in the presence of background competition, additional speech audiometry measures are indicated. Assessment of speech recognition in background noise or competition, as well as dichotic speech-recognition measures are helpful to understand the prognosis for use of hearing aids in older adults, particularly regarding the decision to use unilateral or bilateral amplification.

3. The strategies used to evaluate pediatric patients of various ages differ according to the goals of evaluation. For the infant population, the goals of testing are to identify children at risk for hearing loss and who need further evaluation. Screening measures, such as automated auditory brainstem response testing and otoacoustic emissions are helpful in accomplishing this goal because they can be easily administered to a great number of infants (for the purpose of universal screening of newborns) and provide objective measures of auditory function. Behavioral testing may be used for this population, but is less helpful in accomplishing these goals due to the intensity levels at which infants respond to sound.

   For the evaluation of infants and young children, more comprehensive testing is indicated to determine the degree and type of hearing loss. Otoacoustic emissions and auditory evoked potentials provide objective measures in this age group. Tympanometry provides valuable information about middle-ear function. The major differences in testing children of various ages relate to the behavioral expectations for children. In testing very young infants, behavioral observation audiometry is used to look for behavioral changes that occur in response to suprathreshold acoustic stimulation presented in soundfield. In older infants, visual reinforcement audiometry is used to determine responses to auditory stimulation in soundfield or under earphones by conditioning a child's responses to sound with visual stimuli. In toddlers and preschoolers, conditioned play audiometry allows for ear-specific threshold responses, as children are conditioned to respond to low levels of stimulation with some type of motor response that typically involves the manipulation of toys. Older children perform behavioral testing tasks similar to those of adults. The behavioral responses to pure tones become progressively more specific and reliable with patient age.

   Speech audiometry varies as a function of age as well. In very young infants, behavioral responses to speech are noted. In older infants, speech awareness thresholds are determined using the methods described above for pure tones. In toddlers and preschoolers, speech recognition is often measured with closed-set identification tasks, such as picture pointing or pointing to body parts. Younger children are often capable of demonstrating speech recognition through repetition of word lists that are designed for children, while older children are often tested using the same word lists as adult patients.

4. The role of immittance audiometry changes based upon the suspected etiology of disorder for a patient. Individuals who are referred for otologic testing have varied etiologies for which immittance testing is primarily used. In the population of patients with otologic disorder, some individuals are suspected to have middle-ear dysfunction. Others are expected to have cochlear or retrocochlear dysfunction. For those individuals with evidence of acute or chronic middle-ear dysfunction, tympanometry and acoustic reflexes are evaluated to determine whether a pattern of middle-ear dysfunction exists. Flat tympanograms suggest a likelihood of fluid in the middle-ear space, while significant negative pressure suggests a likelihood of Eustachian tube dysfunction. A large measured volume suggests the likelihood of a perforation in the tympanic membrane, or perhaps indicates the patency of previously placed pressure equalization tubes in the tympanic membrane. A pattern of acoustic reflexes that are absent or elevated in the probe ear are also suggestive of middle-ear dysfunction.

   Immittance testing can also be helpful in determination of cochlear versus retrocochlear pathology. A pattern of abnormal acoustic reflexes coupled with a normal tympanogram is suggestive of sensorineural hearing loss. A sensory, or cochlear, component to a hearing loss can be detected based on the SPAR test. A neural, or retrocochlear, hearing loss can be identified based on a pattern of elevated reflex thresholds as well as abnormal acoustic reflex decay.

5. The role of auditory evoked potentials can be divided into measures of hearing sensitivity and measures of VIIIth cranial nerve and brainstem function. In the pediatric population especially, the auditory brainstem response test and its automated version are useful in screening the hearing of newborns. The ABR is also useful for obtaining ear-specific threshold information in infants and young children who are

too young or unable to provide behavioral threshold responses. In the adult population, the most common use of the ABR is to assess VIIIth cranial nerve and brainstem function. It is often used as a screening tool, particularly for auditory nerve lesions.

6. As was discussed in this chapter, the audiologist must determine the goals for an evaluation and the strategy to be used to accomplish the goal. The audiologist has a number of assessment tools available for the purposes of evaluating auditory function. Some tools provide more valuable information regarding auditory function for a particular population than others. In addition, some tools provide more valuable information regarding particular disorders than others. The more an audiologist knows about a particular medical condition related to hearing loss, the more the audiologist can tailor the testing strategy to obtain the most valid and useful information. Furthermore, the audiologist's knowledge of the structural and functional changes of a disorder, as well as the medical treatment strategies for a disorder, allows the audiologist to interpret audiologic findings appropriately.

   For example, a patient who is undergoing certain forms of chemotherapy is more at risk for developing hearing loss due to ototoxicity. Knowledge of this would prompt the audiologist to use high-frequency pure-tone testing and distortion product otoacoustic emissions testing to monitor hearing function, rather than standard pure-tone audiometry alone, because the highest frequencies are affected first.

   As a second example, consider a pediatric patient with a syndrome that affects both hearing and cognitive function. Knowledge of possible developmental delays may help the audiologist to be prepared to adapt the behavioral testing strategy to be most suitable to the cognitive age of the child.

CHAPTER 11

Answers to Short Answer Questions

1. talking; reports; referrals
2. nature; degree; words
3. clear; knowledge
4. unique
5. changed; enhancements/advancements
6. cause; treatable
7. grief; educational
8. documentation
9. reporting
10. audiogram
11. letter
12. clear; concise; consistent
13. destination
14. history
15. sensorineural
16. degree; configuration
17. change
18. middle ear; immittance
19. speech
20. conclusions
21. retrocochlear; auditory processing
22. recommendations
23. pamphlets
24. templates
25. who; reason
26. otolaryngologist; retrocochlear
27. speech-language pathologist; milestones

Answers to Discussion Questions

1. A parent who is learning about their child's hearing loss is likely to be in some stage of grief regarding the hearing loss. While there is often some suspicion of hearing loss that caused the evaluation to occur, a parent may experience shock or denial upon hearing that their child has a hearing loss. It is important to consider the emotional reaction of the parent to such news. Being informed of even a relatively mild hearing loss often causes great alarm and distress in a concerned parent. Often upon hearing such news, a parent's attention will no longer be directed at the clinician, even if it appears to be. In such a case, delivering excessive amounts of information is probably inadvisable and may serve to confuse and further upset the parent. It is often more helpful initially to provide the parent with a simple explanation of the hearing loss, and offer them the opportunity to express their feelings and to ask questions.
2. Often a simple schematic of the parts of the ear is helpful in describing to the patient or parent where the hearing loss is occurring. Using the term "conductive" provides the patient with the appropriate word to describe the hearing loss. To reinforce this terminology, it may be helpful to describe how there is a problem with conduction of sound through this space in a conductive hearing loss. If there is fluid in the ear, the concept of a "blockage" of sound or trying to hear "underwater" is often helpful in providing a very simple explanation of the hearing dysfunction to patients. The need for medical referral for possible treatment of the disorder should be discussed clearly and simply, so that the patient knows what will happen next in the treatment process.
3. Often a simple schematic of the parts of the ear is helpful in describing to the patient or parent where the hearing loss is occurring. Using the term "sensorineural" provides the patient with the appropriate word to describe the hearing loss. Some clinicians

will describe the "hair cells lining the cochlea." It is explained that when the hair cells are damaged, they are no longer able to sense the sound vibrations, and so the person experiences a loss of hearing ability. It is further explained, assuming that there is no underlying medical condition, that this situation is typically permanent. The patient is counseled regarding appropriate treatment options so that the patient knows what will happen next in the treatment process.

4. Often, a report sent to an otolaryngologist would be in the format of an audiogram report rather than a letter report. The otolaryngologist is familiar with reading an audiogram and is expected to understand the implications of the audiologic testing done by the audiologist. The otolaryngologist's primary concern will be the diagnosis and treatment of underlying medical pathology. Therefore, the report will primarily stress the presence of middle-ear disorder, the nature and degree of hearing loss, and any other relevant site-of-lesion findings.

   A report sent to a school administrator would, typically, be in the formant of a letter report. This may be accompanied by an audiogram if the document is meant to be a part of the student's records. The school administrator is likely to be unfamiliar with the audiogram and will need clear and simple explanation of the findings regarding the nature and degree of hearing loss. In addition, interpretation of these findings in regard to implications for speech and language development is necessary. Of primary importance for such an audience will be the recommendations that are made for treatment and habilitation for the child. The use of medical jargon and nonrelevant information should be avoided. Clear, simple, and concise reporting should be emphasized.
5. The obligation of the audiologist is to the source of the referral. Therefore, it is necessary to accurately determine who made the referral to the audiologist and for what purpose the referral was made. In cases where the patient was self-referred, the audiologist is responsible for both evaluation and management of the patient. In cases where the patient was referred by a physician, the audiologist is obligated to evaluate the patient and report back to the physician with the results. In this case, the audiologist is providing consultation services rather than management services. However, in a case where the physician is referring to the audiologist for the purpose of providing hearing management, then the audiologist is responsible for management of the patient.
6. Recommendation for referral out should be made back to the original referral source. Typically audiologists would refer for either otolaryngology or speech-language pathology services.

   Cases in which referral should be made for otolaryngology consultation include ear pain and fullness; discharge or bleeding from the ear; sudden or progressive hearing loss, even with recovery; unequal hearing between ears or noise in the ear; hearing loss after an injury, loud sound, or air travel; slow or abnormal speech development in children; and balance disturbance or dizziness. Following the audiologic evaluation, otolaryngology referral should be made if otoscopic examination of the ear canal and tympanic membrane reveals inflammation or other signs of disease; immittance audiometry indicates middle-ear disorder; acoustic reflex thresholds are abnormally elevated; air- and bone-conduction audiometry reveals a significant air-bone gap; speech-recognition scores are significantly asymmetric or are poorer than would be expected from the degree of hearing loss or patient's age; or other audiometric results consistent with retrocochlear disorder.

   Cases in which referral should be made for speech-language pathology consultation include: parental concern about speech and/or language development; speech-language development that falls below expected milestones; or observation of deficiencies in speech production or expressive or receptive language ability.

CHAPTER 12

Answers to Short Answer Questions

1. communication; residual; aural
2. audiologic; clearance
3. impressions; programmed
4. age; communication
5. motivation; prognosis
6. otoscopic; pure-tone; discomfort
7. handicap; physical
8. formal; Oriented; Improvement; Handicap; Hearing; Benefit
9. motor; visual
10. patient; too much; configuration; recognition
11. hearing aids; implants
12. behind; in
13. contralateral
14. binaural advantage
15. functional gain
16. classroom; speech
17. speechreading; telephone

Answers to Discussion Questions

1. Diagnostic audiology deals with the identification and quantification of hearing impairment. In this

role, the audiologist diagnoses the presence of hearing loss and provides information important to the medical diagnosis of hearing disorders.

Audiologic management deals with the communication disorder that results from a hearing loss. The goal of audiologic management is to limit this disorder as much as possible. To that end, the audiologist utilizes technological devices to maximize residual hearing and to rehabilitate or habilitate hearing function.

These areas overlap primarily in the realm of audiologic evaluation. During the audiologic evaluation, the audiologist learns important information both about the hearing impairment and about the patient's motivation and need for audiologic management.

2. A patient's motivation for pursuing a hearing aid can come in many forms. Often, patients are motivated to pursue hearing aids due to their own perceived hearing handicap. These patients are choosing to pursue hearing aids for the purpose of improving their own communication situation. While the patient may acknowledge the limitations of their hearing devices, their intrinsic motivation helps them to cope with these limitations and overcome them where possible.

   Unfortunately, many patients are driven to hearing aid use by the external motivation of another individual, such as a spouse or other family member. When this occurs, the patient is often found to be resentful or angry over being "forced" to do something that they did not wish to do. When such a patient is faced with limitations of their hearing devices, they may feel all the more dissatisfied with their hearing aids due to the fact that they did not want them.

   Such a patient is typically considered to be a poor candidate for hearing aid use. While there is a possibility that the patient may try hearing aids and find that they greatly benefit from them, the more likely scenario is that an unmotivated patient would either return the hearing aids for credit and/or would be much less likely to attempt to use hearing devices in the future due to their initial negative experience.
3. The first step in a typical process for obtaining hearing aids is the audiologic assessment. This evaluation allows for determination of hearing status and exploration of patient motivation to use amplification, as well as determining possible contraindications and making a prognosis for hearing device success. Following the audiologic assessment, a medical clearance is typically obtained from a physician. This clearance assures that hearing aid use is not medically contraindicated.

   Once the patient has obtained a medical clearance, they are typically counseled regarding appropriate hearing devices for their hearing loss and communication needs. Impressions of the ears are then made to allow for custom fitting of hearing aids or earmolds as needed. The devices and components are then ordered from the hearing-device manufacturer. Once the devices are delivered to the audiologist, they are programmed to fit the patient's hearing loss, and the patient is counseled in hearing aid use and care. Some type of evaluation of fitting success is typically made upon dispensing of the hearing aids. This type of evaluation is generally continued at follow-up appointments, which allow adjustments to be made to the hearing devices or for problems to be addressed.
4. The patient variable of age greatly impacts audiologic management because the inability of young children to describe their hearing experience makes the challenge of fitting hearing devices more difficult. Extensive habilitation measures are also typically employed in this population because these patients have yet to develop speech and language. In the elderly population, physical and cognitive constraints may be imposed on the ability to effectively use hearing devices. In addition, auditory processing disorders may be manifest in older age, resulting in decreased benefit from amplification.

   The nature of the patient's hearing impairment will impact audiologic management. Patients with a profound hearing loss are more likely to benefit from a cochlear implant than traditional hearing aid amplification. Patients with more mild impairments will be more likely to benefit from some hearing aid styles than others. Patients with auditory processing disorder may benefit more from assistive listening devices than from conventional hearing aids.

   The extent of communication requirements in the daily life of a patient is likely to have an impact on audiologic management. Patient who are in a variety of challenging listening situations are likely to require a great deal of sophistication in their choice of hearing devices. Children in a classroom are likely to require FM systems to increase the signal-to-noise ratio sufficiently to hear the teacher. Patients who lead a more solitary lifestyle will have different needs than either of these populations.
5. Informal hearing needs assessments provide the audiologist with the ability to explore a patient's lifestyle and hearing requirements in depth. In addition, this type of assessment is completed in a more conversational, natural style, which may allow the patient to feel more comfortable in sharing their personal experiences. Furthermore, the communication exchange in which the needs assessment takes place provides the audiologist with the opportunity to observe the patient's communication abilities. However, informal hearing needs assessment does not allow

measurement or quantification of the patient's benefit or lack of benefit from audiologic treatment. In addition, vital information may be missed when needs are discussed in an unstructured format. Furthermore, some patients may not have considered particular areas of concern in the past, and would be unlikely to mention some areas of hearing needs without being prompted by the information provided by a formal questionnaire.

Formalized hearing needs assessments come in many forms. Some formats such as the Client Oriented Scale of Improvement (COSI) provide the opportunity for open-ended responses to hearing needs assessment. Other formats such as the Abbreviated Profile of Hearing Aid Benefit (APHAB) or Hearing Handicap Inventory (HHI) provide for closed-choice responses to commonly experienced hearing needs. Each of these assessment types allows for quantification and ease of documentation of hearing needs. Such measures provide an opportunity for demonstration of audiologic treatment benefit to patients and for third-party reimbursement for services. These measures are also useful for research purposes to demonstrate treatment efficacy.

6. The goal of determining discomfort levels is to set the maximum output of a hearing aid at a level that permits the widest dynamic range of hearing possible without letting loud sounds be amplified to uncomfortable levels.

   Specifically, the patient should be instructed to respond when the level of the sound is uncomfortably loud. Pure-tone signals of 500, 1000, 1500, 2000, and 3000 Hz are then presented using an ascending approach in two or five dB steps until the patient indicates that the uncomfortable level was reached. This process is then replicated until the same level is indicated on two out of three trials. This level is deemed to be the threshold of discomfort.

7. Any of the following, or combination of the following, indicators may signal poor prognosis for hearing aid success:

   - Patient does not perceive a problem (denial; poor motivation)
   - Not enough hearing loss (minimum degree of hearing loss must occur for benefit to be expected)
   - Too much hearing loss (hearing aids can only provide so much gain; word recognition may be poor with too much gain)
   - A "difficult" hearing loss configuration (amplification works best for certain mid- to high-frequencies; hearing loss in only the low-frequencies seldom causes a communication deficit and is more difficult to provide appropriate gain for)
   - Very poor speech-recognition ability (amplification does not improve communication in these cases)
   - Auditory processing disorder (reduce benefit from amplification)
   - Active disease process in the ear canal (use of hearing aid can limit access to ear canal and cause pain and ear canal stenosis)

CHAPTER 13

Answers to Short Answer Questions

1. linear; Nonlinear
2. output
3. peak clipping
4. compression limiting; distortion
5. compression
6. multiple memories
7. omnidirectional
8. microphones; directional; noise
9. analog; digital
10. microphone; amplifier; receiver
11. microphone; electrical
12. telecoil; telephone
13. amplifier
14. frequency response
15. receiver; acoustic
16. gain
17. input-output
18. dynamic range; 100
19. attack time; release time
20. feedback
21. earmold
22. venting; acoustic
23. FM; distance; noise
24. cochlear implant; magnet; speech
25. severe
26. bone-anchored
27. conductive; single

Answers to Discussion Questions

1. The major components of any hearing aid include the microphone or other audio input, the amplifier, and the receiver. The microphone serves to transduce mechanical energy into electrical energy. A hearing aid may have one or more microphones. In addition, it may have some type of direct audio input or telecoil input, which bypasses the microphone function, directly delivering an electric signal. The electrical signal is then increased by the amplifier. The amplifier requires a power source in the form of a battery. The electrical signal is then changed back into an acoustic signal by the receiver, which is also called the loudspeaker.
2. Hearing aids initially used linear amplification, such that soft, medium, and loud sounds were all amplified

to the same extent. This type of amplification required patients to often utilize a volume control to limit the intensity of sound output from the hearing aid. Following the advent of nonlinear amplification, patients were able to have better sound quality, with hearing aid output more appropriately fit to the patient's dynamic range. In addition, less control of the hearing aid was required by the user.

Changes in methods of output limiting also occurred with sound processing changes. Output limiting was traditionally achieved by a method known as "peak clipping." With this method, the peaks of signals were cut off at a certain predetermined level. This created distortion when the input to the hearing aid was above the saturation level. The compression method of output limiting that followed allowed for the signal to be compressed into the listeners dynamic range, reducing distortion of the signal at high input levels.

The next major trend in hearing aid technology was the miniaturization of hearing aids. Patients were more accepting of smaller and more cosmetically appealing hearing aids.

The use of multiple memories in hearing aids allowed for different response parameters for different listening situations. Switching of responses was originally done manually but is now done adaptively. This means that the sound processing capability of the hearing aid allows it to recognize acoustic features of the environment and to automatically determine the appropriate sound processing response for a given listening situation. This is accomplished without patient control and provides for less effort on the part of the patient.

Digital processing has been a major innovation in hearing aid technology. Digital hearing aids have a greater range and number of controls than analog devices. This allows for a more tailored, patient-specific response by the hearing aid.

Sophisticated directional microphones allow hearing aids to focus in space by enhancing signals in front and reducing those coming from behind.

Open-fitting solutions for hearing aids allow sound to be delivered through thin tubing directly to the ear canal or to a loudspeaker in the ear canal. This method of sound delivery greatly reduces the occlusion effect, resulting in overall greater patient satisfaction.

3. The method of peak clipping for limiting the output of a hearing aid works by removing the extremes of alternating current amplitude peaks at some predetermined level. The limitation of this method is that when the input level of the hearing aid reaches this predetermined level (known as the saturation level), and the input signal no longer produces additional output, distortion is introduced, as the output signal no longer resembles the input signal.

   The method of compression limiting works by reducing the gain of the hearing aid at higher intensity levels compared to lower intensity levels. Compression in a hearing aid is used to address the reduced dynamic range of individuals with hearing impairment by making soft sounds louder, but not amplifying loud sounds as much. This is because loud sounds are still perceived as loud at high intensity levels in most individuals with impaired cochlear function. By reducing the amount of gain of the hearing aid as sounds become louder, the hearing aid allows soft sounds to be perceived as soft and loud sounds as loud but not excessive. When loud sounds are amplified less than softer sounds, this effectively limits the output of the hearing aid, which results in a faithful representation of the input signal, and does not introduce distortion at high levels like the peak-clipping method.
4. Acoustic feedback occurs when amplified sound emanating from a loudspeaker is directed back into microphone of the same amplifying system. This causes a "whistling" sound in a device the size of a hearing aid. It is a common phenomenon in hearing aids and is one of the main considerations in selecting an appropriate hearing aid for a patient. This is because the most effective method of reducing the occurrence of feedback is to increase the distance between the microphone and sound output of the hearing aid. The increase of distance decreases the chance that amplified sound will reach the microphone. The distance between microphone and receiver is greatest in a style such as a behind-the-ear hearing aid, where the microphone is at the level of the top of the auricle and the sound emanates into the ear canal. The smaller the style of hearing aid, the closer the microphone is to the receiver increasing opportunities for feedback.

   Another method of feedback prevention in modern hearing aids is the use of feedback reduction circuits. There are two sound processing feedback reduction methods. In one method, the frequency band causing feedback is recognized by the hearing aid processor, and the amplification is reduced in this frequency band. In the second method, the frequency of the feedback is identified by the hearing aid, and a method known as "phase cancellation" is used to reduce the sound.
5. With analog processing, the signal is processed in a manner that is continuously varying over time. With digital processing, the acoustic signal is converted to a signal that is represented as discrete numeric values at discrete moments in time. With a digital signal processing strategy, the numeric signal can be mathematically manipulated to provide control over

a great number of amplification parameters. This is in contrast to an analog signal, which requires specific analog controls to manipulate the signal. A signal can be more easily manipulated with digital processing, allowing for a greater range and number of controls than an analog processing scheme. This makes greater flexibility and fine-tuning available to the audiologist for programming the hearing aid to fit the individual's hearing loss.

6. Omnidirectional microphones are so named because they are sensitive to sounds from all directions.

   Directional microphones are designed to "focus" on sound coming from the front of the hearing aid. This is accomplished by amplifying only the sounds in front of the hearing aid, and not amplifying, or not amplifying as much, sound coming from behind the person. Directionality is best with at least two microphones on a hearing aid to pick up sound. The relationship between sounds picked up by the two microphones allows the signal processing algorithm to amplify the signal coming from a particular direction.

   Modern hearing aids typically come with directional microphones. The use of the directional microphone can be controlled manually through a push button on the hearing aid, or can be adaptively controlled by the hearing aid. In either case, the directional microphone is activated with the goal of helping the individual to hear better in noisy situations.

7. Hardware controls that are available on most modern hearing aids include a volume control and/or a memory selection button. Some behind-the-ear hearing aids may also have an on/off switch of some type, and some in-the-ear hearing aids may power off at the endpoint of the volume control potentiometer range. In addition, some hearing aids may be available with a remote control that provides access to these features.

   The memory selection button is typically used to switch programs specific to particular listening situations, such as in noise or on the telephone. Some higher end hearing aids offer the option for a number of programs to be available for a given hearing aid. There is the potential for the hearing aid to simultaneously include a volume control option.

   For certain populations, having access to a large number of controls over the hearing aid can create challenges. Patients who are not familiar with hearing aids and who may not yet be sophisticated listeners may have trouble understanding the use of programs. Misunderstandings or inability to use the features of the hearing aid are likely to lead to poorer ability to hear in certain situations because the wrong feature is being used. Therefore, when it can be seen that a patient is having difficulty with certain features or it can be foreseen that a patient is likely to have difficulty, limiting the features available on the hearing aid when ordering the aid and/or disabling features during software programming of the hearing aid is often useful for enabling better use of hearing aid for some patients.

8. The implant itself is an electrode array that is inserted into the scala tympani of the cochlear via the round window. There is also a receiver/magnet that is surgically embedded into the temporal bone. The external components of the implant consist of a microphone, located at ear level, an amplifier and speech processor, which can be body worn or ear level, and an external receiver that delivers the electrical signal to the transmitter coil. The transmitter coil contains a magnet that is held in place on the skin opposite to the internal receiver magnet. A battery supply provides power to the amplifier and speech processor.

   The microphone of the implant picks up sound and converts it to an electrical signal. The electrical signal is increased by the amplifier and processed by the digital signal processor. The processed sound is delivered to the internal electrode array, which electrically stimulates the auditory nerve directly.

   The specifics of candidacy for cochlear implants are continually evolving. Generally speaking, a patient with a hearing disorder severe enough to preclude successful use of conventional hearing aids would be considered a candidate for a cochlear implant. There are Food and Drug Administration guidelines for cochlear implantation as well as guidelines provided by individual third party insurance companies. These guidelines are often used to determine whether reimbursement for cochlear implantation will occur. Guidelines for age of recipient, degree and type of hearing loss, and speech audiometric scores, as well as patient and family motivation, and appropriate expectations for cochlear implantation are the major considerations.

   The advantages that cochlear implants provide for appropriate candidates include: better high-frequency hearing, enhanced dynamic range, better speech recognition, and no feedback problems.

CHAPTER 14

Answers to Short Answer Questions

1. prescriptive gain
2. threshold; National Acoustics
3. discomfort; Desired Sensation Level
4. conductive; binaural
5. style
6. feature/technology; intermediate
7. ear impression; block
8. electroacoustic analysis
9. programming

10. program; power
11. probe-microphone
12. real-ear unaided response
13. real-ear aided response
14. real-ear insertion gain
15. loudness
16. functional gain
17. speech-recognition
18. group
19. expectations
20. outcome
21. oral
22. manual
23. total

Answers to Discussion Questions

1. The first step in the process of obtaining hearing aids is the selection of the appropriate hearing aids for a patient. There are numerous patient factors that contribute to determination of the appropriate hearing devices. Once a decision is reached regarding style and technology of the hearing aid, ear impressions are taken if necessary, and the hearing aids and/or earmolds are ordered from the manufacturer.

   The second step is quality control of the product. Electroacoustic analysis is performed on hearing aids received from a manufacturer to ensure that they are performing as specified. A subjective listening check is done with the hearing aids, and the aids are inspected to ensure that they are in good condition and that the order for the hearing aid was appropriately filled.

   The third step in the process involves programming of the hearing aids. Some audiologists prefer to program the hearing aids prior to the dispensing appointment. Others will do the primary programming at the appointment. The gain of the hearing aids is programmed to match the prescriptive formula that is based on the patient's hearing loss. Other options, such as volume controls, memory programs, and power options, are also programmed.

   At the dispensing appointment and afterwards, verification is made to ensure that the hearing aids are performing appropriately. There are several methods of verification, including inspection of physical fit, real-ear measurements, subjective assessments of quality and performance from the patient, functional gain measurements, and aided speech perception measures.

   Once the hearing instruments are dispensed, the patient will return for a follow-up appointment for adjustments to the hearing aid. It is typical that the first fit of a hearing aid does not actually provide enough gain to meet the ultimate prescriptive formula requirements. This is because the patient requires time to acclimate to the sounds of the hearing aid. As the patient becomes more comfortable with the hearing aid, the gain can be increased to provide greater output over time through software programming by the audiologist.
2. The degree and configuration of a hearing loss contribute greatly to the style of hearing aid chosen for a patient. Certain styles of hearing aids are more appropriate for certain degrees of hearing loss, primarily because with a greater degree of hearing loss, more gain is needed to compensate for the hearing loss. With increasing output from the hearing aid, there is more opportunity for feedback to occur. The primary method for reducing feedback is to increase the distance between the microphone and receiver of the aid. This imposes limitations on the appropriate style of hearing aid for a degree of loss.

   The configuration of the hearing loss contributes to style choice as well. Hearing losses that are primarily high frequency in nature will require different options than a hearing loss that involves low-frequency components as well. This is because good hearing in the lower frequencies will be diminished by insertion of an aid into the ear.

   Other factors that relate to style choice of the hearing aid include patient factors such as manual dexterity and vision. Small hearing aids require reasonable visual acuity in order to clean, change batteries, and manipulate. Behind-the-ear hearing aids tend to be more difficult to insert and remove for individuals with poor dexterity.

   The communication needs of the individual are of great importance in determining the technological features of a hearing aid. Patients who are in a great number of challenging listening environments will require a greater number of program options to provide for the best acoustic response in the various situations. Those who are primarily in a quiet listening environment may not be as concerned with having a great deal of flexibility in programming options for the hearing aids.

   Additional factors relating to both style and technology choices are decided according to the personal preferences and financial constraints of the patient. Higher levels of technology typically cost more than lower levels. In addition, personal preference of a patient is often a strong motivator in selection of a hearing aid. Patients who are adamant in their preference for a particular hearing aid style or technology level are likely to reject other options or be less satisfied with hearing aid use.
3. The first step in the creation of an ear impression is the otoscopic examination of the ear. This includes inspection of the ear canal and tympanic membrane for

the presence of excessive cerumen, evidence of infection or trauma, or foreign objects in the ear canal. If there is excessive cerumen in the ear canal, this should be removed prior to making the impression.

The next step in the process involves placement of a foam or cotton block into the ear canal. This provides protection against ear impression material from reaching the tympanic membrane. In addition, proper placement of the block provides a marker for depth of the impression.

Next, the ear canal is filled with impression material. This is typically a two-part material that is combined and filled into an impression syringe. The syringe is inserted into the ear canal and impression material is squeezed into the ear canal as the syringe tip is slowly retracted from the ear canal space. The impression material is then left to set for several minutes.

Once the impression material has had time to set, the impression is removed from the ear canal, with much the same technique as would be used to remove a hearing aid from the ear. The impression is then inspected for quality. If there are voids or other problems with the impression, it will be remade.

Following removal of the impression from the ear, otoscopic examination is again made to determine that there is no residual impression or block material or trauma to the ear canal.

The impression is sent to the manufacturer to be used for making of a custom-made earmold or hearing aid case.

4. First, the physical fit of a hearing aid must be verified. Inspection should be made to determine that the hearing aid has a secure fit and allows for ease of insertion and removal. The patient should be able to manipulate the hearing aid and its controls, and the aid should be physically comfortable in the ear. There should be an absence of feedback, and the occlusion effect should be sufficiently tolerable to allow patient acceptance of the hearing aid.

   Next, real-ear measurements can be made with a probe microphone to determine the electroacoustic characteristics of the hearing aid at or near the tympanic membrane.

   Speech mapping by probe microphone with the hearing aids in both ears can be used to demonstrate that the amplified signal delivered to the tympanic membrane meets the prescriptive target. Ongoing speech is presented via the probe-microphone system at fixed intensity level. The output of the probe microphone is displayed in response to the ongoing speech. With ongoing amplified speech displayed, the hearing aid parameters can be adjusted until the speech map approximates prescriptive targets.

   Subjective assessment by the patient is also used to verify hearing aid output. The patient is probed regarding the quality and intelligibility of speech and other sounds.

   More formal behavioral verification is obtained through the use of functional gain measures, where frequency-specific signals are presented via loudspeaker to the patient in both aided and unaided conditions. The difference between aided and unaided thresholds is the functional gain of the hearing aid.

   Aided speech measures also provide verification of the hearing aid performance. The patient is presented with speech materials, and performance scores are obtained. The goal is to ensure that the patient is hearing and understanding speech in a manner that meets expectations of performance. Performance is judged relative to the patient's degree and configuration of hearing loss.

5. The main focus of a hearing aid delivery orientation is on informational counseling. Typically, the nature of hearing and hearing impairment is discussed, to provide context for the patient to understand the hearing loss. Next, the hearing aids are fit, and components and function of the hearing aids are discussed and demonstrated. It is necessary to ensure that patients are able to insert and remove the hearing aids and that they can manipulate the controls on the hearing aids. Furthermore, it is necessary for patients to understand what the controls are used for and when and how to use them.

   Next, care and maintenance of hearing aids is typically addressed. Patients are taught how to properly clean the hearing aids on a daily basis. Storage of the hearing aids is discussed, as is protecting the hearing aids from moisture and pets. Patients are taught how to insert and remove batteries, and expectations for battery life are discussed.

   Reasonable expectations for hearing aid use are reinforced. Typical experiences, such as telephone use and feedback are discussed. Listening strategies are developed for those situations in which communication remains difficult, even with hearing aids. Discussion is made of other assistive devices that may be needed by the patient, such as special smoke alarms and other alerting devices.

   Troubleshooting of the hearing aids is delineated, and warranty information is provided to the patient.

6. Patients should expect that they will have acceptable hearing in most listening environments. There are certain environments where even individuals with normal hearing would be expected to have a great deal of difficulty. In these situations, hearing aids will not provide perfect hearing. Patients should expect communication

to improve, but not to be perfect. Patients should expect to obtain more benefit from their hearing aids in quiet environments than in noise.

Patients will need to understand that background sounds will be amplified. They should expect environmental sounds to not be uncomfortably loud. Although loud sounds should be perceived as loud, and environmental sounds may seem louder than normal when first acclimating to the hearing aids, the sounds should not be uncomfortable.

Patients should expect amplification to be free of feedback. Under some conditions, such as when any hard surface is placed next to the hearing aid in the ear, feedback from the hearing aid is expected to occur. However, while the hearing aid is in the ear under typical circumstances, feedback should not occur.

Patients should expect that all hearing aids are visible to some degree. Even when hearing aids are made to fit deeply into the ear canal, the faceplate of the hearing aid and the removal cord are both visible to some extent.

Patients should expect that the hearing aids will be reasonably comfortable. They should not expect that they will not feel the hearing aid. Patients may need to be counseled that they will become acclimated to the feel of the hearing aids in their ears over time, just as they would become acclimated to wearing glasses.

The benefits of setting appropriate expectations for hearing aid use cannot be overstated. Prognosis for hearing aid use is good if the patient has reasonable expectations.

CHAPTER 15

Answers to Short Answer Questions

1. sensitivity; high
2. dynamic; nonlinear
3. speech; background noise
4. audible; uncomfortable
5. binaural
6. compression
7. directional; noise
8. probe; loudness; speech
9. self-assessment
10. hearing assistive
11. dexterity
12. auditory
13. speech; language
14. sound pressure level; resonance
15. probe-microphone
16. behind-the-ear; silicone
17. DSL[i/o]
18. Family Expectations; Outcome
19. language; therapy
20. microphone; processing
21 conductive
22. 25
23. cochlear implants

Answers to Discussion Questions

1. Nonlinear loudness growth occurs as a result of cochlear dysfunction. The perception of loud sounds remains loud to the person with hearing loss. However, the perception of soft sounds is diminished, such that sounds go from being perceived as very soft to very loud over a small range of intensities. This creates problems for fitting of hearing aids, because the primary function of a hearing aid is to increase signal gain.

   Currently, technology uses nonlinear signal processing, which is meant to provide appropriate amplification for nonlinear loudness growth. The compression circuit of the hearing aid allows different intensities of sound to be amplified differently. Soft sounds are amplified a great deal, whereas loud sounds are amplified only a little or not at all. This allows sound intensities to be perceived as more normal by the listener, with soft sounds being perceived as soft and loud sounds as loud but not uncomfortable.
2. Sometimes binaural amplification can result in poorer word recognition and communication performance than monaural amplification because the signal from one ear is so highly distorted that it actually interferes with speech recognition by both ears. In other cases, acoustic input from an ear that functions poorly on its own can actually provide additional needed input to improve speech-recognition performance in the better way. One way to assess which case is true for a patient is to test speech recognition performance in a binaural condition. Another way is by trial use of binaural amplification in the real world to evaluate success.
3. Probe-microphone measures are important in children because they have smaller ear canals than adults. This results in greater sound pressure levels being delivered to the ear canal than with adult hearing aid fittings. In addition, the ear canal resonance of a child's ear differs from adults. This can cause unexpected peaks in the frequency gain response output of the hearing aid. Real-ear measures would reflect the occurrence of both of these phenomena, because they demonstrate the sound at the level of the tympanic membrane, after it has been modulated acoustically by the physical characteristics of the ear canal.

   Another reason that probe-microphone measures are so important in children is that children are unsophisticated listeners who typically lack the vocabulary and insight to describe the subjective experience of

listening with hearing aids. Any unusual or problematic output from a hearing aid is likely to be unreported by a child. Real-ear measures allow the audiologist to be more confident that the output of the hearing aid is beneficial and appropriate for the patient.

4. The major goal in treating children with auditory processing disorder is to forestall academic achievement problems by optimizing the signal-to-noise ratio of the classroom acoustic environment. Remote-microphone technology is commonly employed to amplify the teacher's voice in a classroom so that the child has better access to instructions and information provided by the teacher. In addition, preferential seating in the classroom is often recommended so that the child can be in close proximity to the teacher, who is often speaking. Other strategies include auditory training therapy to help children maximize their access to desired sounds.
5. Some advantages of using binaural conventional hearing aids include a considerably lower cost than the bone-anchored hearing aid and not having to undergo the invasiveness of a surgical procedure, as would be needed with the BAHA. Because hearing aids are present in both ears, binaural amplification with conventional hearing aids offers the opportunity for better directional hearing and the other advantages that come with binaural amplification.

   Advantages of the bone-anchored hearing aid relative to conventional hearing aids include ease and comfort of use for most individuals. In addition, there is no feedback from the BAHA aid, allowing for appropriate gain output. There is also excellent sound quality delivered to the cochlea.
6. There are differences in candidacy criteria that are dependent on age. In general, candidacy for cochlear implantation is considered for individuals whose hearing loss is too severe to benefit from conventional amplification.

   Candidacy for infants with hearing loss includes: profound bilateral sensorineural hearing loss, little or no benefit from hearing aid amplification, no medical contraindications, educational placement in a program that emphasizes audition, family support, and appropriate expectations for cochlear implant outcomes. Currently, children under the age of 12 months are rarely implanted. Current cochlear implant candidacy for children older than 2 years of age includes: severe to profound bilateral sensorineural hearing loss, minimal benefit from hearing aid amplification, no medical contraindications, educational placement in a program that emphasizes audition, family support, and appropriate expectations for cochlear implant outcomes. Adult candidacy for cochlear implantation includes: severe to profound bilateral sensorineural hearing loss; limited benefit from hearing aids, defined as scores of 50% or less on open-set sentence recognition measures on the ear to be implanted and 60% or less on the non-implanted ear; no medical contraindications; and appropriate expectations for cochlear implant outcomes.

Glossary

A

ABR - auditory brainstem response

abscissa - horizontal or X axis on a graph, such as frequency axis on an audiogram

acoustic - pertaining to sound

acoustic admittance - total acoustic energy flow through a system; reciprocal of acoustic impedance

acoustic compliance - ease of energy flow through the middle-ear system; reciprocal of stiffness

acoustic coupler - cavity of predetermined shape and volume used for the calibration of an earphone

acoustic feedback - sound generated when an amplification system goes into oscillation; produced by amplified sound from the receiver reaching the microphone and being reamplified

acoustic gain - 1. increase in sound output; 2. in a hearing aid, the difference in dB between the input to the microphone and the output of the receiver

acoustic immittance - global term representing acoustic admittance (total energy flow) and acoustic impedance (total opposition to energy flow) of the middle-ear system

acoustic impedance - total opposition to energy flow of sound through the middle-ear system; reciprocal of acoustic admittance

acoustic nerve - Cranial Nerve VIII; auditory nerve, consisting of a vestibular and cochlear branch

acoustic reflex - reflexive contraction of the intra-aural muscles in response to loud sound; dominated by the stapedius muscle in humans

acoustic reflex decay - perstimulatory reduction in the magnitude of the acoustic reflex; considered abnormal if it is reduced by over 50% of initial amplitude within 10 seconds of stimulus onset

acoustic reflex threshold - lowest intensity level of a stimulus at which an acoustic reflex is detected

acoustic trauma - damage to hearing from a transient, high-intensity sound

acoustic tumor - generic term referring to a neoplasm of Cranial Nerve VIII, most often a cochleovestibular Schwannoma

acoustics - the study and science of sound and its perception

acquired - obtained after birth

acquired hearing loss - hearing loss that occurs after birth as a result of injury or disease; not congenital

action potential - AP; 1. synchronous change in electrical potential of nerve of muscle tissue; 2. in auditory evoked potential measures, whole-nerve or compound action potential of Cranial Nerve VIII, the main component of ECochG and Wave I of the ABR

activity limitations - difficulties an individual has in executing activities

acute - of sudden onset and short duration

acute otitis media - inflammation of the middle ear having a duration of fewer than 21 days

acute serous otitis media - acute inflammation of middle ear mucosa, with serous effusion

acute suppurative otitis media - acute inflammation of the middle ear with infected effusion containing pus

AD - [L. *auris dextra*] right ear

adaptive directional microphone - microphone designed to be differentially sensitive to sound from a focused direction that is activated automatically in response to the detection of noise

adaptive procedure - psychophysical method in which changes are automatically made to some signal parameter based on the subject's response

admittance - total energy flow through a system, express in mhos; reciprocal of impedance

adventitious - not inherited; acquired

afferent - pertaining to the conduction of the ascending nervous system tracts from peripheral to central

agnosia - lack of sensory-perceptual ability to recognize stimuli

aided - fitted with or assisted by the use of a hearing aid

aided threshold - lowest level at which a signal is audible to an individual wearing a hearing aid

AIDS - acquired immunodeficiency syndrome; disease compromising the efficacy of the immune system, characterized by opportunistic infectious diseases

air-bone gap - difference in dB between air-conducted and bone-conducted hearing thresholds for a given frequency in the same ear; used to describe the magnitude of conductive hearing loss

air conduction - method of delivering acoustic signals through an earphone

air-conduction audiometry - measurement of hearing in which sound is delivered via earphones, thereby assessing the integrity of the outer-, middle-, and inner-ear mechanisms

alerting devices - assistive devices, such as doorbells, alarm clocks, smoke detectors, telephones, etc., that use light flashes or vibration instead of sound to alert individuals with deafness to a particular sound

alternate binaural loudness balance test - ABLB test; auditory test designed to measure loudness growth or recruitment in the impaired ear of a patient with unilateral hearing loss

alternating polarity - characteristic of auditory evoked potential stimuli in which the rarefaction and condensation polarity of a click or tone burst are alternated successively

American National Standards Institute - ANSI; association of specialists, manufacturers, and consumers that determines standards for measuring instruments, including audiometers; formerly ASA

amplification - 1. increasing the intensity of sound; 2. generic description of a hearing aid or assistive listening device

amplify - to increase the intensity of sound

amplitude - magnitude of a sound wave, acoustic reflex, evoked potential, etc.

ampulla - bulbous portion at the end of each of the three semicircular canals leading into the utricle

analog hearing aid - amplification device that uses conventional, continuously varying signal processing

analog-to-digital conversion - the process of turning continuously varying (analog) signals into a numerical (digital) representation of the waveform

annular ligament - ring-shaped ligament that holds the footplate of the stapes in the oval window

anomaly - structure or function that is unusual, irregular, or deviates from the norm

anotia - congenital absence of the pinna

ANSI - American National Standards Institute

aperiodic - occurring at irregular intervals; not periodic

aphasia - complete or partial loss of language ability due to brain dysfunction

aplasia - congenital absence of an organ

array microphone - transducer system containing multiple microphones aligned in a row, designed for directionality

articulation index - early term for the numerical prediction of the quantity of speech signal available or audible to the listener, based on speech importance weightings of various frequency bands

AS - [L. *auris sinistra*] left ear

ascending auditory pathway - central auditory nervous system pathway composed of primary afferent fibers, conveying nerve impulses from the periphery to higher centers

ascending-descending method - audiometric technique used in establishing hearing sensitivity thresholds by varying signal intensity from inaudible to audible and then from audible to inaudible

ASSR - auditory steady-state response

assistive listening device - ALD; hearing instrument or class of hearing instruments, usually with a remote microphone for improving signal-to-noise ratio, including FM systems, personal amplifiers, telephone amplifiers, television listeners

asymmetric hearing loss - condition in which hearing loss in one ear is of a significantly different degree than in the other ear

ataxia - condition characterized by lack of muscle coordination, often affecting gait and balance

atresia - congenital absence or pathologic closure of a normal anatomical opening, such as an absence of the opening to the external auditory meatus

atrophy - wasting away or shrinking of a normally developed organ or tissue

attention deficit hyperactivity disorder - ADHD; supramodal disorder involving reduced ability to focus on an activity, task, or sensory stimulus and characterized by restlessness and distractibility

attenuate - to reduce in magnitude; to decrease

attenuator - 1. device used to reduce voltage, current, or power; 2. intensity level control of an audiometer

AU - [L. *auris uterque*] each ear; [L. *aures unitas*] both ears together

Au.D. - Doctor of Audiology; designator for the professional doctorate degree in audiology

audi(o) - combining form: hearing

audibility index - measure of the proportion of speech cues that are audible; also, articulation index, speech-intelligibility index

audible - of sufficient magnitude to be heard

audiogram - graphic representation of threshold of hearing sensitivity as a function of stimulus frequency

audiologic evaluation - assessment of hearing ability

audiologist - healthcare professional who is credentialed in the practice of audiology to provide a comprehensive array of services related to prevention, diagnosis, and treatment of hearing impairment and its associated communication disorder

audiology - branch of healthcare devoted to the study, diagnosis, treatment, and prevention of hearing disorders

audiometer - electronic instrument designed for measurement of hearing sensitivity and for calibrated delivery of suprathreshold stimuli

audiometric configuration - shape of the audiogram, e.g., flat, rising, steeply sloping

audiometric test booth - sound-treated room; designed for audiometric testing to meet standards for ambient room noise

audiometric zero - lowest sound pressure level at which a pure tone at each of the audiometric frequencies is audible to the average normal hearing ear, designated as 0 dB Hearing Level, or audiometric zero, according to national standards

audiometry - measurement of hearing by means of an audiometer

auditory acclimatization - systematic change in auditory perception over time due to a change in the acoustic information available

to the listener; e.g., an ear becoming accustomed to processing sounds of increased loudness following introduction of a hearing aid

auditory adaptation - process by which a constant audible tone becomes inaudible over time

auditory area - primary auditory cortex (Brodmann's area 41); located at the transverse gyrus (Heschl's gyrus) of the temporal lobe

auditory attention - perceptual process by which an individual focuses on specific sounds

auditory brainstem implant - ABI; electrode implanted at the juncture of Cranial Nerve VIII and the cochlear nucleus that receives signals from an external processor and sends electrical impulses directly to the brainstem

auditory brainstem response - ABR; auditory evoked potential, originating from Cranial Nerve VIII and auditory brainstem structures, consisting of five to seven identifiable peaks that represent neural function of auditory pathways and nuclei

auditory cortex - auditory area of the cerebral cortex located on the transverse temporal gyrus (Heschl's gyrus) of the temporal lobe

auditory deprivation - diminution or absence of sensory opportunity for neural structures central to the end organ, due to a reduction in auditory stimulation resulting from hearing loss

auditory disorder - disturbance in auditory structure, function, or both

auditory evoked potential - AEP; electrophysiologic response to sound, usually distinguished according to latency, including ECoG, ABR, MLR, LVR, ASSR, P3

auditory habilitation - program or treatment designed to develop auditory abilities or skills

auditory localization - perceptual process of determining the location of a sound source in an acoustic environment

auditory memory - assimilation, storage, and retrieval of previously experienced sound

auditory nerve - Cranial Nerve VIII, consisting of a vestibular and cochlear branch

auditory neuropathy - auditory dysynchrony; auditory disorder that disrupts synchronous activity of the auditory nervous system, characterized by normal cochlear outer hair cell function, abnormal auditory brainstem response, absent acoustic reflex, and threshold and suprathreshold hearing disorder of varying degrees

auditory-oral method - approach of auditory habilitation that emphasizes speech and the optimization of residual hearing

auditory processing - peripheral and central auditory system manipulation of acoustic signals

auditory processing disorder - APD; reduction in the ability to manipulate acoustic signals, regardless of hearing sensitivity, language, attention, and cognition ability; also, central auditory processing disorder

auditory rehabilitation - program or treatment designed to restore auditory function following adventitious hearing loss

auditory response area - dynamic range of hearing from the threshold of audibility to the threshold of pain across the audiometric frequency range

auditory stead-state response - ASSR; auditory evoked potential, elicited with modulated tones, used to predict hearing sensitivity; a neural potential that follows, or is phase-locked to, the modulation envelope

auditory system - the aggregation of structures related to each other and functioning together to provide hearing

auditory training - aural rehabilitation methods designed to optimize use of residual hearing by structured practice in listening, environmental alteration, hearing aid use, etc.

aural - pertaining to the ear or hearing

aural atresia - absence of the opening to the external auditory meatus

auricle - external or outer ear, which serves as a protective mechanism, as a resonator, and

as a baffle for directional hearing of front-versus-back and in the vertical plane

autoimmune - arising from and directed against the body's own tissue

autoimmune inner-ear disease - AIED; autoimmune disorder affecting the cochlea, characterized by bilateral, asymmetric progressive hearing loss over a period of days to months

automated auditory brainstem response - AABR; method for measuring the auditory brainstem response in which recording parameters are under computer control and detection of a response is determined automatically by computer-based algorithms

axon - efferent process of a neuron that conducts impulses away from the cell body and other cell processes

B

background noise - extraneous surrounding sounds of the environment

bacterial meningitis - inflammation of the meninges due to bacterial infection, which can cause significant auditory disorder due to suppurative labyrinthitis or inflammation of the lining of Cranial Nerve VIII; occurs most often in childhood

balance - harmonious adjustment of muscles against gravity to maintain equilibrium

band-pass filter - an electronic filter that allows a specified band of frequencies to pass, while reducing or eliminating frequencies above and below the band

bandwidth - range of frequencies within a specified band

barotrauma - traumatic inflammation disorder caused by sudden changes in air pressure in the pneumatized spaces of the body, including the temporal bone

baseline audiogram - initial audiogram obtained for comparison with later audiograms to quantify any change in hearing sensitivity

behavioral audiometry - pure-tone and speech audiometry involving any type of behavioral response, in contrast to electrophysiologic or electroacoustic audiometry

behavioral observation audiometry - BOA; pediatric assessment of hearing by observation of a child's unconditioned responses to sounds

behind-the-ear hearing aid - a hearing aid that fits over the ear and is coupled to the ear canal via tubing and/or an earmold

Békésy audiometry - automatic audiometry in which a Békésy audiometer is used to determine threshold of hearing to both interrupted tones and continuous tones; patterns of tracings are generally classified into five types, consistent with various hearing disorders

bel - unit expressing the intensity of a sound relative to a reference intensity; intensity in bels is the logarithm (to the base 10) of the ratio of the power of a sound to that of a reference sound; after Alexander Graham Bell

benign - 1. denoting mild character of an illness; 2. denoting nonmalignant character of a neoplasm

benign paroxysmal positioning vertigo - BPPV; a recurrent, acute form of vertigo occurring in clusters in response to positional changes

BICROS - bilateral contralateral routing of signals; a hearing aid system with one microphone contained in a hearing aid at each ear; the microphones direct sound to a single amplifier and receiver in the better hearing ear of a person with bilateral asymmetric hearing loss

bifurcate - divide into two branches

bilateral - pertaining to both sides, hence to both ears

bilateral hearing loss - hearing sensitivity loss in both ears

binaural - pertaining to both ears

binaural advantage - the cumulative benefits of using two ears over one, including enhanced threshold and better hearing in the presence of background noise

binaural amplification - use of a hearing aid in both ears; also bilateral amplification

binaural summation - cumulative effect of sound reaching both ears, resulting in enhancement in hearing with both ears over one ear; characterized by binaural improvement in hearing sensitivity of approximately 3 dB over monaural sensitivity

Bing test - tuning fork test that measures the occlusion effect by applying fork or other bone vibrator to the head while the ear canal is open and closed, with absence of change in perceived loudness indicating conductive hearing loss

biologic check - assessment of the functioning of various parameters of an audiometer by performing a listening check

bone-anchored hearing aid - BAHA; bone-conduction hearing aid in which a titanium screw is anchored in the mastoid and is attached percuntaneously to an external processor, designed primarily for conductive hearing loss secondary to intractable middle-ear disorder or atresia

bone conduction - method of delivering acoustic signals through vibration of the skull

bone-conduction audiometry - measurement of hearing in which sound is delivered through a bone vibrator, thereby bypassing the outer and middle ears and assessing the integrity of inner-ear mechanisms

bone-conduction hearing aid - hearing aid, used most often in patients with bilateral atresia, in which amplified signal is delivered to a bone vibrator placed on the mastoid, thereby bypassing the middle ear and stimulating the cochlea directly

bone-conduction threshold - absolute threshold of hearing sensitivity to pure-tone stimuli delivered via bone-conduction oscillator

broad-band noise - sound with a wide bandwidth, containing a continuous spectrum of frequencies, with equal energy per cycle throughout the band

C

calibrate - 1. to adjust the output of an instrument to a known standard; 2. in audiometry, to adjust the intensity levels of an audiometer to correspond with ANSI standard levels for audiometric zero

canalithiasis - vestibular disorder caused by free floating otoconia that gravitate from the utricle and collect near the cupula of the posterior semicircular canal, inappropriately stimulating the sensory endorgan and resulting in benign paroxysmal positional vertigo

Carhart's notch - patterns of bone-conduction audiometric thresholds associated with otosclerosis, characterized by reduced bone-conduction sensitivity predominantly at 2000 Hz

carrier frequency - the center or nominal frequency of a complex modulated signal

carrier phrase - in speech audiometry, phrase preceding the target syllable, word, or sentence to prepare the patient for the test signal

cartilage - connective tissue characterized by firm consistency and absence of blood vessels

cauliflower ear - thickening and malformation of the auricle following repeated trauma, commonly related to injury caused by the sport of wrestling

central auditory disorder - functional disorder resulting from diseases of or trauma to the central auditory nervous system

central auditory nervous system - portion from Cranial Nerve VIII to the auditory cortex that involves hearing, including the cochlear nucleus, superior olivary complex, lateral lemniscus, inferior colliculus, medial geniculate, and auditory cortex

central auditory processing disorder - CAPD; disorder in function of central auditory structures, characterized by impaired ability of the central auditory nervous system to manipulate and use acoustic signals, including difficulty understanding speech in noise and localizing sounds; also, auditory processing disorder

central masking - elevation in hearing sensitivity of the test ear, on the order of 5 dB, as a result of introducing masking noise in the nontest ear, presumably due to the influence of masking noise on central auditory function

central nervous system - CNS; that portion of the nervous system to which sensory impulses and from which motor impulses are transmitted, including the cortex, brainstem, and spinal cord

cerebellopontine angle - anatomical angle formed by the proximity of the cerebellum and the pons from which Cranial nerve VIII exists into the brainstem

cerumen - waxy secretion of the ceruminous glands in the external auditory meatus

ceruminectomy - extraction of impacted cerumen from the external auditory meatus

ceruminosis - excessive cerumen in the external auditory meatus

channel - in a hearing aid, a frequency region that is processed independently of other regions

characteristic frequency - the frequency to which an auditory neuron is most sensitive

chemotherapy - treatment of disease with chemical substances or drugs

cholesteatoma - tumorlike mass of squamous epithelium and cholesterol in the middle ear that may invade the mastoid and erode the ossicles, usually secondary to chronic otitis media or marginal tympanic membrane perforation

chorda tympani - branch of the facial nerve that passes through the middle ear and conveys taste sensation from the anterior two-thirds of the tongue and carries fibers to the submandibular and sublingual salivary glands

chronic - of long duration

click - rapid-onset, short-duration, broad-band sound, produced by delivering an electric pulse to an earphone; used to elicit an auditory brainstem response and transient-evoked otoacoustic emissions

closed captioning - printed text of the dialog or narrative on television or video

closed-set test - speech audiometric test with multiple-choice format in which the targeted syllable, word, or sentence is chosen from among a limited set of foils

coarticulation - the influence that a phoneme has on the phonemes that precede and follow in a word or phrase

cochlea - auditory portion of the inner ear, consisting of fluid-filled membranous channels within a spiral canal around a central core

cochlear implant - device that enables people with profound hearing loss to perceive sound; consists of an electrode array surgically implanted in the cochlea, which delivers electrical signals to Cranial Nerve VIII

cochlear labyrinth - intricate maze of connecting channels in the petrous portion of each temporal bone, consisting of canals within the bone and fluid-filled sacs and channels within the canals

cochlear microphonic - minute alternating-current electrical potential of the hair cells of the cochlea that resembles the input signal

cochlear nucleus - cluster of cell bodies of second-order neurons on the lateral edge of the hindbrain in the central auditory nervous system at which fibers from Cranial Nerve VIII have an obligatory synapse

cochleovestibular Schwannoma - benign encapsulated neoplasm composed of Schwann cells arising from the intracranial segment of Cranial Nerve VIII, commonly the vestibular portion

cognition - the processes involved in knowing, including perceiving, recognizing, conceiving, judging, sensing, and reasoning

common-mode rejection - noise-rejection strategy used in electrophysiologic measurement in which noise that is identical (common) at two electrodes is subtracted by a differential amplifier

communication - the act of exchanging information by speech, sign language, writing, etc.

communication disorder - impairment in communication ability, resulting from speech, language, and/or hearing disorders

compensatory skills - those skills a person learns in order to compensate for the loss or reduction of an ability

completely-in-the-canal hearing aid - small amplification device, extending from 1 mm to 2 mm inside the meatal opening to near the tympanic membrane, which allows greater gain with less power due to the proximity of the receiver to the membrane

complex tone - sound containing more than one frequency component

compound action potential - 1. synchronous change in electrical potential of nerve or muscle tissue; 2. in auditory evoked potential measures, whole-nerve potential of Cranial Nerve VIII, the main component of ECochG and Wave I of the ABR

compressed speech - speech that is accelerated, without alteration of the frequency characteristics, by removing segments and compressing the remaining segments

compression - 1. in acoustics, portion of the sound-wave cycle in which particles of the transmission medium are compacted; 2. in hearing aid circuitry, nonlinear amplifier gain used either to limit maximum output (compression limiting) or to match amplifier gain to an individual's loudness growth (dynamic range compression)

concha - shell or bowl-like depression of the auricle, lying just above the lobule, which forms the mouth of or funnel to the external auditory meatus

condensation - in the propagation of sound waves, the time during which the density of air molecules is increased above its static value

conditioned play audiometry - method of hearing assessment of young children in which the correct identification of a signal presentation is rewarded with the opportunity to engage in any of several play-oriented activities

conductive hearing loss - reduction in hearing sensitivity, despite normal cochlear function, due to impaired sound transmission through the external auditory meatus, tympanic membrane, and/or ossicular chain

cone of light - bright triangular reflection on the surface of the tympanic membrane of the illumination used during otoscopic examination

congenital - present at birth

congenital hearing loss - reduced hearing sensitivity existing at or dating from birth, resulting from pre- or perinatal pathologic conditions

context - semantic surroundings of a word or passage that determine its meaning

contraindication - a condition that renders the use of a treatment or procedure inadvisable

contralateral - pertaining to the opposite side of the body

cookie bite audiogram - colloquial term referring to the audiometric configuration characterized by a hearing loss in the middle frequencies and normal or nearly normal hearing in the low and high frequencies

corner audiogram - audiometric configuration characterized by a profound hearing loss with measurable thresholds only in the low-frequency region

corpus callosum - the prominent white-matter band of nerve fibers that connects the cerebral hemispheres

coupler - any device that joins one part of an acoustic system to another

cranial nerve - any of 12 pairs of neuron bundles exiting the brainstem above the first cervical vertebra

craniofacial - pertaining to both the face and cranium

critical period - early years of a child's development during which language is most readily acquired and after which the potential for language acquisition is limited

crossover - the process in which sound presented to one ear through an earphone crosses the head via bone conduction and is perceived by the other ear; also, contralateralization, cross hearing

cued speech - speechreading accompanied by a system of hand positions near the mouth (cues) designed to discriminate between similar visual patterns

custom earmold - earmold made for a specific individual from an ear impression

custom hearing aid - ITE, ITC, or CIC hearing aid made for a specific individual from an ear impression

cycle - 1. complete sinusoidal wave; 2. complete compression and rarefaction of a sound wave

cycles per second - measurement of sound frequency in terms of the number of complete cycles of a sinusoid that occur within a second; Hertz

cytomegalovirus - CMV; prenatal or postnatal herpetoviral infection, usually transmitted in utero, which can cause central nervous system disorder, including brain damage, hearing loss, vision loss, and seizures

D

damage risk criterion - amount of exposure time to sound of a specified frequency and intensity that is associated with a defined risk of hearing loss

daPa - decaPascal; unit of pressure in which 1 daPa equals 10 Pascals

dB - decibel; one-tenth of a bel; unit of sound intensity, based on a logarithmic relationship of one intensity to a reference intensity

dB HL - decibels hearing level; decibel notation referenced to average normal hearing or audiometric zero

dB nHL - decibels normalized hearing level; decibel notation referenced to behavioral thresholds of a sample of normal-hearing persons, used most often to describe the intensity level of click stimuli used in evoked potential audiometry

dB SL - decibels sensation level; decibel notation that refers to the number of decibels above a person's threshold for a given acoustic signal

dB SPL - decibels sound pressure level; dB SPL equals 20 times the log of the ratio of an observed sound pressure level to the reference sound pressure level of 20 microPascals (or 0.0002 dyne/cm^2, 0.0002 microbar, 20 microNewtons/meter^2)

dBA - decibels expressed in sound pressure level as measured on the A-weighted scale of a sound level meter filtering network

dead regions - portions along the basilar membrane without apparent function of the inner hair cells or response of innervated neurons

deaf - having no or very limited functional hearing

deaf culture - ideology, beliefs, and customs shared by many individuals with prelinguistic deafness

deaf speech - quality of speech common among persons with deafness

decaPascal - daPa; unit of pressure in which 1 daPa equals 10 Pascals

decay - diminution of physical properties of a stimulus

decibel - dB; one-tenth of a Bel; unit of sound intensity, based on a logarithmic relationship of one intensity to a reference intensity

degeneration - deterioration of an anatomic structure resulting in diminution of function

dehiscence - an opening or splitting along natural lines of a structure

delayed auditory feedback - condition in which a listener's speech is delayed by a controlled amount of time and delivered back to the listener's ears, interfering with the rate and fluency of the speech

delayed speech and language - general classification of speech and language skills as less well developed than expected for a child's age

dementia - progressive deterioration of cognitive function

demyelinating disease - autoimmune disease process that causes scattered patches of

demyelination of white matter throughout the central nervous system, resulting in retrocochlear disorder when the auditory nervous system is affected

dendrite - afferent process of a neuron that conducts impulses toward the cell body

depolarization - abrupt decrease in membrane electrical potential

detection threshold - absolute threshold of hearing sensitivity

development - natural progression from embryonic to adult life stages

developmental disability - category of mentally or physically handicapping conditions that appear in infancy or early childhood and are related to abnormal development

diabetes mellitus - metabolic disorder caused by a deficiency of insulin, with chronic complications including neuropathy and generalized degenerative changes in blood vessels

diagnosis - determination of the nature of disease or disorder

diagnostic audiometry - measurement of hearing to determine the nature and degree of hearing impairment

dichotic - pertaining to different signals presented to or reaching each ear

dichotic listening - the task of perceiving different signals presented simultaneously to each ear

difference limen - the smallest difference that can be detected between two signals that vary in intensity, frequency, time, etc.

differential amplifier - amplifier used in evoked potential measurement to eliminate extraneous noise; the voltage from one electrode's input is inverted and subtracted from another input so that any electrical activity that is common to both electrodes is rejected

differential diagnosis - determination of a disease or disorder in a patient from among two or more diseases or disorders with similar symptoms or findings

differential sensitivity - the capacity of the auditory system to detect differences between auditory signals that differ in intensity, frequency, or time

differential threshold - difference limen

digital - numeric representation of a discrete value at a discrete moment in time

digital hearing aid - hearing aid that processes a signal digitally

digital signal processing - DSP; manipulation by mathematical algorithms of a signal that has been converted from analog to digital form

digital-to-analog conversion - the process of turning numerical (digital) representation of a waveform into a continuously varying (analog) signal

digitally controlled analog hearing aid - early hybrid hearing device in which microphone-amplifier-loudspeaker functions were analog, but their parameters were under digital control

diotic - pertaining to identical signals presented to or reaching each ear

diotic listening - the task of perceiving identical signals presented simultaneously to each ear

diplacusis - auditory condition in which the sense of pitch is distorted so that a pure tone is heard as two tones or as a noise or buzzing; double hearing

direct audio input - direct input of sound into a hearing aid by means of a hard-wire connection between the hearing aid and an assistive listening device or other sound source

directional microphone - microphone with a transducer that is more responsive to sound from a focused direction; in hearing aids, the microphone is designed to be more sensitive to sounds emanating from the front than from the back

disability - a limitation or loss in function

discrete - separate and distinct, not continuous

disease - pathologic entity characterized by a recognized cause, identifiable signs and symptoms, and/or consistent anatomic alteration

disequilibrium - disturbance in balance function

disorder - abnormality; disturbance of function

distortion - undesired product of an inexact, or nonlinear, reproduction of an acoustic waveform

distortion-product otoacoustic emission - DPOAE; otoacoustic emission measured as the cubic distortion product that occurs at the frequency represented by $2f_1$-f_2, resulting from the simultaneous presentation of two pure tones (f_1 and f_2)

dizziness - general term used to describe various symptoms such as faintness, spinning, lightheadedness, or unsteadiness

dosimetry - the process of measuring accumulated level and duration of noise exposure over a specified time period

Down syndrome - congenital genetic abnormality, characterized by mental retardation and characteristic facial features, with high incidence of chronic otitis media and associated conductive, mixed, and sensorineural hearing loss

dynamic range - the difference in decibels between a person's threshold of sensitivity and threshold of discomfort

dyne - unit of force, defined as the amount necessary to accelerate 1 gram a distance of 1 centimeter per second

dyne/cm^2 - unit of force exerted on 1 square centimeter; the reference level for measuring decibels in sound pressure level is 0.0002 dyne/cm^2

dysfunction - abnormal functioning

E

ear - the organ of hearing, including the auricle, external auditory meatus, tympanic membrane, tympanic cavity and ossicles, and cochlear and vestibular labyrinth

ear impression - cast made of the concha and ear canal for creating a customized earmold or hearing aid

ear protection - imprecise term for hearing protection devices, such as earplugs or muffs, used to attenuate excessive noise levels

ear trumpet - early nonelectronic hearing instrument, often shaped like a trumpet, designed to amplify sound by collecting it through a large opening and directing it through a small passage to the ear canal

ear wax - colloquial term for cerumen, the waxy secretion of the ceruminous glands in the external auditory meatus

earache - pain in the ear

ear canal - external auditory meatus

ear canal resonance - enhancement of sound by passage throughout the external auditory meatus, typically centered near 3000 Hz

ear canal stenosis - narrowed or constricted external auditory meatus

ear canal volume - measure in immittance audiometry of the volume of air between the tip of the acoustic probe and the tympanic membrane

earhook - portion of a behind-the-ear hearing aid that connects the case to the earmold tube and hooks over the ear

earlobe - lower noncartilaginous portion of the external ear

early intervention - hearing habilitation initiated as early as possible following diagnosis

earmold - coupler formed to fit into the auricle that channels sound from the earhook of a hearing aid into the ear canal

earphone - transducer that converts electrical signals from an audiometer into sound delivered to the ear

earplug - hearing protection device, made of any of various materials, that is placed into the external auditory meatus to attenuate excessive noise levels

edema - abnormal accumulation of fluid in body tissue; swelling

educational audiologist - audiologist with a subspecialty interest in the hearing needs of school-age children in an academic setting

effective masking - condition in which noise is just sufficient to mask a given signal when the signal and noise are presented to the same ear simultaneously

efferent - pertaining to the conduction of the descending nervous system tracts from central to peripheral

efferent auditory system - auditory nervous system tracts descending from central to peripheral, serving both inhibitory and excitatory functions

effusion - escape of fluid into tissue or a cavity

elasticity - restoring force of a material that causes components of the material to return to their original shape or location following displacement

electrocochleography - ECochG; method of recording transient auditory evoked potentials from the cochlea and Cranial Nerve VIII, including the cochlear microphonic, summating potential, and compound action potential, with a promontory or ear canal electrode

electrode - specialized terminal or metal plate through which electrical energy is measured from or applied to the body

electrode impedance - resistance to energy flow through an electrode

electrode location - location of electrode placement in auditory evoked potential testing, usually designated according to the 10-20 International Electrode System nomenclature, including left (A1) and right (A2) earlobes, vertex (Cz), and forehead (Fpz)

electromotility - in hearing, changes in the length of outer hair cells in response to electrical stimulation

electronystagmography - ENG; method of measuring eye movements, especially nystagmus, via electro-oculgraphy, to assess the integrity of the vestibular mechanism

elevated threshold - absolute threshold that is poorer than normal and thus at a decibel level that is greater or elevated

embolism - occlusion or obstruction of a blood vessel by a transported clot or other mass

embryo - an organism in its early, developing stage

encephalitis - inflammation of the brain

encoding - process of receiving and briefly registering information through the auditory system

end organ - terminal structure of a nerve fiber

endocochlear potential - electrical potential or voltage of endolymph in the scala media

endongenous hearing impairment - hearing loss of genetic origin

endolymph - fluid in the scala media, having a high potassium and low sodium concentration, that bathes the gelatinous structures of the membranous labyrinth

endolymphatic duct - passageway in the vestibular aqueduct that carries endolymph between the endolymphatic sac and the utricle and saccule of the membranous labyrinth

endolymphatic hydrops - excessive accumulation of endolymph within the cochlear and vestibular labyrinths, resulting in episodic sensorineural hearing loss, vertigo, tinnitus, and a sensation of fullness

endolymphatic sac - saclike portion of the membranous labyrinth, connected via the endolymphatic duct, presumably responsible for absorption of endolymph

envelope - in acoustics, representation of a waveform as the smooth curve joining the peaks of the oscillatory function

environmental alteration - the manipulation of physical characteristics of a room or a person's location within that room to provide an easier listening situation

episodic - appearing in acute, repeated occurrences

epitympanum - attic of the middle-ear cavity

equilibrium - the condition of being evenly balanced

equivalent ear canal volume - typmanometric estimate of the volume of the earcanal between the probe tip and the tympanic membrane

etiology - the study of the causes of a disease or condition

Eustachian tube - passageway leading from the nasopharynx to the anterior wall of the middle ear, which opens to equalize middle- ear pressure

Eustachian tube dysfunction - failure of the eustachian tube to open, usually due to edema in the nasopharynx

evoked otoacoustic emission - otoacoustic emission that occurs in response to acoustic stimulation

evoked potential - electrical activity of the brain in response to sensory stimulation

exogenous hearing impairment - hearing loss of a nongenetic origin; hearing loss caused by environmental factors such as viruses, noise, and ototoxins

exostosis - rounded hard bony nodule, usually bilateral and multiple, growing from the osseous portion of the external auditory meatus, caused by extended exposure to cold water; often found in divers or surfers

external - outside, toward the outside

external otitis - inflammation of the lining of the external auditory meatus

extracorporeal membrane oxygenation - ECMO; therapeutic technique for augmenting ventilation in high-risk infants

extrinsic redundancy - in speech audiometry, the abundance of information present in the speech signal

eyeglass hearing aid - early style of hearing aid built into one or both earpieces of eyeglass frames

F

facial nerve - Cranial Nerve VII; cranial nerve that provides efferent innervation to the facial muscles and afferent innervation from the soft palate and tongue

facial nerve monitoring - intraoperative EMG monitoring of facial nerve function, used to provide a warning if the facial nerve is stimulated during surgery

false-alarm rate - percentage of time that a diagnostic test is positive when no disorder exists

false negative - test outcome indicating the absence of a disease or condition when, in fact, that disease or condition exists

false-negative response - in audiometry, failure to respond to an audible stimulus presentation

false positive - test outcome indicating the presence of a disease or condition when, in fact, that disease or condition is not present

false-positive response - in audiometer, response to a nonexistent or inaudible stimulus presentation

familial deafness - deafness occurring in members of the same family

far field recording - measurement of evoked potentials from electrodes on the scalp at a distance from the source

feedback suppression - reduction of feedback in hearing aid amplification through the use of adaptive filtering or cancellation

fetal alcohol syndrome - syndrome in children of women who abuse alcohol during pregnancy, characterized by low birthweight, failure to thrive, and mental retardation; associated with recurrent otitis media and sensorineural hearing loss

filter - in acoustics, a device that differentially enhances and attenuates certain frequencies, thereby modifying the spectrum of the signal

fingerspelling - form of manual communication in which each letter of the alphabet is represented by a different position or movement of the fingers

fissure - cleft or slit

fistula - an abnormal passage formed within the body by disease, surgery, injury or other defect

fistula test - diagnostic test, designed to detected labyrinthine fistulae, in which the air pressure in the external auditory meatus is changed to determine if nystagmus can be elicited

fitting range - range of hearing loss for which a specific hearing aid circuit, configuration, earmold, etc., is appropriate

flat audiogram - audiogram configuration in which hearing sensitivity is similar across the audiometric frequency range

fluctuating hearing loss - loss of hearing sensitivity, characterized by aperiodic change in degree

FM auditory trainer - classroom amplification system in which a remote microphone/transmitter worn by the teacher sends signals via FM to a receiver worn by the student

FM boot - small bootlike device containing an FM receiver that attaches to the bottom of a behind-the-ear hearing aid

FM system - an assistive listening device, designed to enhance signal-to-noise ratio, in which a remote microphone/transmitter worn by a speaker sends signals via FM to a receiver worn by a listener

footplate - base of the stapes that fits in the oval window

foramen - natural opening through bone

forensic audiology - audiology subspecialty devoted to legal proceedings related to hearing loss and noise matters

frequency - the number of time a repetitive event occurs in a specified time period; e.g., for a sine wave, the number of cycles occurring in 1 second, expressed as cycles per seconds or Hertz (Hz)

frequency control - potentiometer or other controlling device on a hearing aid that changes the frequency response

frequency discrimination - ability to distinguish test signals of different frequencies presented consecutively

full-on gain - hearing aid frequency-gain response with device set to maximum output

functional hearing loss - hearing loss that is exaggerated or feigned

G

gain - the amount in dB by which the output level exceeds the input level

ganglia - masses of cell bodies in the peripheral nervous system

genetic counseling - advising of potential parents as to the probability of inherited disorders and conditions in their offspring

genetic disorder - any inherited abnormality or disturbance of function

genetic hearing loss - hearing loss related to heredity

gentamicin; gentamycin - ototoxic aminoglycoside antibiotic, used in the treatment of gram-negative infections

geriatrics - branch of medicine concerned with pathologic aspects of aging

gestational age - age since conception, measured in weeks and days from the first day of the last normal menstrual period

glia - non-neuronal supporting tissues of the nervous system

glioblastoma - rapidly growing and malignant tumor composed of undifferentiated glial cells

glumos tumor - small neoplasm of paraganglionic tissue with a rich vascular supply located near or within the jugular bulb

glue ear - inflammation of the middle ear with thick, viscid, mucuslike effusion

ground electrode - in electrophysiologic measurement, the electrode that attaches the patient to ground

H

habilitation - program or treatment designed to develop abilities or skills

habituation - process of becoming accustomed

hair cells - sensory cells of the organ of Corti to which nerve endings from Cranial Nerve VIII are attached; so named because of the hairlike stereocilia that project from the apical end

half-gain rule - gain and frequency response prescriptive strategy for fitting hearing aid amplification in which the amount of amplification at a given frequency is one half the amount of pure-tone hearing loss at that frequency

half-shell earmold - earmold consisting of a canal and thin shell, with a bowl extending only part of the way to the helix

hammer - colloquial term for malleus

handicap - the obstacles to psychosocial function resulting from a disability

hard-of-hearing - having a hearing impairment ranging from mild to severe

harmonic - component of a complex tone, the frequency of which is an integral multiple of the fundamental frequency

hear - to perceive sound

hearing - the perception of sound

hearing aid - any electronic device designed to amplify and deliver sound to the ear; consists of a microphone, amplifier, and receiver

hearing aid analyzer - instrument used for the electroacoustic analysis of various parameters of the response of a hearing aid

hearing aid dispenser - individual licensed to fit and dispense hearing instruments

hearing aid effect - effect of the physical presence of a hearing aid on an observer's attitude toward the hearing aid wearer

hearing aid evaluation - process of choosing suitable hearing aid amplification for an individual, based on measurement of acoustic properties of the amplification and perceptual response to the amplified sound

hearing aid orientation - process of teaching a new hearing aid wearer proper use and application of amplification

hearing aid trial period - length of time, typically mandated by law, during which an individual can return a purchased hearing aid and receive a refund

hearing conservation program - occupational safety and health program designed to quantify the nature and extent of hazardous noise exposure, monitor the effects of exposure on hearing, provide abatement of sound, and provide hearing protection when necessary

hearing disability - functional limitations resulting from a hearing impairment

hearing disorder - disturbance of structure and/or function of hearing

hearing handicap - obstacles to psychosocial function resulting from a hearing disability

hearing impairment - abnormal or reduced function in hearing resulting from auditory disorder

hearing level - the decibel level of sound referenced to audiometric zero, which is used on audiograms and audiometers, expressed as dB HL

hearing loss - reduction in hearing ability

hearing protection device - any of a number of devices used to attenuate excessive environmental noise to protect hearing, including those that block the ear canal or cover the external ear

hearing screening - the application of rapid and simple hearing tests to a large population consisting of individuals who are undiagnosed and typically asymptomatic to identify those who require additional diagnostic procedures

hearing sensitivity - capacity of the auditory system to detect a stimulus, most often described by audiometric pure-tone thresholds

hearing test - process of evaluation of hearing, usually hearing sensitivity to pure-tone stimuli

hearing threshold - absolute threshold of hearing sensitivity, or the lowest intensity level at which sound is perceived

helicotrema - passage at the apical end of the cochlea, connecting the scala tympani and the scala vestibuli

helix - prominent ridge of the auricle, beginning just superior to the opening of the external auditory meatus and coursing around most of the edge of the auricle

hereditary - genetically determined

hereditary deafness - hearing loss or deafness of genetic origin

Hertz - Hz; unit of measure of frequency; representing number of cycles per second; after physicist Heinrich Hertz

Heschl's gyrus - transverse temporal gyrus that contains the auditory area of the cerebral cortex

high frequency - nonspecific term referring to frequencies above approximately 2000 Hz

high-risk register - list of factors that put a child at risk for having or developing hearing loss

hit rate - percentage of time that a diagnostic test is positive when a disorder exists

HIV - human immunodeficiency virus; cytopathic retrovirus that causes AIDS and can result in infectious disease of the middle ear and mastoid as well as peripheral and central auditory nervous system disorder

hydraulic - pertaining to the movement and force of liquid

hydrocephalus - excessive accumulation of cerebrospinal fluid in the subarachnoid or subdural space

hyperacusis - abnormally sensitive hearing in which normally tolerable sounds are perceived as excessively loud

hyperbilirubinemia - abnormally large amount of bilirubin (red bile pigment) in the blood at birth; risk factor for sensorineural hearing loss

I

iatrogenic hearing loss - hearing sensitivity loss induced during or by treatment

idiopathic hearing loss - hearing loss of unknown cause

immittance - encompassing term for energy flow through the middle ear, including admittance, compliance, conductance, impedance, reactance, resistance, and susceptance

immittance audiometry - battery of immittance measurements, including static immittance, tympanometry, and acoustic reflex threshold determination, designed to assess middle-ear function

impact noise - intermittent noise of short duration, usually produced by nonexplosive mechanical impact such as pile driving or riveting; distinguishable from impulse noise by longer rise times and long duration

impacted cerumen - cerumen that causes blockage of the external auditory meatus

impairment - abnormal or reduced function

impedance - total opposition to energy flow or resistance to the absorption of energy; expressed in ohms

impedance matching device - structure or circuit designed to bridge an impedance mismatch; e.g., the middle ear acts as an impedance matching device by providing a bridge from the low-impedance air pressure waves striking the eardrum to the high-impedance hydraulic system of the cochlea

impedance mismatch - condition in which two devices or media between which energy flows have difference impedances

impulse noise - intermittent noise with an instantaneous rise time and short duration that creates a shock wave; usually produced by gunfire or explosion; distinguishable from impact noise by shorter rise time and duration

in phase - condition in which the pressure waves of two signals crest and trough at the same time

in situ - in position; e.g., in the case of hearing aids, on the patient in position for use

in-the-canal hearing aid - custom hearing aid that fits mostly in the external auditory meatus with a small portion extending into the concha

in-the-ear hearing aid - custom hearing aid that fits entirely in the concha of the ear

in utero - within uterus; not yet born

incidence - frequency of occurrence, expressed as the number of new cases of a disease or condition in a specified population over a specified time period

incus - middle bone of the ossicular chain, located in the epitympanic recess, consisting of a body and two crura, the shorter of which fits into the fossa incudis and the longer of which attaches to the head of the stapes

induction coil - conductor wound into a spiral to create a high concentration of material into which current flow is induced when a magnetic field enters its vicinity; in a hearing aid,

the telecoil is the induction coil, and a telephone produces the magnetic field

industrial audiometry - assessment of hearing, including determination of baseline sensitivity and periodic monitoring, to determine the effects of industrial noise exposure on hearing sensitivity

infarction - sudden insufficiency of blood supply due to occlusion of arterial supply or venous drainage

infection - morbid state caused by invasion and multiplication of pathogenic microorganisms within the body

inferior colliculus - central auditory nucleus of the midbrain; its central nucleus receives ascending input from the cochlear nucleus and superior olivary complex, and its pericentral nucleus receives descending input from the cortex

inflammation - tissue response to injury or destruction of cells, characterized by heat, swelling, pain, redness, and sometimes loss of function

informational counseling - the act of providing factual information in a postassessment encounter

informed consent - agreement between a patient or guardian and a healthcare provider specifying the potential benefits, risks, and complications of a proposed course of management or of participation in a research study

infrared system - assistive listening device consisting of a microphone/transmitter placed near the sound source of interest that broadcasts over infrared light waves to a receiver/amplifier, thereby enhancing the signal-to-noise ratio

inherent - natural to and characteristic of an organism, condition, behavior, or situation

inhibit - to restrain a process

inner ear - structure comprising the sensory organs for hearing and balance, including the cochlea, vestibules, and semicircular canals

inner hair cells - sensory hair cells arranged in a single row in the organ of Corti to which the primary afferent nerve endings of Cranial Nerve VIII are attached

innervation - distribution of nerve fibers to a structure

insert earphone - earphone whose transducer is connected to the ear through a tube leading to an expandable cuff that is inserted into the external auditory meatus

insertion loss - difference in SPL at the tympanic membrane with the ear canal open and with the ear canal occluded by an earmold or nonfunctioning hearing aid

insidious - moving or progressing in an unnoticeable way

intelligibility - the extent to which speech can be understood

intensity - 1. sound power transmitted through a given area; 2. generic term for any quantity relating to the amount or magnitude of sound

intensive care nursery - ICN; hospital unit designed to provide care for newborns needing extensive support and monitoring

interaural - between the ears

interaural attenuation - reduction in the sound energy of a signal as it is transmitted by bone conduction from one side of the head to the other

internal auditory meatus - an opening on the posterior surface of the petrous portion of the temporal bone through which the auditory and facial nerves pass

interoctave - between octaves

interpreter - someone who translates one language to another

interstimulus interval - the time between successive stimulus presentation

intervention - the process of modifying a situation, such as treatment of a disease or disorder

intraoperative monitoring - continuous assessment of the integrity of cranial nerves during surgery; e.g., during acoustic tumor removal, Cranial Nerve VII is monitored because of proximity of the dissection, and

Cranial Nerve VIII is monitored in an attempt to preserve hearing

intrinsic - originating within; inherent

intrinsic redundancy - in speech audiometry, the abundance of information present in the central auditory system due to the capacity inherent in its richly innervated pathways

ipsilateral - pertaining to or situated on the same side

ipsilateral competing message - in speech audiometry, noise or other competing signal that is delivered to the same ear as the target signal

ischemia - localized shortage of blood due to obstruction of blood supply

J

jaundice - disorder characterized by yellowish staining of tissue with bile pigments (bilirubin) that are excessive in the serum; in its severe form, it has been associated with sensorineural hearing loss

K

kHz - kilohertz; 1000 Hz

L

labyrinth - the inner ear, so named because of the intricate maze of connecting pathways in the petrous portion of each temporal bone, consisting of the canals within the bone and fluid-filled sacs and channels within the canals

labyrinthectomy - surgical excision of the labyrinth

labyrinthitis - inflammation of the labyrinth, affecting hearing, balance, or both

language - complex system of symbols for communication

large vestibular aqueduct syndrome - congenital disorder, often associated with Mondini dysplasia, resulting from faulty embryogenesis of the endolymphatic duct and sac, leading to endolymphatic hydrops and childhood onset, bilateral, progressive sensorineural hearing loss

lasix - ototoxic loop diuretic used in the treatment of edema or hypertension that can cause sensorineural hearing loss secondary to degeneration of the stria vascularis

latency - time interval between two events; as between a stimulus and a response

latent - not manifest but having the potential to be

lateral lemniscus - large fiber tract or bundle, formed by dorsal, intermediate, and ventral nuclei and consisting of ascending auditory fibers from the CN and SOC, that runs along the lateral edge of the pons and carries information to the inferior colliculus

lateral semicircular canal - one of three bony canals of the vestibular apparatus containing sensory epithelia that respond to angular motion; also, horizontal semicircular canal

lateralize - to become perceived in one ear rather than the other

lesion - structural or functional pathologic change in body tissue

light reflex - bright triangular reflection on the surface of the tympanic membrane of the illumination used during otoscopic examination; cone of light

linear amplification - hearing aid amplification in which the gain is the same for all input levels until the maximum output is reached

listening - the voluntary direction of attention to a sound source

listening check - regular informal assessment of the output of a hearing aid or audiometer to ensure its proper functioning

listening strategies - techniques used to improve volitional access to auditory information

lobule - inferior fleshy aspect of the auricle; earlobe

localization - identification of the location in space of a sound source

logarithmic scale - measurement scale, such as the decibel scale, that is based on exponents of a base number

longitudinal fracture - linear break that courses longitudinally through the temporal bone, often tearing the tympanic membrane and disrupting the ossicles; typically caused by a blow to the parietal or temporal regions of the skull

loop amplification system - assistive listening device in which a microphone/amplifier delivers signals to a loop of wire encircling a room; the signals are received by the telecoil of a hearing aid via magnetic induction

loudness - perception or psychological impression of the intensity of sound

loudness adaptation - reduction in perceived loudness of a signal over time

loudness recruitment - exaggeration of nonlinearity of loudness growth due to sensorineural hearing loss, wherein loudness grows rapidly at intensity levels just above thresholds but may grow normally at high intensity levels

loudness summation - the addition of loudness by expansion of bandwidth, even when overall sound pressure level remains the same

loudspeaker - transducer that converts electrical energy into acoustic energy

low frequency - nonspecific term referring to frequencies below around 1000 Hz

low-frequency hearing loss - nonspecific term referring to hearing sensitivity loss occurring at frequencies below approximately 1000 Hz

M

malignant - 1. resistant to treatment; of progressive severity; 2. pertaining to a neoplasm that is locally invasive and destructive; cancerous

malingering - deliberately feigning or exaggerating an illness or impairment such as hearing loss

malleus - largest and lattermost bone of the ossicular chain, articulated on one end to the tympanic membrane and on the other to the incus

manual communication - method of communicating that involves the use of fingerspelling, gestures, and sign language

manubrium - handle of the malleus that extends from the head of the malleus, just below the middle of the tympanic membrane, to the umbo, at the upper part of the pars tensa

mask - in audiometry, to introduce sound to one ear while testing the other in an effort to eliminate any influence of contralateralization of sound from the test ear to the nontest ear

masked threshold - pure-tone or speech audiometric threshold obtained in one ear while the other ear is effectively masked

masking dilemma - challenge in audiometric testing of bilateral moderate-to-severe conductive hearing loss presented when the introduction of masking noise to the nontest ear is sufficient to cross over and mask the test ear

mass - quantity of matter in a body

mastoid - conical projection of the temporal bone, lying posterior and inferior to the external auditory meatus, that creates a bony protuberance behind and below the auricle

mastoidectomy - excision of the bony partitions from the mastoid air cells to treat middle ear and mastoid infections that are unresponsive to drug therapy

mastoiditis - inflammation of the mastoid process

measles - highly contagious viral infection characterized by fever, cough, conjunctivitis, and cutaneous rash, which can cause purulent labyrinthitis and consequent bilateral severe to profound sensorineural hearing loss

meatus - any anatomical passageway or channel, especially the external opening of a canal

medial geniculate - auditory nucleus of the thalamus, divided into central and surrounding pericentral nuclei, that receives primary ascending fibers from the inferior colliculus and sends fibers, via the auditory radiation, to the auditory cortex

medial nucleus of the trapezoid body - MNTB or MTB; a nucleus of the superior olivary complex that receives primary ascending projections from the contralateral anterior ventral cochlear nucleus and sends projections to the ipsilateral superior olive and lateral lemniscus

medulloblastoma - soft, infiltrating malignant glioma of the roof of the fourth ventrical and cerebellum

membrane - thin layer of pliable tissue that connects structure, divides spaces or organs, and lines cavities

membranous labyrinth - soft-tissue, fluid-filled channels within the osseous labyrinth that contain the end organ structures of hearing and vestibular function

memory - information-processing function of the central nervous system that receives, modifies, stores, and retrieves information in short-term or long-term form

Ménière's disease - idiopathic endolymphatic hydrops, characterized by episodic vertigo, hearing loss, tinnitus, and aural fullness

meninges - the three membranes—arachnoidea, dura mater, and pia mater—covering the brain and spinal cord

meningioma - benign tumor arising from the sigmoid and petrosal sinuses at the posterior aspect of the petrous pyramid that may encroach on the cerebellopontine angle, resulting in retrocochlear disorder

meningitis - bacterial or viral inflammation of the meninges that can cause significant auditory disorder due to suppurative labyrinthitis or inflammation of the lining of the Cranial Nerve VIII

message-to-competition ratio - MCR; in speech audiometry, the ratio in dB of the presentation level of a speech target to that of background competition

microphone - transducer that converts sound waves into an electric signal

microcephaly - abnormal smallness of the head

microtia - abnormal smallness of the auricle

microvolt - μV; one millionth of a volt; 1 microvolt equals 0.000001 volts

mid frequency - nonspecific term referring to frequencies around 1000 Hz to 2000 Hz

mid-frequency hearing loss - nonspecific term referring to hearing sensitivity loss occurring at frequencies around 1000 Hz to 2000 Hz

middle ear - portion of the hearing mechanism extending from the medial membrane of the tympanic membrane to the oval window of the cochlea, including the ossicles and middle-ear cavity; serves as an impedance matching device of the outer and inner ears

middle-ear cavity - space in the temporal bone, including the tympanic cavity, epitympanum, and Eustachian tube

middle-ear disorder - any deficiency in middle ear functioning

mild hearing loss - loss of hearing sensitivity of 25 dB HL to 40 dB HL

minimal hearing loss - loss of hearing sensitivity of 15 to 25 dB HL

millimho - mmho; one thousandth of a mho; a unit of electrical conductance, expressed as the reciprocal of an ohm

mixed hearing loss - hearing loss with both a conductive and a sensorineural component

moderate hearing loss - loss of hearing sensitivity of 40 dB HL to 55 dB HL

moderately severe hearing loss - loss of hearing sensitivity of 55 dB HL to 70 dB HL

modiolus - central bony pillar of the cochlea through which the blood vessels and nerve fibers of the labyrinth course

monaural - pertaining to one ear

Mondini dysplasia - congenital anomaly of the osseous and membranous labyrinths exhibiting a wide range of morphologic and functional abnormality, including severe loss of hearing and vestibular function

monitored live voice - MLV; speech audiometric technique in which speech signals are presented via a microphone with controlled vocal output

monitoring - continuous assessment of the integrity of function over time, such as intraoperative or ototoxicity monitoring

monosyllabic word - a word of one syllable

monotic - presented to one ear

morphology - in auditory evoked potentials, the qualitative description of an auditory evoked potential; related to the replicability of the response and the ease with which component peaks can be identified

most comfortable loudness - MCL; intensity level at which sound is perceived to be most comfortable

motility of outer hair cells - the capacity of outer hair cells to change shape in response to electrical stimulation

motor neuron - efferent nerve fiber that conveys impulses from the central nervous system to peripheral muscles

msec - millisecond; one thousandth of a second

mucoid - thick, viscid

mucosa - any epithelial lining of an organ or structure, such as the tympanic cavity, that secretes mucus; mucous membrane

multichannel hearing aid - hearing aid in which each of two or more frequency bands is controlled independently

multifrequency tympanometry - tympanometric assessment of middle-ear function with a conventional 220-Hz probe tone and with one or more additional probe-tone frequencies

multiple sclerosis - MS; demyelinating disease in which plaques form throughout the white matter of the brainstem, resulting in diffuse neurologic symptoms, including hearing loss, speech-understanding deficits, and abnormalities of the acoustic reflexes and ABR

multitalker babble - continuous speech noise composed of several talkers all speaking at once

mumps - contagious systemic viral disease; characterized by painful enlargement of parotid glands, fever, headache, and malaise; associated with sudden, permanent, profound unilateral sensorineural hearing loss

myelin - tissue enveloping the axon of myelinated nerve fibers; composed of alternating layers of lipids and protein

myogenic - originating in muscle

myringitis - inflammation of the tympanic membrane, associated with infection of the middle ear or external auditory meatus

myringotomy - passage of a needle through the tympanic membrane to remove effusion from the middle ear

N

narrow-band filter - filter that allows a specified band of frequencies to pass through while reducing or eliminating frequencies above and below the band; SYN: band-pass filter

narrow-band noise - band-pass filtered noise that is centered at one of the audiometric frequencies, used for masking in pure-tone audiometry

nasopharynx - cavity of the nose and pharynx into which the eustachian tube opens

neckloop - transducer worn as part of an FM amplification system, consisting of a cord from the receiver that is worn around the neck and that transmits signals via magnetic induction to the telecoil of a hearing aid

negative middle-ear pressure - air pressure in the middle-ear cavity that is below atmospheric pressure; resulting from an inability to equalize pressure due to eustachian tube dysfunction

neonatal hearing screening - the application of rapid and simple tests of auditory function, typically AABR or OAE measures, to newborns prior to hospital discharge to identify those who require additional diagnostic procedures

neonatal intensive care unit - hospital unit designed to provide care for newborns needing greater than normal support and monitoring; also, intensive-care nursery

neonate - infant during the first 4 weeks of life

neoplasm - abnormal new growth of tissue, resulting from an excessively rapid proliferation of cells that continue to grow even after cessation of the stimuli that initiated the new growth

nerve - cordlike structure made of nerve fibers surrounded by connective tissue sheath through which nervous impulses are conducted to and from the central nervous system

neural plasticity - the capacity of the nervous system to change over time in response to changes in sensory input

neuritis - inflammation of a nerve with corresponding sensory or motor dysfunction

neurofibromatosis II - NF2; autosomal dominant disorder characterized by bilateral cochleovestibular Schwannomas that are faster growing and more virulent than the unilateral type; associated with secondary hearing loss and other intracranial tumors

neurologic - pertaining to the nervous system

neuromaturational delay - slower than normal onset of development and growth of the nervous system

neuron - basic unit of the nervous system, consisting of an axon, cell body, and dendrite

neuropathy - any disorder involving the cranial or spinal nerves

neurotology - branch of medical science specializing in the study, diagnosis, and treatment of disease of the peripheral and central auditory and vestibular nervous systems

neurotransmitter - chemical agent released by a presynaptic cell upon excitation that crosses the synapse and excites or inhibits the postsynaptic cell

newborn hearing screening - the application of rapid and simple tests of auditory function, typically AABR or OAE measures, to newborns prior to hospital discharge to identify those who require additional diagnostic procedures

noise - 1. highly complex sound produced by random oscillation; 2. unwanted sound

noise exposure - level and duration of noise to which an individual is subjected

noise floor - in any amplification system, the continuous baseline-level of background activity or noise from which a signal or response emerges

noise-induced hearing loss - permanent sensorineural hearing loss caused by exposure to excessive sound levels

noise notch - pattern of audiometric thresholds associated with noise-induced hearing loss, characterized by sensorineural hearing loss predominantly at 4000–6000 Hz

nonlinear - a condition whereby the magnitude of an output does not grow in proportion to the input

nonlinear amplification - amplification whose gain is not the same for all input levels

nonsense syllable - single-syllable speech utterance that has no meaning; used in speech audiometric measures

normal hearing - hearing ability, including threshold of sensitivity and suprathreshold perception, that falls within a specified range of normal capacity

notch filter - filtering network that removes a discrete portion of the frequency range; used in evoked potential measurement to remove 60-Hz noise and in hearing aids to limit amplification in a discrete frequency region

nystagmus - pattern of eye movement, characterized by a slow component in one direction that is periodically interrupted by a saccade, or fast component in the other; results from the anatomical connection between the vestibular and ocular systems

O

objective - physically measurable; independent of subjective interpretation

objective tinnitus - ringing or other head noises that can be heard and measured by an examiner

occlusion - a blockage or obstruction

occlusion effect - low-frequency enhancement in the loudness level of bone-conducted signals due to occlusion of the ear canal

occupational hearing conservation program - industrial program designed to quantify the nature and extent of hazardous noise exposure, monitor the effects of exposure on hearing, provide abatement of sound, and provide hearing protection when necessary

octave - frequency interval between two tones with a 2 to 1 ratio, so that one frequency is twice the frequency of the other

ohm - unit of resistance of a conductor to electrical or other forms of energy

omnidirectional microphone - microphone with a sensitivity that is similar regardless of the direction of the incoming sound

open-canal fitting - hearing aid fitting with an open earmold or tubing-only in the ear canal

open-set test - speech audiometric test in which the targeted syllable, word, or sentence is chosen from among all available targets in the language

oral-aural communication - method of communicating that involves hearing, speaking, and speechreading

oral interpreter - a professional who silently repeats the speech source to provide enhanced lipreading opportunity to a person with hearing loss

oralism - method of deaf education that emphasizes the use of verbal communication to the exclusion of manual communication

ordinate - vertical or Y axis on a graph, such as the intensity axis on an audiogram

organ of Corti - hearing organ, composed of sensory and supporting cells, located on the basilar membrane in the cochlear duct

organic hearing loss - hearing loss due to a pathologic process in the auditory system

oscillation - periodic vibration back and forth between two points

oscillator - electronic instrument designed to produce pure-tone oscillation

oscillopsia - oculomotor disorder, characterized by blurring of vision during movement, that occurs due to uncoupling of the vestibulo-ocular reflex caused by bilateral vestibular disorder

osseous labyrinth - intricate maze of connecting channels in the petrous portion of each temporal bone that contains the membranous labyrinth

osseous spiral lamina - bony shelf in the cochlea projecting out from the modiolus onto which the inner margin of the membranous labyrinth attaches and through which the nerve fibers of the hair cells course

ossicles - the three small bones of the middle ear—the malleus, incus, and stapes—extending from the tympanic membrane through the tympanic cavity to the oval window

ossicular chain - the ossicles considered collectively

ossification - a change into bone

otalgia - ear pain

otitis - inflammation of the ear

otitis externa - inflammation of the outer ear, usually the external auditory meatus

otitis media - inflammation of the middle ear, resulting predominantly from eustachian tube dysfunction

otitis media with effusion - OME; inflammation of the middle ear with an accumulation of fluid of varying viscosity in the middle-ear cavity and other pneumatized spaces of the temporal bone

otoacoustic emission - OAE; low-level sound emitted by the cochlea, either spontaneously or evoked by an auditory stimulus, related to the function of the outer hair cells of the cochlea

otoconia - structures in the maculae of the utricle and saccule, located on the gelatinous material in which the stereocilia of the hair

cells are embedded, which increase the sensitivity of the underlying hair cells to linear acceleration

otolaryngologist - physician specializing in the diagnosis and treatment of diseases of the ear, nose, and throat, including diseases of related structures of the head and neck

otolaryngology - branch of medicine specializing in the diagnosis and treatment of diseases of the ear, nose, and throat

otologist - physician specializing in the diagnosis and treatment of ear disease

otorrhea - discharge from the ear

otosclerosis - remodeling of bone, by resorption and new spongy formation around the stapes and oval window, resulting in stapes fixation and related conductive hearing loss

otoscope - a speculum-like instrument for visual examination of the external auditory meatus and tympanic membrane

ototoxic - having a poisonous action on the ear, particularly the hair cells of the cochlear and vestibular end organs

outer ear - peripheral-most portion of the auditory mechanism, consisting of the auricle, external auditory meatus, and lateral surface of the tympanic membrane

outer-ear canal - canal extending from the auricle to the tympanic membrane; external auditory meatus

outer hair cells - mobile cells within the organ of Corti with rich efferent innervation, which appear to be responsible for fine-tuning frequency resolution and potentiating the sensitivity of the inner hair cells

output sound pressure level - maximum output generated by the receiver of a hearing aid, determined with the hearing aid gain control at its full-on position and a 90 dB SPL input signal

oval window - opening in the labyrinthine wall of the middle- ear space, leading into the scala vestibuli of the cochlea, into which the footplate of the stapes fits

overmasking - condition in which the intensity level of masking in the nontest ear is sufficient to contralateralize to the test ear, thereby elevating the test-ear threshold

P

paroxysmal - pertaining to abrupt, recurrent onset of a symptom

pars flaccida - smaller and more compliant or flaccid portion of the tympanic membrane, containing two layers of tissue, located superiorly

pars tensa - larger and stiffer portion of the tympanic membrane, containing four layers of tissue

participation restrictions - problems an individual experiences in involvement in life situations

Pascal - Pa; unit of pressure, expressed in Newtons per square meter

patent - open; unobstructed; patulous

pathologic - pertaining to or caused by disease

patulous eustachian tube - abnormally patent eustachian tube, resulting in sensation of stuffiness, autophony, tinnitus, and audible respiratory noises

PB max - highest percentage-correct score obtain on monosyllabic word-recognition measures (PB word lists) presented at several intensity levels

PE tube - pressure-equalization tube

peak clipping - process of limiting maximum output intensity of a hearing aid or amplifier by removing alternating current amplitude peaks at a fixed level

pediatric audiologist - audiologist with a subspecialty interest in the diagnosis and treatment of hearing disorders in children

perception - awareness, recognition, and interpretation of speech signals received by the brain

perforation - abnormal opening in a tissue or structure

performance-intensity function - graph of percentage-correct speech-recognition

scores as a function of presentation level of the target signals

perilymph - cochlear fluid, found in the scala vestibule, scala tympani, and spaces within the organ of Corti, that is high in sodium and calcium and has an ionic composition that resembles cerebrospinal fluid

perilymphatic fistula - abnormal passageway between the perilymphatic space and the middle ear, resulting in the leak of perilymph at the oval or round window, caused by congenital defects or trauma

perinatal - pertaining to the period around the time of birth, from the 28th week of gestation through the seventh day following delivery

period - length of time for a sine wave to complete one cycle

periodic - recurring at regular time intervals

peripheral auditory system - hearing mechanisms, including the external ear, middle ear, cochlea, and Cranial Nerve VIII

permanent threshold shift - irreversible hearing sensitivity loss following exposure to excessive noise levels

petrous bone - section of the temporal bone of the skull that houses the sensory organ of the peripheral auditory system

phase - relative position in time of a point along a periodic waveform, expressed in degrees of a circle

phoneme - smallest distinctive class of sound in a language that represents the variations of a speech sound that are considered the same sound and represented by the same symbol

phonetic - pertaining to individual speech sounds

phonetically balanced - descriptive of a list of words containing speech sounds that occur with the same frequency as in conversational speech

pinna - external cartilaginous portion of the ear

pitch - perception or psychological impression of the frequency of a sound

plateau method - method of masking the nontest ear in which masking is introduced progressively over a range of intensity levels until a plateau is reached, indicating the level of masked threshold of the test ear

pneumatic otoscopy - inspection of the motility of the tympanic membrane with an otoscope while varying air pressure in the external auditory meatus

positional nystagmus - usually abnormal presence of nystagmus that occurs with the head placed in a particular position; subtypes are classified as geotropic or ageotropic and direction-changing or direction-fixed nystagmus

posterior semicircular canal - one of three bony canals of the vestibular apparatus containing sensory epithelia that respond to angular motion

postlinguistic - occurring after the time of speech and language development

potentiometer - a resistor connected across a voltage that permits variable change of a current or circuit; on a hearing aid, a control that permits adjustment of the response

precipitous hearing loss - sensorineural hearing loss characterized by a steeply sloping audiometric configuration

prelinguistic - occurring prior to the time of speech and language development

prenatal - before birth

presbyacusis - age-related hearing impairment

prescriptive fitting - strategy for fitting hearing aids by the calculation of a desired gain and frequency response, based on any number of formulas that incorporate pure-tone audiometric thresholds and may incorporate uncomfortable loudness information

pressure - force exerted per unit area, expressed in dynes per square centimeter, Newtons per square meter, or Pascals

pressure-equalization tube - PE tube; small tube or grommet inserted in the tympanic membrane following myringotomy to provide equalization of air pressure within the middle-ear space as a substitute for a nonfunctional eustachian tube

pressure vent - small vent in an earmold or hearing aid to provide pressure equalization in the external auditory meatus

prevalence - number of existing cases of a specific disease or condition in a given population at a given time

probe microphone - microphone transducer with a small-diameter probe-tube extension for measuring sound near the tympanic membrane

probe-microphone measurements - electroacoustic assessment of the characteristics of hearing aid amplification near the tympanic membrane using a probe microphone

probe tone - in immittance measurement, the pure tone that is held at a constant intensity level in the external auditory meatus; used to indirectly measure changes in energy flow through the middle-ear mechanism

processing strategy - referring primarily to any of the algorithms used in a cochlear implant to translate acoustic signals to a multichannel electrode

profound hearing loss - loss of hearing sensitivity of greater than 90 dB HL

prognosis - prediction of the course or outcome of a disease or proposed treatment

programmable hearing aid - any hearing aid in which the parameters of the instrument are under computer control

progressive - advancing, as in a disease

prolapsed canal - external auditory meatus that is occluded by cartilaginous tissue that has lost rigidity

promontory - bony prominence in the labyrinthine wall of the middle-ear cavity, separating the oval and round windows and serving as the wall of the basal turn of the cochlea

proprioception - awareness of posture, movement, or position in space

prosthetic device - device replacing or augmenting a missing or dysfunctional part

pseudohypacusis - hearing sensitivity loss that is exaggerated or feigned

psychoacoustics - branch of psychophysics concerned with the quantification of auditory sensation and the measurement of psychological correlates of the physical characteristics of sound

psychogenic deafness - rare disorder characterized by apparent, but nonorganic, hearing loss resulting from psychological trauma

psychophysical procedures - behavioral procedures designed to assess the relationship between the subjective sensation to and physical characteristics of sensory stimuli

PTA - pure-tone average

pulsatile tinnitus - objective tinnitus, characterized by pulsing sound, that results from vascular abnormalities such as glomus tumor, arterial anomaly, and heart murmurs

pure tone - 1. a signal in which the instantaneous sound pressure varies as a sinusoidal function of time; 2. sound wave having only one frequency of vibration

pure-tone audiogram - graph of the threshold of hearing sensitivity, expressed in dB HL, as determined by pure-tone air-conduction and bone-conduction audiometry at octave and half-octave frequencies ranging form 250 Hz to 8000 Hz

pure-tone average - PTA; average of hearing sensitivity thresholds to pure-tone signals at 500 Hz, 1000 Hz, and 2000 Hz

Q

quinine - antimalarial drug that when taken during pregnancy can affect the auditory system of the fetus, or, taken in large doses, can cause temporary or permanent hearing loss in the person taking the drug

R

radionecrosis - death of tissue due to excessive exposure to radiation, which in the auditory system may occur immediately or have later onset; characterized by atrophy of the spiral and annular ligaments resulting in degeneration of the organ of Corti

Ramsay Hunt syndrome - herpes zoster infection that lingers in the ganglia and can be activated by systemic disease, resulting in vesicular eruptions of the auricle, facial nerve palsy, and sensorineural hearing loss

range of normal hearing - dispersion of hearing threshold levels around audiometric zero for the population of those with normal hearing

rarefaction - in the propagation of sound waves, the time during which the density of air molecules is decreased below its static value

real ear - pertaining to measurements made in the ear canal with a probe microphone

real-ear aided gain - REAG; measurement of the difference, in dB as a function of frequency, between the SPL in the ear canal and the SPL at a field reference point for a specified sound field with the hearing aid in place and turned on

real-ear aided response - REAR; probe-microphone measurement of the sound pressure level, as a function of frequency, at a specified point near the tympanic membrane with a hearing aid in place and turned on; expressed in absolute SPL or as gain relative to stimulus level

real-ear coupler difference - RECD; measurement of the difference, in dB as a function of frequency, between the output of a hearing aid measured by a probe microphone in the ear canal and the output measured in a 2-cc coupler

real-ear gain - nonspecific term referring generally to the gain of a hearing aid at the tympanic membrane, measured as the difference between the SPL in the ear canal and the SPL at the field reference point for a specified sound field

real-ear insertion gain - REIG; probe-microphone measurement of the difference, in dB as a function of frequency, between the real-ear unaided gain and the real-ear aided gain at the same point near the tympanic membrane

real-ear insertion response - REIR; probe-microphone measurement of the difference, in dB as a function of frequency, between the real-ear unaided response and the real-ear aided response at the same point near the tympanic membrane

real-ear occluded gain - REOG; probe-microphone measurement of the difference, in dB as a function of frequency, between the SPL at a field reference point for a specified sound field with a hearing aid in place and turned off

real-ear occluded response - REOR; probe-microphone measurement of the sound pressure level, as a function of frequency, at a specified point near the tympanic membrane with a hearing aid in place and turned off; expressed in absolute SPL or as gain relative to stimulus level

real-ear unaided gain - REUG; probe-microphone measurement of the difference in dB as a function of frequency, between the SPL in an unoccluded ear canal and the SPL at the field reference point for a specified sound field

real-ear unaided response - REUR; probe-microphone measurement of the sound pressure level, as a function of frequency, at a specified point near the tympanic membrane in an unoccluded ear canal

receiver - 1. device that converts electrical energy into acoustic energy, such as an earphone or a loudspeaker in a hearing aid; 2. portion of an FM system worn by the listener that receives signals from the FM transmitter

recruitment - exaggeration of nonlinearity of loudness growth in an ear with sensorineural hearing loss, wherein loudness grows rapidly at intensity levels just above threshold but may grow normally at high intensity levels

redundancy - in speech audiometry, the abundance of information available to the listener due to the substantial information content

of a speech signal and to the capacity inherent in the richly innervated pathways of the central auditory nervous system

reference microphone - a second microphone used to measure the stimulus level during probe-microphone measurements or to control the stimulus level during the probe-microphone equalization process

reflex - involuntary response to a stimulus

reflex decay - perstimulatory reduction in the amplitude of an acoustic reflex in response to continuous stimulus presentation

regular-care nursery - RCN; hospital unit designed to take care of newborns who do not need special care

rehabilitation - program or treatment designed to restore function following disease or injury

Reissner's membrane - membrane within the cochlear duct, attached to the osseous spiral lamina and projecting obliquely to the outer wall of the cochlea, that separates the scala vestibuli and scala media

release from masking - reduction in the effectiveness of masking as a result of a change in some aspect of the masking signal or the signal being masked; e.g., binaural release from masking, in which a change in phase of binaural tones causes them to be audible in noise

reliability - extent to which a test yields consistent scores on repeated measures

remote control - hand-held unit that permits volume and/or program changes in a programmable hearing aid

repair strategies - compensatory strategies used by individuals with hearing impairment to clarify missed or misunderstood utterances

reserve gain - the remaining gain in a hearing aid; the difference between use gain and the gain at which feedback occurs

residual hearing - the remaining hearing ability in a person with hearing loss

resistance - opposition to energy flow due to dissipation

resonance - condition of peak vibratory response upon excitation of a system that can vibrate freely

resonant frequency - frequency at which a secured mass will vibrate most readily when set into free vibration

retrocochlear - pertaining to the neural structures of the auditory system beyond the cochlea, especially Cranial Nerve VIII and the auditory portions of the brainstem

retrocochlear disorder - hearing disorder resulting from a neoplasm or other lesion located on Cranial Nerve VIII or beyond in the auditory brainstem or cortex

right-ear advantage - tendency in most individuals for right-ear performance on speech perception measures to be better than left-ear performance

Rinne test - tuning fork test in which the fork is alternately held to the mastoid for bone-conducted stimulation and near the auricle for air-conducted stimulation in an effort to detect the present of a conductive hearing loss

rise time - time required for a gated signal to reach a specified percentage of its maximum amplitude

risk factors - health, environmental, and lifestyle factors that enhance the likelihood of having or developing a specified disease or disorder

rollover - paradoxical decrease in speech-recognition ability with increasing level at high-intensity levels, consistent with retrocochlear disorder

round window - membrane-covered opening in the labyrinthine wall of the middle-ear space, leading into the scala tympani of the cochlea

rubella - mild viral infection, characterized by fever and a transient eruption or rash on the skin resembling measles; when occurring in pregnancy, may result in abnormalities in the fetus, including sensorineural hearing loss

S

saccades - rapid eye movements that maintain the image of fast-moving objects on the fovea, constituting the quick component of nystagmus

saccule - smaller of the two sac-like structures in the vestibule containing a macula that is responsive to linear acceleration as experienced in locomotion

saturation - level in an amplifier circuit at which an increase in input signal no longer produces additional output

saturation sound pressure level 90 - SSPL 90; electroacoustic assessment of a hearing aid's maximum output; expressed as a frequency response curve to a 90-dB input with the hearing aid gain control set to full on

scala media - middle of three channels of the cochlear duct, bordered by the basilar membrane, Reissner's membrane, and the spiral ligament, that is filled with endolymph and contains the organ of Corti

scala tympani - lowermost of two perilymph-filled channels of the cochlear duct, separated by the scala media, terminating apically at the helicotrema and basally at the round window

scala vestibuli - uppermost of two perilymph-filled channels of the cochlear duct, separated by the scala media, terminating apically at the helicotrema and basally in the vestibule at the oval window

Scarpa's ganglia - two adjacent cell-body masses of the peripheral vestibular neurons, located in the internal auditory canal; associated with the superior and inferior divisions of the vestibular nerve portion of Cranial Nerve VIII

Scheibe dysplasia - developmental abnormality of the phylogenetically newer parts of the inner ear, especially the cochlea and saccule, and sparing of the utricle and semicircular canals, with associated sensorineural hearing loss

Schwabach test - bone-conduction tuning-fork test in which the patient's ability to hear the vibrating fork applied to the mastoid is compared to the examiner's

Schwann cells - cells that produce and maintain the myelin sheath of the axons of most cranial nerves

sclerosis - a hardening of tissue, especially from inflammation

screening - the application of rapid and simple tests to a large population consisting of individuals who are undiagnosed and typically asymptomatic to identify those who require additional diagnostic procedures

semantic - pertaining to meaning, or the relationship between symbols and their referents in language

senescent - pertaining to aging, growing old

sensation - change in the state of awareness resulting from stimulation of an afferent nerve

sensation level - SL; the intensity level of a sound in dB above an individual's threshold; usually used to refer to the intensity level of a signal presentation or a response above a specified threshold, such as pure-tone threshold or acoustic reflex threshold

sensitivity - capacity of a sense organ to detect a stimulus

sensitivity prediction by the acoustic reflex - SPAR; test designed to predict the presence or absence of cochlear hearing loss by determining the difference between acoustic reflex thresholds elicited by pure tones and by broad-band noise, a difference that is smaller in ears with hearing loss

sensitized speech measures - speech audiometric measures in which speech targets are altered in various ways to reduce their informational content in an effort to more effectively challenge the auditory system, including low-pass filtering and time compression

sensorineural acuity level test - SAL test; method for quantifying the size of an air-bone gap by establishing air-conduction thresholds under earphones in quiet and in the presence of bone-conducted noise and comparing the shift in threshold to normative values

sensorineural hearing loss - cochlear or retrocochlear loss in hearing sensitivity due to disorders involving the cochlea and/or the auditory nerve fibers of Cranial Nerve VIII

sensory - pertaining to sensation; conveying impulses from the sense organs to the central nervous system

sensory deprivation - condition of being without perception from one or more of the senses

sentential approximations - contrived nonsense sentences used in speech audiometry; designed to be syntactically appropriate but meaningless

sequelae - a condition or disease following or occurring as a consequence of another condition or disease

serial audiogram - one of a series of audiograms obtained at regular intervals, usually on an annual basis as part of a hearing conservation program

serous otitis media - inflammation of middle-ear mucosa with serous effusion

severe hearing loss - loss of hearing sensitivity of 70 dB HL to 90 dB HL

severe-to-profound hearing loss - loss of hearing sensitivity of more than 70 dB HL

sex-linked inheritance - inheritance in which the disordered gene is on the X chromosome

shadow curve - an audiogram reflecting cross hearing from an unmasked nontest ear with normal or nearly normal hearing, obtained while testing an ear with a severe or profound loss; indicative of the organicity of the loss in the test ear

short-term memory - that aspect of the information-processing function of the central nervous system that receives, modifies, and stores information briefly

signal averaging - in auditory evoked potential measurement, the averaging of successive samples of EEG activity time-locked to an acoustic stimulus; designed to enhance the response (signal) evoked by the stimulus by reducing the unrelated EEG noise

signal-to-noise ratio - SNR; relative difference in dB between a sound of interest and a background of noise

simple harmonic motion - continuous, symmetric, periodic back and forth movement of an object that has been set into motion

sinusoid - harmonic motion plotted as a function of time

site of lesion - the locus of a pathologic change

skeleton earmold - earmold in which the bowl has been cut out, leaving an outer concha rim, but retaining the portion that seals the external auditory meatus

ski-slope audiogram - colloquial term for precipitous, high-frequency hearing loss

sloping hearing loss - audiometric configuration in which hearing loss is progressively worse at higher frequencies

smooth pursuit - eye movement used to track slowly and smoothly moving objectives

sound - vibratory energy transmitted by pressure waves in air or other media that is the objective cause of the sensation of hearing

sound field - circumscribed area or room into which sound is introduced via a loudspeaker

sound field amplification - amplification of a classroom or other open area with a public address system or other small-room system to enhance the signal-to-noise ratio for all listeners

sound field testing - in pediatric audiometry or hearing aid fitting, the determination of hearing sensitivity or speech recognition ability made with signals presented in a sound field through loudspeakers

sound intensity - sound power transmitted through a given area, expressed in watts/m^2

sound level meter - an electronic instrument designed to measure sound intensity in dB in accordance with an accepted standard

sound pressure level - SPL; magnitude or quantity of sound energy relative to a reference pressure, 0.0002 dyne/cm^2 or 20 μPa

sound wave - energy generated by a vibrating source that transmits a series of alternating compressions and rarefactions of an elastic medium

space-occupying lesion - neoplasm that exerts its influence by growing and impinging on neural tissues, as opposed to a lesion caused by trauma, ischemia, or inflammation

SPAR - sensitivity prediction by the acoustic reflex

spatial localization - ability to determine the location of a sound source in three-dimensional space

specificity - the ability of a test to differentiate a normal condition from the disorder that the test was designed to detect, expressed as the percentage of negative results in patients without the disorder

spectral analysis - measurement of the distribution of magnitudes of the frequency components of a sound

spectrum - distribution of magnitude of the frequency components of a sound

speech - act of respiration, phonation, articulation, and resonation that serves as a medium for oral communication

speech audiometry - measurement of the hearing of speech signals, includes measurement of speech awareness, speech reception, word and sentence recognition, sensitized speech processing, and dichotic listening

speech-awareness threshold - SAT; lowest level at which a speech signal is audible

speech-detection threshold - SDT; lowest level at which a speech signal is audible

speech frequencies - audiometric frequencies at which a substantial amount of speech energy occurs, conventionally considered to be 500 Hz, 1000 Hz, and 2000 Hz

speech-intelligibility index - ANSI standard identifier of the articulation or audibility index; a measure of the proportion of speech cues that are audible

speech-language pathologist - healthcare professional who is credentialed in the practice of speech-language pathology to provide a comprehensive array of services related to prevention, evaluation, and rehabilitation of speech and language disorders

speech noise - broad-band noise that is filtered to resemble the speech spectrum

speech perception - awareness, recognition, and interpretation of speech signals received by the brain

speech processor - in a cochlear implant system, the component responsible for transforming acoustic speech signals into electrical impulses to be delivered to the implanted electrode

speech-reception threshold - threshold level for speech recognition, expressed as the lowest intensity level at which 50% of spondaic words can be identified; speech recognition threshold

speech recognition - the ability to perceive and identify speech targets

speech recognition threshold - SRT; threshold level for speech recognition, expressed as the lowest intensity level at which 50% of spondaic words can be identified

speechreading - the process of visual recognition of speech communication, combining lipreading with observation of facial expressions and gestures

spiral ganglia - cell bodies of the auditory nerve fibers, clustered in the modiolus

spiral lamina - shelf of bone arising from the modiolar side of the cochlea, consisting of two thin plates of bones between which course the nerve fibers of the auditory nerve to and from the hair cells

spiral ligament - band of connective tissue that affixes the basilar membrane to the outer bony wall, against which lies the stria vascularis within the scala media

spiral limbus - mound of connective tissue in the scala media, resting on the osseous spiral lamina, to which the medial end of the tectorial membrane is attached

spondee - a two-syllable word spoken with equal emphasis on each syllable; spondaic word

spontaneous nystagmus - ocular nystagmus that occurs in the absence of stimulation

spontaneous otoacoustic emission - measurable low-level sound that is emitted by the cochlea in the absence of an evoking stimulus; related to the function of the outer hair cells

standing wave - periodic waveform produced in a closed sound field from the interference of reflective waves of the same frequency and kind that add and subtract, resulting in different amplitudes at various points in the room

stapedectomy - surgical removal of the stapes footplate in whole or part, with prosthetic replacement, as treatment for stapes fixation

stapedial reflex - reflexive contraction of the stapedius muscle in response to loud sound

stapedius - along with the tensor tympani, one of two striated muscles of the middle ear classified as a pinnate muscle, consisting of short fibers directed obliquely onto the stapedius tendon at the midline, innervated by the facial nerve

stapes - smallest and medialmost bone of the ossicular chain, the head of which articulates to the lenticular process of the incus and the footplate of which fits into the oval window of the cochlea

stapes fixation - immobilization of the stapes at the oval window, often due to new bony growth resulting from otosclerosis

stapes footplate - flat, oval-shaped base of the stapes bone that fits in the oval window and is attached by the annular ligament

stapes mobilization - surgical procedure used to restore movement to a fixated stapes footplate

startle reflex - normal reflexive extension and abduction of the limb and neck muscles in an infant when surprised by a sudden sound

Stenger principle - principle stating that when two tones of the same frequency are introduced simultaneously in both ears, only the louder tone will be perceived

Stenger test - test for unilateral functional hearing loss based on the Stenger principle in which signals are presented to the normal ear at suprathreshold levels and the poorer ear at a higher level; lack of a response indicates nonorganicity

stenosis - narrowing in the diameter of an opening or canal

stereocilia - stiffened, hairlike microvilli that project from the apical end of the inner and outer hair cells

stimulus - anything that can elicit or evoke a response in an excitable receptor

stria vascularis - highly vascularized band of cells on the internal surface of the spiral ligament within the scala media extending from the spiral prominence to Reissner's membrane

subjective - not physically measurable, but perceived only by the individual involved

subjective tinnitus - perception by an individual of ringing or other noise in the ear or head that is not evident to the examiner

sudden hearing loss - acute rapid-onset loss of hearing that is often idiopathic, unilateral, and substantial and that may or may not resolve spontaneously

superior semicircular canal - one of three bony canals of the vestibular apparatus containing sensory epithelia that respond to angular motion

suppression - reduction in magnitude

suppurative - pertaining to the formation of pus

suprathreshold - pertaining to an intensity level above threshold

swimmer's ear - colloquial term for diffuse red, pustular lesions surrounding hair follicles in the ear canal usually due to gram-negative

bacterial infection during hot, humid weather and often initiated by swimming

symmetric hearing loss - hearing loss that is identical or nearly so in both ears

syndrome - aggregate of symptoms and signs resulting from a single cause or occurring together commonly enough to constitute a distinct clinical entity

syntax - word order in a language

syphilis - specific congenital or acquired disease caused by the spirochete Treponema pallidum; in its secondary and tertiary stages may result in auditory and vestibular disorders due to membranous labyrinthitis

T

tactile device - hearing aid that converts sound into vibration for tactual stimulation; designed as a replacement for auditory stimulation in cases of profound deafness; vibrotactile hearing aid

tectorial membrane - gelatinous membrane within the scala media projecting radially from the spiral limbus and overlying the organ or Corti in which the cilia of the outer hair cells are embedded

telecoil - t-coil; an induction coil included in a hearing aid to receive electromagnetic signals from a telephone or a loop amplification system

telecommunication device for the deaf - TDD; telephone system used by those with significant hearing impairment in which a typewritten message is transmitted over telephone lines and is received as a printed message

telephone amplifier - any of several types of assistive devices designed to increase the intensity level output of a telephone receiver

temporal - 1. pertaining to time; 2. pertaining to the lateral portion of the upper part of the head

temporal bone - bilateral bones of the cranium that form most of the lateral base and sides of the skull, consisting of the squamous, mastoid, petrous and tympanic portions, and the styloid process

temporal lobe - portion of the cerebrum, located below the lateral sulcus and above and adjacent to the temporal bone, containing the primary auditory cortex

temporary threshold shift - TTS; transient or reversible hearing loss due to auditory fatigue following exposure to excessive levels of sound

tensor tympani muscle - along with the stapedius, one of two striated muscles of the middle ear, classified as a pinnate muscle; consisting of short fibers directed obliquely onto the stapedius tendon at the midline, innervated by the trigeminal nerve, Cranial Nerve V

teratogen - a drug or other agent or influence that causes abnormal embryologic development

tertiary - third in order

test ear - the ear under test

thalidomide - tranquilizing drug that can have a teratogenic effect on the auditory system of the developing embryo when taken by the mother during pregnancy, resulting in congenital hearing loss

threshold - level at which a stimulus or change in stimulus is just sufficient to produce a sensation or an effect

threshold shift - change in hearing sensitivity, usually a decrement, expressed in dB

timbre - the characteristic quality of a sound

time-compressed speech - speech signals that have been accelerated by the process of time compression

time-weighted average - measure of daily noise exposure, expressed as the product of durations of exposure at particular sound levels relative to the allowable durations of exposure for those levels

tinnitus - sensation of ringing or other sound in the head without an external cause

tinnitus masker - electronic hearing aid device that generates and emits broad-band or

narrow-band noise at low levels, designed to mask the presence of tinnitus

tinnitus retraining therapy - TRT; comprehensive treatment approach to tinnitus management aimed at habituation of the tinnitus

tone - a periodic sound of distinct pitch

tone burst - a brief pure tone having a rapid rise and fall time with a duration sufficient to be perceived as having tonality

tone decay - perstimulatory adaptation, in which an audible sound becomes inaudible during prolonged stimulation

tonotopic organization - topographic arrangement of structures within the peripheral and central auditory nervous system according to tonal frequency

TORCH infections - congenital perinatal infections grouped as risk factors associated with hearing impairment and other disorders, including *t*oxoplasmosis, *o*ther infections, especially syphilis, *r*ubella, *c*ytomegalovirus infection, and *h*erpes simplex

total communication - habilitative approach used in individuals with severe and profound hearing impairment consisting of the integration of oral/aural and manual communication strategies

toxin - poisonous substance

tragus - small cartilaginous flap on the anterior wall of the external auditory meatus

transcranial CROS - contralateral routing of signal (CROS) strategy for unilateral hearing loss in which a high-gain in-the-ear hearing aid is fitted to the poor ear in an effort to transfer sound across the skull by bone conduction to the cochlea of the good ear

transducer - a device that converts one form of energy to another, such as an earphone converting electrical energy to acoustic energy

transient - response of a transducer to the rapid onset or offset of an electrical signal, resulting in a short-duration, broad-band click characterized by bandwidth that increases as the duration of the electrical signal decreases

transient distortion - the inexact reproduction of a sound resulting from failure of an amplifier to process or follow sudden changes of voltage

transient evoked otoacoustic emission - TEOAE; low-level acoustic sound emitted by the cochlea in response to a click or transient auditory stimulus; related to the integrity and function of the outer hair cells of the cochlea

transient hearing loss - temporary loss of hearing sensitivity

transpositional hearing aid - hearing aid that converts high-frequency acoustic energy into low-frequency signals for individuals with profound hearing loss who have measurable hearing only in the lower frequencies

transverse fracture - a break that traverses the temporal bone perpendicular to the long axis of the petrous pyramid; usually caused by a blow to the occipital region of the skull, resulting in extensive destruction of the membranous labyrinth

transverse wave - wave in which the particles of the medium move at right angles to the direction of the wave movement

trauma - an injury produced by external force

traveling wave - sound-induced displacement pattern along the basilar membrane that describes fundamental cochlear processing; characterized by maximum displacement at a location corresponding to the frequency of the signal

tubing - tubelike portion of a hearing aid that serves as the transmission line from the receiver to the tip of the earmold

Tullio phenomenon - transient vertigo and nystagmus caused by substantial movement of the inner-ear fluid in response to a high-intensity sound, occurring commonly in congenital syphilis

tumor - abnormal growth of tissue, resulting from an excessively rapid proliferation of cells

tuning curve - graph of the frequency-resolving properties of the auditory system showing

the lowest sound level at which a nerve fiber will respond as a function of frequency, or the SPL of a stimulus that just masks a probe as a function of masker frequency

tuning fork test - any of several tests in which a tuning fork is used to assess the presence of a conductive hearing loss

tympanic cavity - one of three regions of the middle-ear cavity lying directly between the tympanic membrane and the inner ear, containing the ossicular chain

tympanic membrane - TM; thin, membranous vibrating tissue terminating in the external auditory meatus and forming the major portion of the lateral wall of the middle-ear cavity, onto which the malleus is attached

tympanic membrane perforation - abnormal opening into the tympanic membrane

tympanic membrane retraction - a drawing back of the eardrum into the middle-ear space due to negative pressure formed in the cavity secondary to eustachian tube dysfunction

tympanitis - inflammation of the tympanic membrane

tympanocentesis - aspiration of middle-ear fluid with a needle through the tympanic membrane

tympanogram - graph of middle-ear immittance as a function of the amount of air pressure delivered to the ear canal

tympanometric gradient - characterization of the shape of a tympanogram by the slope of its sides near its peak; measured as the difference between the peak and the average amplitude at ± 50 da Pa

tympanometric peak pressure - air pressure, in daPa, at which the peak of a tympanogram occurs

tympanometric width - characterization of the shape of a tympanogram, measured as the air pressure, in daPa, at half the height of the tympanogram from peak to tail

tympanometry - procedure used in the assessment of middle-ear function in which the immittance of the tympanic membrane and middle ear is measured as air pressure delivered into the ear canal is varied

tympanoplasty - reconstructive surgery of the middle ear, usually classified in types according to the magnitude of the reconstructive process

tympanosclerosis - formation of whitish plaques on the tympanic membrane and nodular deposits in the mucosa of the middle ear, secondary to chronic otitis media, that may result in ossicular fixation

Type A tympanogram - normal tympanogram with maximum immittance at atmospheric pressure

Type A_d tympanogram - deep (d) Type A tympanogram associated with a flaccid middle-ear mechanism; characterized by excessive immittance that is maximum at atmospheric pressure

Type A_s tympanogram - shallow (s) Type A tympanogram associated with ossicular fixation; characterized by reduced immittance that is maximum at atmospheric pressure

Type B tympanogram - flat tympanogram associated with increase in the mass of the middle-ear system; characterized by little change in immittance as ear canal air pressure is varied

Type C tympanogram - tympanogram associated with significant negative pressure in the middle-ear space; characterized by immittance that is maximum at a negative ear canal pressure equal to that of the middle-ear cavity

U

ultra-high frequency - refers to frequencies above the normal audiometric range beyond 8000 Hz

ultrasound - sound having a frequency above the range of human hearing, approximately 20,000 Hz

umbo - projecting center of a rounded surface, such as the end of the cone of the tympanic

membrane at the tip of the manubrium of the malleus

unaided - not fitted with or assisted by the use of a hearing aid

uncomfortable loudness level - intensity level at which sound is perceived to be uncomfortably loud

unilateral - pertaining to one side only

unilateral hearing loss - hearing sensitivity loss in one ear only

universal newborn hearing screening - the application of rapid and simple tests of auditory function, typically AABR or OAE measures, to all newborns prior to hospital discharge to identify those who require additional diagnostic procedures

unmasked - pertaining to a response obtained with no masking in the nontest ear

unoccluded - open, as the normal external auditory meatus

Usher syndrome - autosomal recessive disorder characterized by congenital sensorineural hearing loss and progressive loss of vision due to retinitis pigmentosa

utricle - larger of the two sac-like structures in the vestibule containing a macula that is responsive to linear acceleration, particularly to the accelerative forces of gravity experienced during body or head tilt

V

validity - the extent to which a test measures the nature of a trait

Valsalva maneuver - attempt to force open the eustachian tube by blowing with the nostrils and mouth closed

vascular - pertaining to blood vessels

vent - bore made in an earmold or hearing aid that permits the passage of sound and air into the otherwise blocked external auditory meatus; used for aeration of the canal and/or acoustic alteration

ventricle - a normal cavity in the brain

vertigo - a form of dizziness, describing a definite sensation of spinning or whirling

vestibular - pertaining to the vestibule

vestibular aqueduct - small canal in the medial wall of the vestibule containing the endolymphatic duct

vestibular dysfunction - abnormal functioning of the vestibular mechanism

vestibular labyrinthitis - inflammation of the vestibular labyrinth

vestibular nerve - portion of Cranial Nerve VIII consisting of nerve fibers from the maculae of the utricle and saccule and the cristae of the superior, lateral, and posterior semicircular canals

vestibular rehabilitation - comprehensive management approach to treating balance disorders

vestibular Schwannoma - benign encapsulated neoplasm composed of Schwann cells arising from the vestibular portion of Cranial Nerve VIII; SYN: cochleovestibular Schwannoma, acoustic neuroma, acoustic tumor

vestibular system - biological system that, in conjunction with the ocular and proprioceptive systems, functions to maintain equilibrium

vestibule - ovoid cavity forming the central portion of the bony labyrinth continuous with the semicircular canals and cochlea, that contains the utricle and saccule and communicates with the tympanum through the oval window

vestibulo-ocular reflex - VOR; reflex arc between the vestibular system and extraocular muscles, activated by asymmetric neural firing rate of the vestibular nerve, serving to maintain gaze stability by generating compensatory eye movements in response to head rotation

vestibulopathy - degeneration of the vestibular labyrinth, particularly with aging, resulting in motion-induced vertigo

vestibulotoxic - having a poisonous action on the hair cells of the cristae and maculae of the vestibular labyrinth

vibration - vibratory motion

vibrotactile - pertaining to the detection of vibrations via the sense of touch

vibrotactile hearing aid - device designed for profound hearing loss in which acoustic energy is converted to vibratory energy and delivered to the skin

vibrotactile response - in bone-conduction audiometry, a response to a signal that was perceived by tactile stimulation rather than auditory stimulation

video otoscopy - endoscopic examination of the external auditory meatus and tympanic membrane displayed on a video monitor

visual alerting systems - household devices such as alarm clocks, doorbells, and fire alarms in which the alerting sound is replaced by flashing light

visual reinforcement audiometry - VRA; audiometric technique used in pediatric assessment in which a correct response to signal presentation, such as a head turn toward the speaker, is rewarded by the activation of a light or lighted toy

volume control - VC; manual or automatic control designed to adjust the output level of a hearing instrument

W

Waardenburg syndrome - autosomal dominant disorder characterized by lateral displacement of the medial canthi, increased width of the root of the noise, multicolored iris, white forelock, and mild to severe sensorineural hearing loss

warble tone - frequency-modulated pure tone, often used in sound field audiometry

wave - orderly disturbance of the molecules of a medium caused by the vibratory motion of an object; propagated disturbance in a medium

waveform - form or shape of a wave, represented graphically as magnitude as a function of time

waveform morphology - in auditory brainstem response measure, the overall quality and reproducibility of an averaged response

wavelength - length of a sound wave; defined as the distance in space that one cycle occupies

Weber test - test in which a tuning fork or bone vibrator is placed on the midline of the forehead; lateralization to the poorer-hearing ear suggests the presence of a conductive hearing loss, lateralization to the better ear suggests sensorineural hearing loss

weighting scale - sound level meter filtering network, such as the dBA scale, that is based on emphasizing the measurement of one range of frequencies over another

Wernicke's area - in early classification system, term for the cortical region in the temporal lobe responsible for reception of oral language

white noise - broad-band noise having similar energy at all frequencies

wide-dynamic-range compression - WDRC; hearing aid compression algorithm, with a low threshold of activation; designed to deliver signals between a listener's thresholds of sensitivity and discomfort in a manner that matches loudness growth

word recognition - the ability to perceive and identify a word

word-recognition score - WRS; percentage of correctly identified words

word-recognition test - speech audiometric measure of the ability to identify monosyllabic words, usually presented in quiet

X

X-linked hearing disorder - hereditary hearing disorder due to a faulty gene located on the X chromosome, such as that found in Alport syndrome or Hunter syndrome

X-linked inheritance - any genetic trait related to the X chromosome; transmitted by a mother to 50% of her sons, who will be affected, and 50% of her daughters, who will be carriers; transmitted by a father to 100% of his daughters

Index

A

AAA (American Academy of Audiology), 4, 31
ABA (American Board of Audiology), 28, 34
Abbreviated Profile of Hearing Aid Benefit (APHAB), 543, 646–647, 646f
ABR. *See* Auditory brainstem response
Absolute sensitivity, 81–82. *See also* Differential sensitivity; Hearing sensitivity; Threshold of audibility
Absolute threshold. *See* Threshold of audibility
Accessory auricle, 139
Accreditation, 33, 34
Acoustic feedback, 597, 598
Acoustic reflex threshold, 327–333. *See also* Immittance audiometry
  decay test, 330, 331f, 332
  in functional hearing loss assessment, 467
  interpretation of, 329, 330f, 332, 333
  measurement of, 328–330
  overview, 75, 327–328, 345
  reflex arc, defined, 345–346
  suprathreshold analysis of, 330–331
Acoustic trauma, 137. *See also* Noise-induced hearing loss
Acoustic tumors. *See also* Retrocochlear disorder
  auditory symptoms of, 179, 215–216
  cochleovestibular schwannoma, 179–181, 215
  hearing loss resulting from, 103, 111–112, 112f, 179–180, 180f
  overview, 138, 180
Acquired ototoxicity, 167
Acquired sensory hearing disorders, 159–177
Activity limitations, 220, 221
Admittance, 317
Adults
  audiologic referrals of, 427–428
  case histories for, 203, 206
  evaluation of older, 431–437, 435f, 436f, 437f
  evaluation of younger, 428–431, 432f, 433f
  functional hearing loss in, 463–434
  progressive adult-onset hearing loss, 159
  sensorineural hearing loss in, 657–661, 660f, 661f
  speech audiometry for, 274
  treatment strategies for, 657–661, 660f, 661f
AEP. *See* Auditory evoked potentials
Afferent abnormalities, 346, 348f
Age of onset of hearing loss, 118
Air-bone gap, 105, 215, 264–265, 314–315
Air-conduction pure-tone audiometry. *See also* Air-conduction threshold; Earphones; Pure-tone audiometry
  defined, 244–245
  interaural attenuation, 259, 260t
  masking, 246, 261–265
Air-conduction threshold. *See also* Air-bone gap
  in conductive hearing loss, 89, 91f, 104–105, 215, 250–252, 314–315, 539
  in mixed hearing loss, 109, 110f, 251f, 252
  in normal hearing, 87–88, 89f
  plotting on audiogram, 244–246, 245f, 249–250
  in sensorineural hearing loss, 88–90, 106, 107f, 215, 250–252, 256, 314–315
Alerting devices, 606
Alexander aplasia, 155
Alport syndrome, 157
Alternate binaural loudness balance (ABLB) test, 303
American Academy of Audiology (AAA), 4, 31
American Academy of Otolaryngology, 520
American Board of Audiology (ABA), 28, 34
American National Standards Institute (ANSI)
  audiogram symbol standards, 246
  calibration standards, 93–95, 238

hearing aid output standards, 630
hearing level standards, 85
noise level standards, 242
American Speech-Language-Hearing Association (ASHA)
audiogram symbol standards, 246
Certificate of Clinical Competence in Audiology, 28, 30, 34
definition of audiologist, 4
policy on hearing aid dispensing, 24
Aminoglycosides, ototoxicity of, 167–168, 186
Amplification. *See also* Hearing aids
challenges of, 546–549, 548f
differential, 361
linear, 564, 564f, 570, 570f, 579–581, 581f
nonlinear, 565, 570, 571f, 579, 581–584, 583f
situation-specific, 535
technological advances in, 29, 563–565, 564f
Amplifiers, hearing aid, 566, 566f, 568–572
Amplifiers, personal, 600
Amplitude, 47f, 330
Ampulla, 77, 77f, 78f, 79–80
Analog hearing aids, 585–586, 586f
Annular ligament, 60
Anotia, 139
ANSI. *See* American National Standards Institute
APD. *See* Auditory processing disorder
Articulation index, 300–302
ASHA. *See* American Speech-Language-Hearing Association
Assistive listening devices (ALDs), 600–606
ASSR. *See* Auditory steady-state response
Ataxia, 186
Atresia, 139–141, 140f
Attention deficit disorder (ADD), 113
Attenuation, 103, 105. *See also* Interaural attenuation
Attenuators, 237, 237f
Au.D., 26, 27, 28, 31, 33
Audibility. *See* Threshold of audibility
Audibility index, 300–302
Audiogram report, 489, 504–508, 506f, 507f, 508f
Audiograms, pure-tone. *See also* Air-conduction pure-tone audiometry; Audiometric configuration; Bone-conduction pure-tone audiometry
air- and bone-conduction, 244–246, 245f
and configuration of hearing loss, 247–248, 249f
defined, 84
and degree of hearing loss, 247, 248f
history of, 29
and interaural symmetry, 248, 250f
overview, 84–89, 243–244
patient preparation for, 253–254
symbols, 246–247, 246f
and type of hearing loss, 248–252, 251f
in workplace screenings, 228
Audiologic management, 530–532
Audiologic referrals
evaluating adults, 427–428
evaluating pediatric patients, 445, 447, 449–450
lines of referral, 516–520
secondary, 518–519
sources of, 199–201
Audiologists
professional requirements of, 27–28, 33–35
roles of, 3–10, 19–20, 76
types of practices, 10–19
Audiology
history of, 2–3, 25–33
related professions, 19–25
Audiometers, pure-tone, 228, 236–238, 237f, 238f
Audiometric configuration. *See also specific hearing disorders*
of aging men and women, 174, 174f
and amplification challenges, 547–548, 548f
of conductive hearing loss, 105, 249–252, 251f
of mixed hearing loss, 251–252, 251f
patterns of, 121, 122f, 247–248, 249f
reporting, 495–496, 496t
of sensorineural hearing loss, 106–107, 107f, 250–252, 251f
and speech sound audibility, 119, 121–125, 124f, 125f, 126f
Audiometric zero
defined, 84, 85f
standard output levels for (RETSPL), 95, 95f
Audiometry. *See also specific audiometric measures*
calibration standards, 93–95
history of, 31–32
Auditory adaptation, 128, 304–305
Auditory brainstem response (ABR)
automated (AABR), 441
clinical applications of, 370, 378–380
in cochlear disorder evaluation, 413, 416
discovery of, 31
frequency components of, 362
impact on infant screening success, 358
in infant screening, 224–227, 366, 372–374, 374f, 377–378, 441
in older children, 451
overview, 9–10, 357, 366, 367f, 379
rapid threshold prediction technique, 372–374, 374f
reporting results, 501t, 505–508, 508f

in young children, 449
Auditory cortex, 73, 74f
Auditory evoked potentials (AEPs). *See also* Auditory brainstem response; Auditory steady-state response; Late latency response
in auditory processing disorder evaluation, 368, 456, 459–460, 471–472
in central auditory nervous system evaluation, 216–217, 358, 378–381
in cochlear disorder evaluation, 366, 410
electrocochleogram, 357, 365–366, 365f, 381
in hearing sensitivity evaluation, 213, 371–376
in infant screening, 376–378 (*See also under* Auditory brainstem response)
measurement of, 359–364, 360f
middle latency response, 357, 367–368, 380–381
overview, 200, 357–359
in pediatric assessment, 358, 372, 449
reporting results, 499–500, 505–508, 508f
in retrocochlear disorder evaluation, 419, 426, 427f
in surgical monitoring, 10, 358–359, 370–371, 381–382
Auditory labyrinth. *See* Cochlea
Auditory nervous system, 71–76, 81. *See also* Central auditory nervous system; Peripheral auditory nervous system
Auditory neuropathy, 138, 177–186, 215–216, 277
Auditory pathology, 136–138
Auditory processing ability
assessment of, 115, 219, 277–278
defined, 218
reporting assessment results, 502
speech processing, 75, 182
Auditory processing disorder (APD)
in children, 113
and chronic otitis media, 146
in elderly patients, 115–116, 129
and hearing aid candidacy, 549
impact of, 129
overview, 23, 111, 113–116, 114t
treatment strategies for children, 673–678, 677f, 678f
Auditory processing disorder (APD), assessment of
with auditory evoked potentials, 368, 456, 459–460, 471–472
diagnostic challenges, 454–456
with immittance audiometry, 460, 461f
overview, 456–462, 457t, 459f, 461f, 463f, 464f
with speech audiometry measures, 115, 456, 457–459, 457t, 459f
Auditory response area, 83–84, 83f
Auditory steady-state response (ASSR)
in functional hearing loss assessment, 472
in infant assessment, 358, 370, 372, 374–375, 375f
overview, 358, 368–370, 369f
Auditory system, 55–76, 56f
Auditory training, 6, 647–648
Auricle, 56–57, 57f, 138–141, 139, 143
Auricular aplasia, 139
Autoimmune inner-ear disease (AIED), 175, 176f
Automatic gain control (AGC), 584

B

Background noise, 115–116, 125, 129. *See also* Competing noise
BAHA devices. *See* Bone-anchored hearing aids
Balance disorders, 76
Balance system, 76
Baldocchi, Kate, 252
Barotrauma, 152
Basal-cell carcinoma, 143
Basilar artery, 65, 73
Basilar membrane, 63–64, 66
BBN (broad-band noise), 341
Behavioral measures, 5, 303–305, 306, 440, 446, 448–449. *See also* Speech audiometry
Behavioral verification of electroacoustic characteristics, 639–642
Behind-the-ear (BTE) hearing aids
acoustic feedback reduction in, 597
for adult sensorineural hearing loss, 658
directionality in, 599
ear impressions for, 629–630
FM couplers for, 603, 603f
overview, 553, 591–594, 591f, 592f, 593f, 594f
for pediatric sensorineural hearing loss, 668, 669, 671–672
for permanent conductive hearing loss, 680–682, 683f
for severe and profound sensorineural hearing loss, 685–686
Békésy audiometry, 305
Bell, Alexander Graham, 49
Benign paroxysmal positional vertigo (BPPV), 184–185
Binaural advantage, 551
Bing Siebenmann malformation, 155
Bing test, 266–267
Body-worn hearing aids, 563
Bone-anchored hearing aids (BAHAs)
overview, 612–613, 612f

for permanent conductive hearing loss, 606, 679–680, 681–684, 683f
for single-sided deafness, 606
Bone-conduction pure-tone audiometry. *See also* Pure-tone audiometry
contributing factors, 258
defined, 245
interaural attenuation in, 260
masking, 246, 262–265
Bone-conduction threshold. *See also* Air-bone gap
in conductive hearing loss, 104–105, 104f, 215, 314–315, 539
contributing factors, 258
diagnostic information from, 256–257
in mixed hearing loss, 109, 110f
in normal hearing, 88, 89f
in otosclerosis, 150, 151f
plotting on audiogram, 244–246, 245f, 249–250
in sensorineural hearing loss, 88–89, 90f, 106, 107f, 215, 250–252, 251f
Bone-conduction vibrators, 94–95, 237, 241, 241f, 257, 260
Bone disorders, 137
Bony atresia, 139
Bony labyrinth
anatomy and physiology of, 61, 62f, 76, 77
and cholesteatoma, 149
effect of otosclerosis on, 150
malformations of, 154
Borden General Hospital (Oklahoma), 29, 30
Brainstem, auditory, 9, 306
Brainstem disorders
glioma, 138
identifying with auditory evoked potentials, 329, 331, 378–380
immittance patterns for, 349–350, 350f
infarcts, 181
lesions, 103, 111, 299
overview, 181–182
Branchio-oto-renal syndrome, 157
Broad-band noise (BBN), 341
BTE hearing aids. *See* Behind-the-ear hearing aids
Bunch, C. C., 29

C

CAA (Council on Academic Accreditation), 33
Carcinomas, 143
Carhart, Raymond, 29–30, 150, 254, 290
Carrier phrase, 286, 291
Case history, 201–205, 494–495, 538
CCC-A (Certificate of Clinical Competence in Audiology), 27–28
Central auditory nervous system. *See also* Neural hearing disorders
effect of changes in, 111, 115, 177–178, 215
evaluating with auditory evoked potentials, 216–217, 358, 378–381
evaluating with speech audiometry, 277–278
function of, 218
intrinsic redundancy of, 280, 282, 282t
overview, 3, 72–76, 74f
Central Institute for the Deaf (CID) sentence test, 280
Central pathway abnormalities, 346, 349–350, 350f
Central perforation of tympanic membrane, 148
Cerebellopontine angle, 180
Cerebral artery, middle, 73
Cerebrovascular accidents, 21, 182
Certificate of Clinical Competence in Audiology (CCC-A), 27–28
Cerumen, 9, 58, 141, 142f, 208–209
Ceruminosis, 141
Cervico-oculo-acoustic syndrome, 157
CHARGE association, 157
Chemicals, ototoxic, 137, 161, 167–169, 169f
Chemotherapy, 14, 168, 169f, 391
Children
case histories for, 204, 206–207
developmental expectations, 522–523
and hearing aids, 532
impacted cerumen in, 141
rehabilitation approaches for, 532, 648–649
school-age screening, 15–16, 237–238
treatment strategies for, 666–678, 671f, 672f, 677f, 678f
Children, evaluation of
with acoustic reflex threshold, 342–343, 343f
with auditory brainstem response, 366, 449, 451
with auditory evoked potentials, 358, 372, 449
and auditory processing concerns, 198
with auditory steady-state response, 449
with behavioral measures, 448–449, 450
challenges, 437–438
with conditioned play audiometry, 450
cross-check principle, 451–452
goals, 444
with immittance audiometry, 448, 449, 450
with otoacoustic emissions, 390–391, 447–448, 449, 450
sample reporting strategy, 511, 513f, 514f, 515f
with speech audiometric measures, 274, 284–285, 288, 450

young children, 447–449, 447f, 452–454, 453f, 454f, 455f
Children, hearing disorders in
auditory processing disorder, 113, 673–678, 677f, 678f
nonsyndromic, 158
otitis media, 143, 144–147
Children, hearing loss in
conductive, 127, 141
functional, 463–464
sensorineural, 666–673, 667, 671f, 672f
Cholesteatoma, 140, 149–150, 149f
Circumaural earphones, 239
Cleft pinna, 139
Client Oriented Scale of Improvement (COSI), 543
Clinical audiometers, 236, 237–238
Clinics, hearing and speech, 15
Closed captioning, 606
Closed-fit technique for BTE hearing aids, 553
Closed-set speech materials, 284
CMV (cytomegalovirus), 155
Co-articulation, 125
Cochlea
anatomy and physiology of, 61–65, 62f, 64f, 65f, 66f
evaluating function with otoacoustic emissions, 389
monitoring function during chemotherapy, 391
Cochlear artery, 65
Cochlear disorders. *See also* Site-of-lesion prediction
amplification for, 549
cochlear neuritis, 181
cochlear otosclerosis, 176, 177f
and evaluation of auditory nervous system processing, 283
inner-ear anomalies, 153–156
recruitment in, 128
Cochlear disorders, evaluating
with acoustic reflex thresholds, 328–329, 330, 330f
with auditory evoked potentials, 366, 410
goals, 408
illustrative cases, 410–416
with immittance audiometry, 339–341, 342–345, 408–409
with otoacoustic emissions, 410
with pure-tone audiometry, 409
with speech audiometry, 276, 410
Cochlear implants
audiologist's role in treatment, 6
candidacy criteria for, 684–685
external components of, 609–610, 611f
fitting and verification of, 685, 686f, 687
history of, 31, 32–33
internal components of, 608–609, 609f, 610f
outcome measurement for, 687, 690, 690f, 691, 692f
overview, 5, 6, 530, 606–611
rehabilitative treatment plans for, 688
signal processing in, 611
technological advances in, 607–608, 607f
Cochlear microphonic response (CM), 365
Cochlear nerve action potential (CNAP), 381–382
Cochlear neurons, 71, 72f, 173
Cochlear nucleus, 72–75, 74f
Cochlear partition, 63, 64f
Cochleovestibular schwannoma
evaluation of, 419–422, 420f, 421f, 422f, 423f
overview, 179–180, 215
Coloboma lobuli, 139
Common-cavity malformation, 154
Common-mode rejection, 361
Communication demands on patients, 118–119, 428, 532
Communication needs assessment
in audiologic evaluation, 206, 430
for older adults, 436
in treatment assessment, 540–545, 627
for younger adults, 431
Compensatory strategies, 118
Competing noise, 125, 280, 283, 283t, 295–297
Completely-in-the-canal (CIC) hearing aids
advantages of, 599
ear impressions for, 629
overview, 553, 595–596, 596f
technological advancement of, 564, 564f
Compound action potential (AP), 365
Compression
across dynamic range, 581–584, 583f
of maximum output, 571–572, 572f, 581, 584–585
Condensation, 43, 45f, 47f
Conditioned play audiometry, 450–451
Conductive hearing disorders, 138–153
Conductive hearing loss
assessment of, 89, 91f, 104–105, 215, 250–252, 314–315, 539
audiometric configuration of, 105, 249–252, 251f
in children, 127, 141
degree of, 105

effect on air- and bone-conduction thresholds, 89, 91f, 104–105, 104f, 250–252, 251f
impact of, 126–127
medical treatment for, 531
overview, 102–105, 214
speech recognition in, 105
treatment strategies for permanent, 531, 679–684, 682f, 683f
Conductive hearing loss, causes of
atresia, 139–141, 140f
cholesteatoma, 149–150, 149f
glomus tumors, 152–153
impacted cerumen, 141, 142f
otitis media with effusion, 143–144, 146, 147f
otosclerosis, 150–151, 151f
tympanic membrane perforation, 148, 148f
tympanosclerosis, 150, 400
Congenital hearing disorders, 118, 153–159
Connected Speech Test, 280
Continuous discourse, 278
Contralateral reflexes, 328, 332
Contralateral routing of signals (CROS), 552
Contralateral suppression, 391
Controls, hearing aid, 573–577, 575f
Conversion disorders, 116f, 117
Council on Academic Accreditation (CAA), 33
Count-the-dots procedure, 300, 301f
Cranial nerves. *See* VIIIth cranial nerve; VIIth cranial nerve
Crista, 79
Crossed reflex threshold, 328, 332
Crossover, 258–259
Cupula, 79, 80
Cycle, 46, 51
Cytomegalovirus (CMV), 155

D

Davis, Hallowell, 30
Decruitment, 128, 303
Degrees of hearing loss
audiogram description of, 247, 248f
conductive, 105
hearing sensitivity, 119–126, 119t, 485t
reporting, 495–496, 496t
sensorineural, 106
speech recognition, 275
Delayed auditory feedback test, 468
Deshon General Hospital (Pennsylvania), 29
Desired sensation level (DSL), 624
Developmental defects, 136–137
Diabetic cranial neuropathy, 181
Diagnostic audiology, 30–32, 216–217
Diagnostic Békésy audiometry, 305
Dichotic measures, 115, 283, 283t, 297–298, 457
Dichotic Sentence Identification (DSI) test, 298
Dichotic stimuli, 115, 219
Difference limen, 82, 89, 90–91, 92f
Differential amplifiers, 361
Differential diagnosis, 277
Differential sensitivity, 82, 89, 90–91, 92f
Differential threshold. *See* Difference limen
Digital signal processing (DSP), 585, 586–589, 586f, 587f, 624
Direct audio input (DAI), 567
Distortion, 95
Distortion-produced otoacoustic emissions (DPOAE), 384, 386–388, 387f, 388f, 389, 391
Documenting test results, 488–489
Dominance, right-ear, 75
Dominant hereditary hearing loss, 159
Dominant progressive hearing loss, 159
Drugs, ototoxic, 136, 137, 155, 156, 161, 167
Dynamic range
broadness of, 81
compression, 582–584, 583f
defined, 76
and nonlinear amplification, 581–582
normal, 108
in sensorineural hearing loss, 108, 109f
and threshold of discomfort, 540
use in word-recognition testing, 293–294

E

Eardrum. *See* Tympanic membrane
Ear impressions, 9, 628–630
Earlobe, 56–57, 57f, 139
Early hearing detection and intervention (EHDI), 224, 226
Earmolds, 592, 592f
Earphones. *See also* Air-conduction pure-tone audiometry; Insert earphones; Supra-aural earphones
calibration of, 94–95
and minimum audibility curve, 83
output levels of, 237
placement of, 241
types of, 239–241, 239f, 240f
ECoG (electrocochleogram), 357, 365–366, 365f, 381
Education
accreditation of programs, 33, 34
of audiologists, 27, 33, 34–35
audiologists' roles in, 7, 16

EEG (electroencephalography), 359–362, 361f
Efferent abnormalities, 346–348, 349f
Effusion, 143, 144
EHDI (early hearing detection and intervention), 224
VIIIth cranial nerve. *See also* Auditory brainstem response
  anatomy of, 76, 79
  location of, 57f
  monitoring function during surgery, 10, 358–359, 370–371
  physiology of, 62, 70, 71, 80
VIIIth cranial nerve disorders
  evaluating with acoustic reflex thresholds, 329, 330, 331
  evaluating with auditory brainstem response, 358, 378–380
  impact of, 128–129
  tumors, 179–181, 180f, 299
Elderly patients. *See also* Adults
  assessing impact of hearing loss, 543
  auditory processing disorder in, 115–116, 129
  nonsyndromic hearing disorders in, 158
  presbyacusis in, 171–175, 174f
  speech audiometry for, 274–275
  treatment strategies for, 661–666, 665f
  using auditory steady-state response with, 375–376
Electrocochleogram (ECoG), 357, 365–366, 365f, 381
Electronystagmography (ENG), 9
Electrophysiologic measures. *See also* Auditory brainstem response; Auditory evoked potentials; Electrocochleogram; Late latency response; Middle latency response; Otoacoustic emissions
  history of, 32
  reporting results of, 499–500, 501t
  use in hearing assessment, 9
Endolymph, 63, 64, 79
Endolymphatic hydrops, 171, 413–415, 414f
ENG (electronystagmography), 9
EOAEs (evoked otoacoustic emissions), 384–388, 385f
Epidemic parotitis (mumps), 166
Epidermoid carcinoma, 143
Ethics of referrals, 516–520
Eustachian tube, 57f, 59, 143–144, 152, 210, 322
Evaluation, audiologic
  overview, 5, 197–199, 399–400
  role in treatment, 533, 538–540
  technological advances in, 29
Evoked otoacoustic emissions (EOAEs), 384–388, 385f
External auditory meatus, 57–58
Extrinsic redundancy in speech communication, 281–283, 282t, 283t
Eye-glass hearing aids, 563

F

Facial nerve disorders, 346–348, 349f
Factitious hearing loss, 116f, 117, 464
Fairbanks, Grant, 30
Family referrals, 199–200
Federal Trade Commission (FTC), 33
Feedback suppression, 589. *See also* Acoustic feedback
Fenestral malformations, 140
Filtering systems in hearing aids, 569, 569f
Fitting range of hearing aids, 573, 574f
Follow-up visits, 645, 646
Frequency, difference limen for, 90–91, 92f
Frequency, signal
  and basilar membrane movement, 66–68, 69f
  coding by VIIIth cranial nerve, 71
  effect on hearing sensitivity, 82–84, 83f, 86f
  overview, 47, 47f, 48f, 51
  and pitch, 93
Frequency response
  of hearing aid amplifiers, 554–555, 572, 577–579, 578f, 579f
  of hearing aid receivers, 573
FTC (Federal Trade Commission), 33
Functional gain, 556, 640
Functional hearing loss
  assessment of, 343–345, 392, 467–475, 470f
  indicators of, 465–467
  overview, 101, 116–117, 116f, 462–465

G

Gain
  overview, 554–555, 577–579, 578f, 579f
  verification of real-ear, 635–637
Geriatric patients. *See* Elderly patients
Gerontology, 22
Glasgow Hearing Aid Benefit Profile (GHABP), 543–544, 647
Gliomas, 182
Glomus tumor, 152–153
Group practices, 13

H

Hair cells, auditory. *See* Inner hair cells; Outer hair cells
Hair cells, vestibular, 77, 78f, 80, 80f, 183–186
Half-gain rule, 554
Hardy, William G., 30

Hearing acuity. *See* Differential sensitivity
Hearing aid analyzers, 630–631, 631f
Hearing aids. *See also* Amplification; Bone-anchored hearing aids
  analog, 585–586, 586f
  binaural, 531, 551
  components of, 566–577, 566f
  conventional, 589–599
  durability of, 599
  electroacoustic characteristics of, 577–586
  history of, 530
  signal processing in, 586–589, 586f, 587f
  styles of, 553, 590–596
  technological advances in, 29, 31, 32, 563–565, 564f
Hearing aids, dispensing
  by audiologists, 8–9, 24, 31
  by nonaudiologists, 24–25
  process of, 531–532
  requirements for, 28, 34
Hearing aids, fitting and verification. *See also* Hearing aids, selecting
  amplification strategies, 550–554
  assessing candidacy, 531, 532–533, 542f, 546–549
  assessing patients' communication needs, 536–537, 540–545, 627
  discussing cost, 545, 627
  fitting to patient, 573, 574f, 627–630, 634–635
  inspecting, 630–631, 631f
  orientation, 642–645
  overview, 550–555, 622
  prescribing gain, 622–626, 625f
  prognosis for use, 212, 217, 534, 644
  programming, 631–634, 632f, 633f
  verifying electroacoustic output, 635–642
Hearing aids, outcome measurement
  for adult sensorineural hearing loss, 661
  for geriatric sensorineural hearing loss, 663
  overview, 556–557, 645–647
  for pediatric auditory processing disorder, 675
  for pediatric sensorineural hearing loss, 670, 673
Hearing aids, selecting. *See also* Hearing aids, fitting and verification
  adult sensorineural hearing loss, 657, 658, 659, 660, 660f, 661f
  geriatric sensorineural hearing loss, 662–663, 665–666, 665f
  for interaural asymmetry, 552
  overview, 621–622, 626–627
  pediatric auditory processing disorder, 675
  pediatric sensorineural hearing loss, 667, 668–669, 669–670, 671–672, 672f, 673
  permanent conductive hearing loss, 679–680, 680–681, 683f
  style considerations, 597–599
Hearing assistive technology (HAT), 600–615
Hearing disability, 220
Hearing disorders. *See also* Functional hearing loss; Hearing loss; Hearing sensitivity loss; Suprathreshold hearing loss
  congenital, 118, 153–159
  hereditary, 136, 150–151, 156–157, 158–159, 158f
  impact of, 117–129
Hearing handicap, 101–102, 220
Hearing Handicap Inventory for the Elderly (HHIE), 543, 646
Hearing impairment, 220
Hearing in Noise Test (HINT), 296–297
Hearing instrument manufacturers, 17–18
Hearing instruments. *See* Hearing aids; Hearing assistive technology; Microphones, remote
Hearing level (HL) scale, 51, 84–86, 85f, 86f, 243
Hearing loss. *See also* Functional hearing loss; Hearing sensitivity loss; Suprathreshold hearing loss
  causes of, 136–138
  congenital, 118, 153–159
  determining type of, 214–217
  hereditary, 159
  idiopathic, 113
  measuring impact of, 219–221
  prevention of, 7
  reporting, 495–496, 496t
  risk factors for, 159–160, 224, 225t, 439–440
Hearing range, human, 51
Hearing sensitivity. *See also* Threshold of audibility
  absolute, 81–82
  defined, 81–82, 212
  differential, 82, 89, 90–91, 92f
  normal, 119
  and otoacoustic emissions, 388–389
Hearing sensitivity, assessment of, 212–213, 371–376, 401. *See also* Auditory evoked potentials; Pure-tone audiometry; Speech recognition-threshold measurement
Hearing sensitivity loss. *See also* Conductive hearing loss; Mixed hearing loss; Sensorineural hearing loss
  degree and configuration of, 119–121, 120f, 122f
  impact on communication, 121–126
  overview, 101, 102–110

Hearing threshold. *See* Threshold of audibility
Helicotrema, 63
Hereditary hearing disorders, 136, 150–151, 156–157, 158–159, 158f
Herpes zoster oticus, 166
Hirsch, Ira, 30
HIV, 155
HL (hearing level) scale, 51, 84–86, 85f, 86f, 243
Hoff General Hospital (California), 29
Hospitals, audiologists in, 14–15

I

Idiopathic sudden sensorineural hearing loss, 177
IL (intensity level), 49, 292–293
Immittance, 317, 325–327, 329
Immittance audiometry. *See also* Acoustic reflex threshold; Static immittance; Tympanometry
  as cross-check for pure-tone audiometry, 314, 315
  history of use, 31, 211–212, 314–315
  instruments for, 315–317, 316f
  interpretation of, 331–332
  overview, 211–212, 317–318
  reporting results of, 498t, 505, 507f
  in school-age screening, 227–228
  in treatment assessment, 539
Immittance audiometry, clinical applications of
  auditory processing disorder evaluation, 460–461
  cochlear disorder evaluation, 339–345, 408–409, 410–412
  functional hearing loss evaluation, 472, 473f
  outer- and middle-ear disorder evaluation, 333–338, 333t, 401–403
  retrocochlear disorder evaluation, 345–350, 417, 419–421
Immittance meters, 315–317, 316f
Immune system disorders, 138
Impedance audiometry. *See* Immittance audiometry
Implantable hearing technology, 606–615. *See also* Bone-anchored hearing aids; Cochlear implants
Incudomaleolar joint, 61
Incudostapedial joint, 151
Incus, 60f, 151
Industry
  audiologists in, 18–19
  damage-risk criteria for, 161, 162t
  noise measurement in, 94
  ototoxins in, 137, 161, 169
Inertial bone conduction, 258
Infants
  evaluation of, 213, 437–443, 445–446, 445f
  nonsyndromic hearing disorders in, 158
  risk for hearing loss in, 159–160, 224, 225t, 439–440
  use of high-frequency tympanograms for, 323–325, 326f
Infant screening and assessment
  auditory brainstem response, 358, 366, 370–374, 374f, 377–378, 441
  with auditory steady-state response, 358, 370, 372, 374–375, 375f
  with behavioral measures, 440, 446
  with combined methods, 445–446
  false results, 378
  with high-frequency tympanograms, 323–325, 326f
  history of, 32, 377–378
  with otoacoustic emissions, 227, 389–390, 441–442, 445–446
  overview, 224–227, 376, 438–439
Infections, 136–137, 155–156, 165–167
Inferior colliculus, 73, 74f
Inferior pontine syndrome, 181
Inferior vestibular nerves, 79
Inner ear
  anatomy of, 57f, 61–65, 62f, 63f, 64f, 65f, 66f
  anomalies of, 153–156
  autoimmune inner-ear disease (AIED), 175, 176f
  Ménière's disease, 138, 170–171, 186
  physiology of, 41, 66–70, 69f
Inner hair cells
  anatomy of, 64, 65f, 66f, 68f
  changes in, 173
  physiology of, 67–70, 69f
Input-output characteristics of hearing aids
  linear, 564, 564f, 570, 570f, 579–581, 581f
  nonlinear, 565, 570, 571f, 579, 581–584, 583f
  overview, 577, 579–585, 580f
Insert earphones
  interaural attenuation of, 241, 259, 260, 260t
  overview, 239–241, 239f, 256
  placement of, 254
Intensity, difference limen for, 90–91, 92f
Intensity, sound
  overview, 46, 84–86, 86f, 93
  range of, 47–49, 48f, 51
Intensity level (IL), 49, 292–293
Interaural asymmetry, 552
Interaural attenuation, 259–260, 260t, 261
Interaural symmetry, 248, 250f
Internal auditory artery, 65
Internal auditory meatus, 65

International Organization for Standardization (ISO), 93–94
International Outcome Inventory for Hearing Aids (IOI-HA), 544, 647
Interrupter switches, 237, 237f
In-the-canal (ITC) hearing aids, 553, 594–596, 595f, 596f, 599
In-the-ear (ITE) hearing aids
  directionality in, 599
  ear impressions for, 630
  FM couplers for, 603, 603f
  for geriatric patients with sensorineural hearing loss, 662
  overview, 553, 591, 594–596, 595f, 596f
Intrinsic redundancy, 280, 282, 282t
Ipsilateral reflexes, 328
Irrigation, 209
ISO (International Organization for Standardization), 93–94
ITC (in-the-canal) hearing aids, 553, 594–596, 595f, 596f, 599
ITE hearing aids. *See* In-the-ear hearing aids

J

Jerger, James, 30–31, 254
Jervell and Lange-Nielsen syndrome, 167
Johnson, Kenneth O., 30
Just noticeable difference. *See* Difference limen

K

Kim, Don, 628
Kinocilia, 77, 78f, 80

L

Labyrinthine artery, 65
Labyrinthitis, 165, 167, 181, 346, 347f
Large vestibular aqueduct syndrome, 154
Late latency response (LLR)
  in auditory processing ability assessment, 380–381
  in functional hearing loss assessment, 472
  overview, 357, 368, 370
  use with older patients, 375–376
Lateral inferior pontine syndrome, 181–182
Lateralizing sound, 115
Lateral lemniscus, 72, 73, 74f
Learning disabilities, 113, 146
Lesions, 103, 111–112, 298–299, 299t. *See also* Retrocochlear disorder; Tumors
Letter report, 489–490
Licensure, 28, 33–34
Lines of referral, 516–520
LLR. *See* Late latency response
Lobule, 56–57, 57f, 139
Lombard voice intensity test, 468
Loudness, 93, 105, 109f, 127–128. *See also* Dynamic range; Hearing sensitivity loss; Intensity; Recruitment; Suprathreshold hearing
Loudness judgment ratings, 640
Loudspeakers, 83, 239. *See also* Receivers, hearing aid
Low-pass filtering, 282–283, 283t, 295
Low-set ears, 139

M

Macrotia, 139
Maculae, 79
Magnetic resonance imaging (MRI), 216, 379
Malingering, 116f, 117, 276, 462. *See also* Functional hearing loss
Malleus, 59, 60f, 151
Manual controls on hearing aids, 574–575, 575f
Manubrium, 59, 60f
Marginal perforation of tympanic membrane, 148
Masking
  in air-conduction pure-tone audiometry, 261–262
  binaural release from, 306
  in bone-conduction pure-tone audiometry, 262
  dilemma, 264–265, 265f
  and earphone types, 240–241
  interaural attenuation levels for, 260, 260t
  overview, 245–246, 258–260
  strategies, 262–264, 263f
Masking level difference (MLD), 306
McCaslin, Devin, 184
Measles, 166
Measurement technique, 317–318
Meatus, external auditory, 57–58
Meatus, internal auditory, 65
Medial geniculate, 72, 73, 74f
Melotia, 139
Membranous atresia, 139
Membranous labyrinth
  auditory, 61, 62–64, 63f, 64f
  malformations of, 154–155
  vestibular, 77, 77f
Membranous labyrinthitis, 167
Ménière, Prosper, 170
Ménière's disease, 138, 170–171, 172f, 186, 277, 299
Meningiomas, 180

Meningitis, 137, 155, 165–166
Meningo-neuro-labyrinthitis, 181
Message-to-competition ratio (MCR), 458
Michel deformity, 154
Microphones
  as consideration in hearing aid choice, 598–599
  directional, 564f, 565, 567, 588, 603
  omnidirectional, 567, 588
  overview, 566–568, 566f
Microphones, remote
  in classrooms, 670, 674, 678
  overview, 568, 601, 602, 602f
  personal amplifiers, 604, 605f
  personal FM systems, 601–603, 601f, 602f, 670, 674, 676–678, 678f
  television listeners, 603–604
Microtia, 138–139, 141
Middle cerebral artery, 73
Middle ear
  anatomy and physiology of, 57f, 59–61, 59f
  impacted cerumen in, 9, 141, 142f, 208–209
  infections of, 137
  trauma to, 137, 151–152, 164
Middle ear, evaluating function of
  with acoustic reflex measurement, 327–331, 333
  with immittance audiometry, 211–212, 315–318, 333–350
  otoscopic inspection, 208–209
  overview, 207–212
  reporting results, 497–498, 498t
  with static immittance, 325–327, 329, 332, 333
  with tympanometry, 318–325, 329, 333
Middle-ear disorders
  anomalies of, 138–141
  chronic otitis media, damage from, 146
  decrease in stiffness, 322–323, 324f, 497
  evaluation of, 333–338, 333t, 400–407
  excessive immittance, 334–335, 338f
  glomus tumors in, 152–153
  increase in mass, 321, 321f, 324f, 334, 336f, 497
  increase in stiffness, 322, 324f, 334, 337f, 497
  negative pressure, 322, 324f, 338, 340f, 497
  tympanic membrane perforation, 147–149, 148f, 327, 336–337, 339f, 497
Middle-ear implants, 606, 613–615, 614f
Middle latency response (MLR), 357, 367–368, 380–381
Minimum audibility curve, 82–83, 83f
Minimum auditory field response, 83
Minimum auditory pressure response, 83
Mixed hearing loss
  audiometric configuration of, 251–252, 251f
  in cochlear otosclerosis, 176, 177f
  overview, 103, 109–110, 110f, 214
MLD (masking level difference), 306
MLR (middle latency response), 357, 367–368, 380–381
Mondini malformation, 154
Monitored-live voice testing, 286, 289, 291–292
Monosyllabic word lists, 279
Morgan, Susan, 371
MTO switch, 575, 575f
Mucoid effusion, 144
Multimodality sensory evoked potentials, 8
Multiple sclerosis
  acoustic reflex characteristics for, 331
  effect on hearing function, 138, 182
  evaluation of, 380, 423–426
  immittance results for, 349–350, 350f, 423, 424f
Multisensory modality, 10, 358–359, 370–371, 381–382
Multitalker babble, 280
Mumps (epidemic parotitis), 166
Murray, Anne, 462
Myringotomy, 147

N

National Acoustic Laboratory (NAL) formula, 623–624, 625f
National Institute for Occupational Safety and Health (NIOSH), 18
Naval Hospital (Pennsylvania), 29, 30
Neonatal hearing screening. *See* Newborn hearing screening
Neonatology, 21
Neoplasms. *See* Tumors
Neural degeneration, 115
Neural hearing disorders, 115, 138, 177–186, 181, 215–216, 277
Neural system, 6
Neuritis, 138
Neurofibromatosis, 180
Neurology, 21
Neuromaturation, 378, 390
Neurons, cochlear, 71, 72f, 173
Newborn hearing screening. *See also* Infant screening
  history of, 32, 377–378
  overview, 224–227
Newborns
  age range of, 10
  neuromaturation in, 378
  risk factors for hearing loss, 159–160, 224, 225t, 439–440

Newby, Hayes, 30
NIOSH (National Institute for Occupational Safety and Health), 18
Noise-induced hearing loss (NIHL)
evaluation of, 430–431, 432f, 433f
overview, 137, 160–164, 162f, 162t, 163f, 164f
Noise measurement and control, 94
Noise reduction strategies, 589
Nonorganic hearing loss. *See* Functional hearing loss
Nonsense syllables, 279
Nonsuppurative effusion, 144
Nonsyndromic hereditary hearing disorders, 158–159
Nuclei, cochlear, 72–75, 74f
Nuclei, vestibular, 79, 81

O

OAE. *See* Otoacoustic emissions
Occlusion, 597–598
Occlusion index, 266–267
OME. *See* Otitis media with effusion
Omnidirectional microphones, 567
Oncology, 22
Open-fit technique, 553, 564f, 565, 592–593, 593f, 594f
Open-set speech materials, 283–284
Organ of Corti, 64, 65f, 66f
Oscillators, 236–237, 237f
Oscillopsia, 186
Osseotympanic bone conduction, 258
Osseous labyrinth. *See* Bony labyrinth
Osseous spiral lamina, 71
Ossicular chain. *See also* Otosclerosis
anatomy of, 57f, 59–60, 60f
and cholesteatoma, 149
and middle-ear stiffness, 211
physiology of, 60, 61, 75
Ossicular discontinuity, 151, 152f, 334–335, 338f
Ossicular dysplasia, 140
Otitis externa, 143
Otitis media with effusion (OME)
complications of, 146–150
evaluation of, 403, 404f, 405f
immittance results for, 334, 336f
overview, 143–147, 145–146t, 147f
sample case history form, 205
treatment for, 147
Otitis media without effusion, 144
Otoacoustic emissions (OAEs)
in cochlear disorder evaluation, 410
in cochlear function evaluation, 389, 391
distortion-product, 384, 386–388, 387f, 388f, 389, 391
evoked, 384–388, 385f
in functional hearing loss assessment, 467, 474, 475f
in infant screening, 227, 389–390, 441–442, 445–446
in neurological disorder evaluation, 392
overview, 227, 383
in pediatric assessment, 390–391, 447–448, 449, 450
in retrocochlear disorder evaluation, 392, 418–419
spontaneous, 384
transient-evoked, 384–386, 385f, 392
Otoconia, 79
Otolaryngology, 19–21
Otolithic membrane, 79, 80
Otoliths, 77, 78f, 79
Otologic disease, signs of, 520
Otologic referrals
evaluating cochlear disorder for, 408–415
evaluating outer- or middle-ear disorders for, 400–407
evaluating retrocochlear disorder for, 415–427
lines of referral, 516–520
overview, 399–400
Otology, 19–20
Otorhinolaryngology, 19–21
Otosclerosis
cochlear, 176, 177f
evaluation of, 403–407, 406f, 407f
immittance results for, 334, 337f
overview, 137, 150–151, 151f
tympanometry results for, 322, 324f
Otoscopy, 208, 209f, 210f, 539
Otosyphilis, 166–167
Ototoxicity
congenital, 153, 167
of drugs and chemicals, 137, 156, 161, 167–170, 391
evaluation of, 410–413, 411f, 412f
hearing loss from, 168, 169f
and noise-induced hearing loss, 161
Outer ear
anatomy and physiology of, 56–59, 57f
congenital anomalies of, 138–141
evaluating disorders of, 400–407, 404f, 405f, 406f, 407f
evaluating function of, 207–210, 211–212
impacted cerumen in, 141, 142f, 208–209

infections of, 137
Outer hair cells
anatomy and physiology of, 64, 65f, 66f, 67f, 68–70
changes in, 173
loss of, 107, 108f
and otoacoustic emissions, 383, 388
Output limiting, 564, 570–572, 571f, 572f, 577, 584–585
Output transducers, 238–242
Oval window of cochlea, 60, 63, 64f, 140
Overmasking, 263, 263f

P

Palliative care, 604
Parkinson's disease, 380
Pars flaccida, 58–59, 58f, 148
Pars tensa, 58–59, 58f, 148
Participation restrictions, 220, 221
Patient perspectives
expectations for hearing aid use, 644–645
motivation for treatment, 534–535, 547
overview, 486–488
PB (phonetically balanced) word lists, 279, 290–291. *See also* Word-recognition testing
Peak clipping, 571, 571f, 584
Pediatric audiologic evaluation. *See* Children, evaluation of; Infants, evaluation of
Pediatric audiologic referrals, 445, 447, 449–450
Pediatrics, 21
Pediatric Speech Intelligibility (PSI) test, 458
Pendred syndrome, 157
PE (pressure-equalization) tubes, 147
Performance-intensity (PI) function, 293–294, 294f
Perilymph, 63
Period, 51
Peripheral auditory nervous system. *See also* Auditory evoked potentials
defined, 5
effect of changes in, 111, 115, 177, 215 (*See also* Neural hearing disorders)
evaluating function of, 358, 378–381
neuropathies from diabetes, 181
Peripheral hearing loss. *See* Hearing sensitivity loss
Permanent threshold shift (PTS), 160–164
Persistent pulmonary hypertension of the newborn (PPHN), 159–160
Personal amplifiers, 600
Personal FM systems, 601–603, 601f, 602f, 670, 674, 676–678, 678f
Phase, 46, 47, 48f, 51–52, 53f, 54f
Phonemes, 278, 279
Phonetically balanced (PB) word lists, 279, 290–291
Physician referrals, 200
Physicians' practices, audiologists in, 13
PI. *See* Performance-intensity function
Pinna, 56–57, 57f, 138–141, 139, 143
Pitch, 51, 93, 105. *See also* Suprathreshold hearing perception
Plateau method of masking, 262–263, 263f
Polyotia, 139
Potentiometers, 573
Practices, audiology, 8–19
Praxis Examination in Audiology, 27–28, 33
Preauricular malformations, 139
Presbyacusis, 171–175, 173f, 174f
Pressure. *See* Sound pressure
Pressure-equalization (PE) tubes, 147
Private practice, 11–13
Probe-microphone measurement of hearing aid frequency response, 621–622, 635–637, 636f, 637f
Profound sensorineural hearing loss, treatment of, 684–693, 689f, 690f, 692f
Prognosis for hearing aid success, 118, 534, 644
Programmable hearing aid technology, 564–565, 564f, 576–577
Progressive adult-onset hearing loss, 159
Proprioception, 76
Pseudohypacusis. *See* Functional hearing loss
Psychoacoustics, 81
PTS (permanent threshold shift), 160–164
Pulsatile tinnitus, 153
Pure-tone audiometry. *See also* Air-conduction pure-tone audiometry; Audiometers, pure-tone; Bone-conduction pure-tone audiometry; Masking
calibration standards, 93–95
masking, 246, 261–262
monitoring cochlear function with, 391
preparing patients for, 253–254
in school-age screening, 227
testing technique, 254–255, 255f
use of bone-conduction vibrators in, 88
use of earphones in, 83, 87–89
use of loudspeakers in, 83
Pure-tone audiometry, clinical applications of
cross-checking immittance audiometry results, 314, 315
cross-checking speech recognition threshold measurements, 276, 285, 288
evaluating auditory processing disorder, 462, 463f
evaluating cochlear disorders, 408, 409, 412, 412f, 413, 415f

evaluating functional hearing loss, 466, 472, 474f
evaluating outer- and middle-ear disorders, 402, 403, 405, 405f, 407f
evaluating retrocochlear disorders, 417–418, 421, 421f, 425, 425f
measuring threshold of audibility, 86–89, 212–213, 242–243
Pure-tone average (PTA), 276, 285, 288
Pure tones, 52, 341
Purulent effusion, 144

R

Radiographic techniques, 9
Radionecrosis, 164–165
Ramsey Hunt syndrome, 166
Rarefaction, 43, 45f, 47f
Real-ear gain verification, 635–637
Receiver-in-the-canal (RIC) fittings, 553, 593–594, 594f, 597
Receivers, hearing aid, 566f, 573
Receptive language processing disorders, 113–114, 114f
Recessive hereditary sensorineural hearing loss, 159
Recommendations, reporting of, 502–503, 504t, 517
Recruitment, 109f, 127–128, 128, 303–304
Redundancy in speech and hearing
and auditory processing disorder, 115, 457
extrinsic, 124–125, 278–279, 281–283, 281f
intrinsic, 280, 282, 282t
overview, 280–283
Reference equivalent threshold sound pressure levels (RETSPL), 95, 95t
Referrals, audiologic
and adult evaluation, 427–428
and pediatric evaluation, 445, 447, 449–450
Referrals, lines of, 516–520
Referrals, otologic
and cochlear disorder evaluation, 408–415
and outer- or middle-ear disorder evaluation, 400–407
overview, 399–400
and retrocochlear disorder evaluation, 415–427
Referrals, sources of, 199–201
Referrals to other professionals
counselors, 25
geneticists, 24–25
lines and ethics of, 516–520
otologists, 520–521
speech-language pathologists, 522–523
Rehabilitation, post-fitting
for adults, 658
auditory training and speechreading, 647–648
communication development training, 648–649
for geriatric patients, 663–664, 666
for pediatric patients, 670, 675
for permanent conductive hearing loss, 681
Reissner's membrane, 63
Reporting test results
audiogram report, 489
content of report, 494–504, 496t, 498t, 501t, 504t
information needs of readers, 492–494
letter report, 489–490
to patients, 482–488, 485t
sample strategy, 509–515, 510f, 511f, 512f, 513f, 514f, 515f
tips, 491
Residual hearing, 128
Retrocochlear disorder
abnormal auditory adaptation in, 128, 304
causes of, 111–112, 138, 215
decruitment in, 128, 303
overview, 111–112, 112f, 128–129, 214
speech perception in, 128
Retrocochlear disorder, evaluating. *See also* Site-of-lesion testing
with acoustic reflex thresholds, 328–329, 330–331, 330f, 345–346
with auditory evoked potentials, 419
goals, 415–416
illustrative cases, 419–427
with immittance audiometry, 345–350, 417
with otoacoustic emissions, 392, 418–419
with pure-tone audiometry, 417–418
screening methods, 216–218
with speech audiometry, 276, 418
RETSPL (reference equivalent threshold sound pressure levels), 95, 95t
Reverberation, 125
RIC (receiver-in-the-canal) fittings, 553, 593–594, 594f, 597
Rinne test, 266
Rollover effect of PI function, 293, 294f
Round window of cochlea, 63, 64f
Roush Jackson, 17
Rubella, 155–156

S

Saccular macula, 79
Saccule, 77, 79–80
Salicylates, ototoxicity of, 169, 170f
SAL (sensorineural acuity level) test, 264

Sanguineous effusion, 144
SAT (speech awareness threshold), 275, 285, 288–290. *See also* Speech audiometry
Scala media, 63, 64f
Scala tympani, 63, 64f
Scala vestibuli, 63
Scarpa's ganglion, 79
Scheibe aplasia, 155
Schools, screening in, 15–16, 227–228
Schwabach test, 266
Scope of practice, 8–10
Screening audiometers, 236
Screening hearing function. *See also* Infant screening
  audiologist's role in, 5
  overview, 198, 221–223
  in schools, 15–16, 227–228
  in workplaces, 223
Scroll ear, 139
SDT (speech detection threshold), 275, 285, 288–290. *See also* Speech audiometry
Self-assessment scales
  measuring impact of hearing loss with, 221, 222f, 543
  measuring treatment success with, 556, 645–647, 646f
Self-referrals, 199–200
Semicircular canals, 77–79, 78f
Sensitivity. *See* Hearing sensitivity; Hearing sensitivity loss
Sensitivity Prediction by the Acoustic Reflex (SPAR) test, 341–345, 342f, 343f
Sensitized speech audiometry. *See also* Speech audiometry
  in auditory processing ability assessment, 115, 219, 277–278
  in auditory processing disorder assessment, 457–459, 459f
  methods of sensitizing signals, 282–283, 283t, 295
  overview, 295–298
  and performance-intensity (PI) function, 293–294
Sensorineural acuity level (SAL) test, 264
Sensorineural hearing loss
  in adults, 657–661, 660f, 661f
  audiometric configuration of, 106–107, 107f, 250–252, 251f
  in children, 666–673, 667, 671f, 672f
  defined, 102–103, 214
  degree of, 106
  detecting with SPAR test, 341–345, 342f, 343f
  effect on air- and bone-conduction thresholds, 88–89, 90f, 106–107, 107f, 250–262, 251f
  overview, 105–109, 107f, 108f, 109f, 127–128, 657
  recruitment in, 109f, 127–128
  risk factors for, 159–160, 224, 225t, 439–440
Sensorineural hearing loss, causes of
  autoimmune inner-ear disease, 175, 176f
  cochlear disorders, 153–156, 176, 177f, 181
  congenital infections, 155–156
  hereditary disorders, 156–159, 158f
  idiopathic, 177
  infections, 136–137, 155–156, 165–167
  lesions, 103, 111–112, 298–299
  Ménière's disease, 170–171, 172f
  noise-induced, 137, 160–164, 162f, 162t, 163f, 164f
  ototoxicity, 156, 167–170, 169f, 391
  overview, 136–138, 153
  physical trauma, 164–165
  presbyacusis, 171–175, 173f, 174f
  retrocochlear disorders, 103, 111–112, 112f
  tumors, 103, 111–112, 112f, 179–180, 180f
Sensorineural hearing loss, treatment strategies for
  in adults, 657–661, 660f, 661f
  in children, 666–673, 671f, 672f
  in elderly patients, 661–666, 665f
  in severe and profound hearing loss, 684–693, 689f, 690f, 692f
Sensory cells. *See* Hair cells, vestibular; Inner hair cells; Outer hair cells
Sensory epithelia, vestibular, 77–79
Sensory hearing disorders, 153–177
Sentences, use in speech audiometric measures, 280
Sentential approximations, 279
Serous effusion, 144
Serous labyrinthitis, 165
VIIth cranial nerve disorders, 346–348, 349f
Sherwood, Jennifer, 223
Short increment sensitivity index (SISI), 304
Signal averaging, 362–364, 364f
Signal processing
  choices in amplification, 552
  digital, 564f, 565
  in hearing aids, 585–589, 586f, 587f
Signal-to-noise ratio (SNR), 361, 457, 458
Sign language, 648
Silverman, S. Richard, 30
Simple harmonic motion. *See* Sinusoidal motion
Single-syllable word lists, 279
Sinusoidal motion, 45–46, 46f, 47f, 52–54, 53f, 54f
Site of disorder, reporting, 501–502
Site-of-lesion testing, 298–299, 299f, 303–305
SNR (signal-to-noise ratio), 361, 457, 458

SOAEs (spontaneous otoacoustic emissions), 384
Sound, 42–55, 93–95
Sound field, 446
Sound level meters, 94
Sound pressure. *See also* Sound pressure levels
  and intensity, 48–49, 48f
  relationship to hearing sensitivity, 83
  units of measurement, 50t
  waves, 42–43
Sound pressure levels (SPLs)
  defined, 49–51
  reference equivalent threshold (RETSPL), 95
  representing in audiograms, 84–85, 85f
  and static immittance measurement, 325–327
SPAR (Sensitivity Prediction by the Acoustic Reflex) test, 341–345, 342f, 343f
Spectrum, 52–54, 55f
Speech audiometry. *See also* Sensitized speech audiometry; Speech detection threshold; Speech recognition threshold; Word-recognition testing
  in auditory processing ability assessment, 277–278
  in auditory processing disorder assessment, 457–459, 457t, 459f, 460, 464f
  in cochlear disorder evaluation, 410, 412–413
  in differential diagnosis, 277
  in functional hearing loss assessment, 466
  history of, 31
  materials, 278–285
  in outer- and middle-ear disorder evaluation, 402–403, 407
  overview, 274–275, 285
  reporting results of, 498–499, 505
  in retrocochlear disorder evaluation, 418, 421–422, 422f, 425, 426f
  in treatment assessment, 539
  types of measures, 285–299
Speech awareness threshold (SAT). *See* Speech detection threshold
Speech detection threshold (SDT), 275, 285, 288–290. *See also* Speech audiometry
Speech discrimination testing. *See* Word-recognition testing
Speech frequencies, 213
Speech intelligibility index. *See* Audibility index
Speech-language pathology, 22–24, 26, 521–523
Speech mapping, 638–639
Speech perception, and hearing loss, 120–125, 123f, 124f, 125f, 126f
Speech-Perception-in-Noise (SPIN) test, 280, 296
Speech perceptual judgments, 639–640
Speech processing, 75, 182
Speechreading, 118, 647–648
Speech reception threshold. *See* Speech-recognition threshold
Speech recognition. *See also* Speech audiometry; Suprathreshold hearing perception
  in conductive hearing loss, 105
  defined, 112
  as indicator of auditory processing ability, 115
  in Ménière's disease, 171
  predicting from audiograms, 300–302
  in presbyacusis, 174–175, 175f
  in retrocochlear disorder, 112, 128–129, 179, 218
  and site of lesion prediction, 298–299, 299f
Speech recognition testing. *See also* Speech recognition-threshold measurement; Word-recognition testing
  aided, 556, 640–642, 641f
  extrinsic redundancy as factor in, 278–279, 281–283
  methods, 217–218, 276–277
Speech-recognition threshold (SRT)
  materials and procedure, 285–288, 286t
  overview, 275
  as pure-tone cross-check, 276, 285, 288, 402, 466
Speech targets, 555
Speech threshold (ST), 275
Spiral ganglion, 71
Spiral ligament, 173
SPL. *See* Sound pressure levels
Spondaic words, 279–280, 285–286, 286t
Spondee threshold. *See* Speech-recognition threshold
Spontaneous otoacoustic emissions (SOAEs), 384
Squamous-cell carcinoma, 143
SRT. *See* Speech-recognition threshold
Staggered Spondaic Word (SSW) test, 298
Stapedius muscle, 60, 75, 327–328
Stapes, 59, 60f, 66, 150, 151, 176
Static immittance, 325–327, 329, 332, 333. *See also* Immittance audiometry
Stenger test, 468, 469–470
Stenosis, 143
Step masking, 263–264
Stereocilia, 77, 80
Stria vascularis, 173
Stroke, 23, 182
Style of hearing aids, 553
Summating potential (SP), 365
Superior canal dehiscence, 185

Superior olivary complex, 72, 73, 75
Superior vestibular nerves, 79
Suppurative effusion, 144
Supra-aural earphones
  interaural attenuation of, 241, 259, 260, 260t
  overview, 239, 240f, 241, 256
  placement of, 254
Supramodal disorders, 114, 114f
Suprathreshold adaptation test (STAT), 304–305
Suprathreshold hearing disorders, 101, 110–116. *See also* Auditory processing disorder; Retrocochlear disorder
Suprathreshold hearing perception, 92–93, 105, 108–109, 217
Surgical monitoring of cochlea and VIIIth nerve, 10, 358–359, 370–371, 381–382
Swimmer's ear, 143
Syndromic hereditary hearing disorders, 156–157
Synthetic Sentence Identification (SSI) test, 280, 297
Syphilis, 156, 166–167

T

Target gain, 554–555
T-coil. *See* Telecoil
Telecoil, 568, 575
Telephone amplifiers, 604–605
Television listeners, 600, 603–604
Temporal lobe, 75
Temporal-lobe disorder, 182
Temporal processing, 661
Temporary threshold shift (TTS), 160–164
Tensor tympani muscles, 60
TEOAEs (transient-evoked otoacoustic emissions), 384–386, 385f, 392
Text telephones, 606
Threshold of audibility. *See also* Air-conduction threshold; Bone-conduction threshold
  and audiometric zero, 84
  measuring, 86–89, 212–213, 242–243
  and otoacoustic emissions, 388–389
  overview, 82–84, 83f, 89, 242
  variability of, 85–86, 242–243
Threshold of discomfort (TD), 539–540, 541–542
Threshold of feeling, 82–84, 83f
Threshold sensitivity. *See* Threshold of audibility
Time compression, 282–283, 283t, 295
Time course of hearing disorders, 102
Tinnitus, 153, 200
Tone decay test (TDT), 304–305
Toxicity. *See* Ototoxicity; Vestibulotoxicity
Toxic labyrinthitis, 165
Toxoplasmosis, 156
Transducers, 238–242
Transient-evoked otoacoustic emissions (TEOAE), 384–386, 385f, 392
Trauma
  acoustic, 137 (*See also* Noise-induced hearing loss)
  physical, 137, 151, 164–165
  from sudden pressure changes, 152
  tympanic membrane perforation from, 148
Traveling wave, 66–68, 69f
Treatment. *See also specific hearing disorders*
  audiologist's role in, 5–6
  communicating to patient, 486
  determining candidacy for, 538–545
Tremblay, Kelly, 70
Tumors. *See also* Cochleovestibular schwannoma; Retrocochlear disorder
  acoustic, 138, 179–181, 180f, 215–216
  defined, 21
  irradiation of, 165
  in middle ear, 152–153
  surgical removal of, 381
  on temporal lobe, 112, 112f
  on VIIIth cranial nerve, 103, 111–112, 112f, 179–180
Tuning fork tests, 265–267
Tympanic membrane
  anatomy of, 57f, 58–59
  fluid accumulation behind, 211
  function of, 41, 59
  infections of, 137
  perforation of, 147–149, 148f, 327, 336–337, 339f, 497
Tympanograms
  diagnostic types, 323, 324f, 332, 333f
  for faulty Eustacian tube function, 322, 324f
  for fluid-filled middle ear, 321, 321f, 324f
  for normal middle ear, 320–321, 320f
  for ossicular chain with reduced stiffness, 322–323, 324f
  peak pressure, 323
  for stiffened ossicular chain, 322, 324f
Tympanometric peak pressure (TPP), 323
Tympanometric width, 323, 325f
Tympanometry. *See also* Immittance audiometry; Tympanograms
  diagnostic use of, 323, 333
  in infants, 445–446
  overview, 318–325, 319f, 321f, 329, 333
  probe-tone frequency, 323–325
Tympanometry measures, 318–325, 329, 333
Tympanosclerosis, 150, 400

U

United States Food and Drug Administration, 31, 33
Universities, audiologists in, 16
Usher syndrome, 157
Utricle, 77, 79–80
Utricular macula, 79

V

Vascular disorders, 138
Venting of hearing devices, 598
Vertigo, 171, 183–185, 186
Vestibular artery, 65
Vestibular disorders, 183–186
Vestibular function, assessment of, 9, 76
Vestibular hair cells, 77, 78f, 80, 80f, 183–186
Vestibular labyrinth, 77, 77f
Vestibular nerves, 79
Vestibular neuritis, 186
Vestibular system, 77–81, 80f
Vestibulotoxicity, 185–186
Vision and balance, 76
Visual reinforcement audiometry (VRA), 448
Von Recklinghausen's disease, 180

W

Waardenburg syndrome, 157
Warble tones, 448
Weber test, 266–267
Wharton, Jeanne, 536
Wilson-Bridges, Teri, 284
Wireless connectivity of hearing aids, 564f, 565, 568
Word discrimination. *See* Word-recognition testing
Word-recognition testing. *See also* Speech audiometry
  contrasted with speech-recognition threshold measurement, 286–287
  interpretation of, 295, 296t
  in outer- and middle-ear assessment, 403
  overview, 218, 276, 290
  procedure for, 293–295
  word lists, 290–291
Workman, Rhiannon, 590
Workplaces, noise exposure in, 94
Workplaces, screening in, 223

X

X-linked hearing disorder, 159
X-ray irradiation, trauma from, 164–165