# AUDIOLOGY
# Science to Practice

*Fourth Edition*

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Typeset in 11/13 ITC Garamond Std by Achorn International Inc.
Printed in the United States of America by McNaughton & Gunn



Library of Congress Cataloging-in-Publication Data

Names: Kramer, Steven J., author. | Brown, David K. (Professor of audiology), author.
Title: Audiology : science to practice / Steven Kramer, David K. Brown.
Description: Fourth edition. | San Diego, CA : Plural Publishing, Inc., [2023] | Includes bibliographical references and index.
Identifiers: LCCN 2021029578 (print) | LCCN 2021029579 (ebook) | ISBN 9781635503463 (paperback) | ISBN 1635503469 (paperback) | ISBN 9781635503470 (ebook)
Subjects: MESH: Hearing—physiology | Hearing Disorders | Audiology—methods | Hearing Tests—methods
Classification: LCC QP461 (print) | LCC QP461 (ebook) | NLM WV 270 | DDC | 612.8/—dc23
LC record available at https://lccn.loc.gov/2021029578
LC ebook record available at https://lccn.loc.gov/2021029579

# Contents

# Preface

This textbook provides an introductory, yet comprehensive, look at the scientific and clinical aspects of the field of audiology. It is designed for undergraduate students in speech and hearing sciences/communicative disorders, audiology doctoral students, graduate speech-language pathology students, and other professionals who work closely with audiologists. It is expected that the knowledge obtained from this textbook will be applicable to the readers' future education or clinical practices. For some, it may help them decide to go into the profession of audiology. From science to practice, the fourth edition of this textbook covers the profession of audiology, acoustic properties and perception of sounds, anatomy and physiology of the hearing (auditory) and balance (vestibular) systems, pure-tone audiometry, speech measures, masking, audiogram interpretation, tympanometry, wideband acoustic immittance, acoustic reflexes, otoacoustic emissions, auditory brainstem responses, hearing screening, vestibular assessment, hearing aids, assistive listening devices and listening aids, cochlear and other implantable devices, aural (re)habilitation, and the role of the speech-language pathologist related to patients with hearing or balance concerns. Beginning students also have interest in knowing about some common hearing disorders, and this book provides concise descriptions of selected auditory and vestibular pathologies with typical complaints and test results for many of the more commonly found diseases and disorders to help the student learn how to integrate information from multiple tests. The two chapters about the profession of audiology include information about career outlook, what it takes to become an audiologist, and what audiologists do and where they practice. As a special addition, James Jerger, a legend in audiology, provides his perspectives on the history of audiology in the United States; these can be found throughout the various chapters as set-aside boxes (Historical Vignettes), and a complete chapter on the history of audiology in the United States by James Jerger and Cheryl DeConde Johnson can be found on the companion website. Gus Mueller, a well-known contributor to the field, with an emphasis on hearing aids, has updated his chapter on hearing aids.

Although this textbook is intended for readers with little or no background in audiology, it is not a cursory overview. Instead, it presents a comprehensive and challenging coverage of hearing and balance science and clinical audiology but written in a style that makes new and/or difficult concepts relatively easy to understand. The approach to this textbook is to keep it readable and to punctuate the text with useful figures and tables. Each chapter begins with a list of key objectives, and throughout the chapter, key words or phrases are highlighted in blue and brief definitions are included in a glossary at the end of the textbook. In addition, most of the chapters have strategically placed review material (synopses) that can serve as quick refreshers before moving on or provide a "quick read" of the entire text, especially useful as a review for the Praxis exam. Having taught beginning students for many years, the authors have learned how students learn and what keeps them motivated. After getting the students interested in the profession of audiology, information about acoustics is presented so that they have the tools to understand how the ear works and how hearing loss is assessed (which is what they really want to know), and these areas form the bulk of the text. Of course, the order of the chapters can be changed to suit any instructor.

## FEATURES AND ADDITIONS TO THE FOURTH EDITION

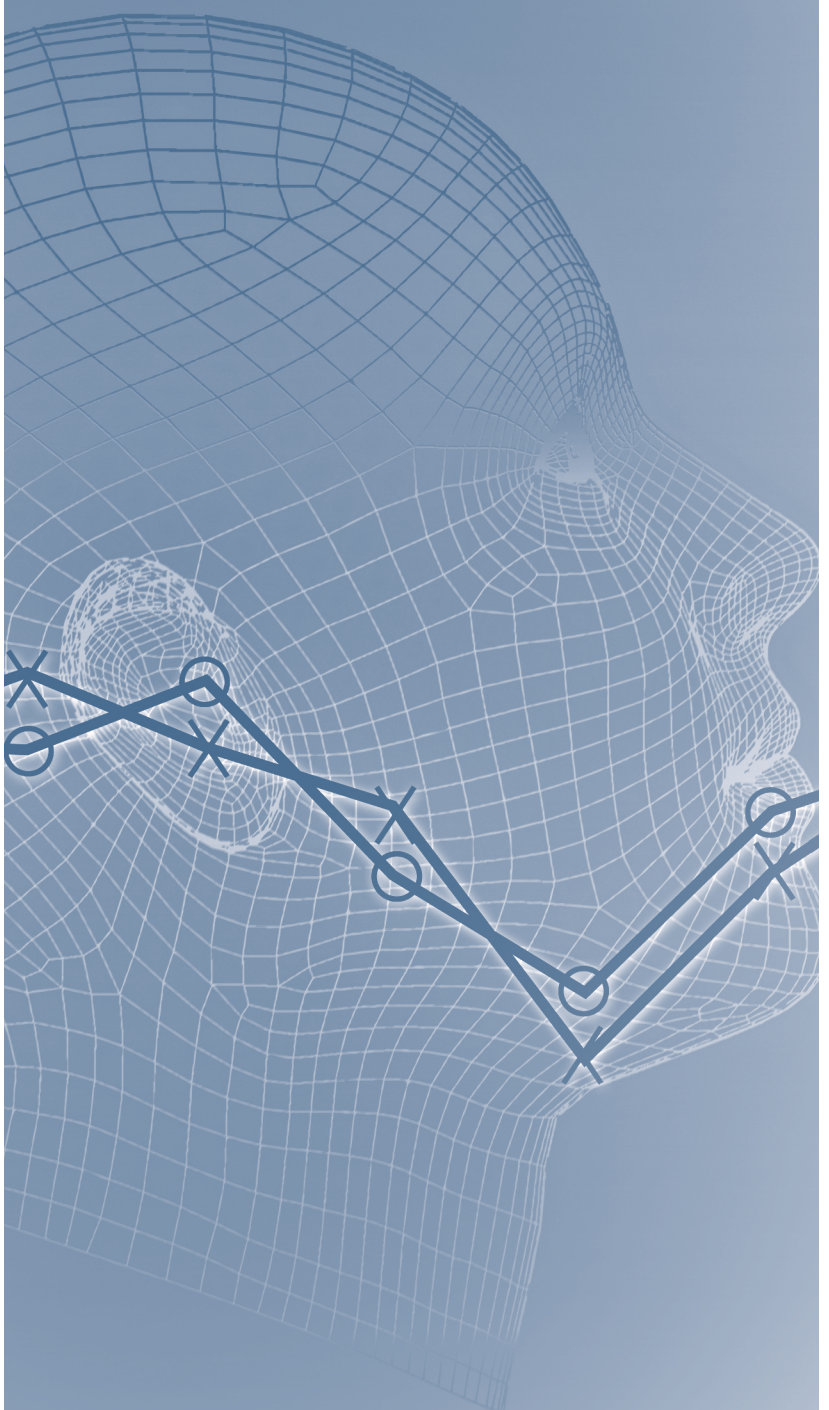
This fourth edition of *Audiology: Science to Practice* has been carefully revised and updated from the previous edition. This edition continues the collaboration with coauthor David Brown, whose experience and expertise in audiology and hearing science provides an opportunity to again update and expand the textbook. We have also incorporated some of the feedback received through a survey of faculty who are current or interested users of the textbook. For this edition, we are pleased to have an illustrator, Maury Aaseng, draw 18 new figures (in two-color format) and colorize (in two-color format) 63 other figures.

Each of the chapters from the previous edition was systematically reviewed and updated, expanded, reorganized, and references updated, to make it even more useful to the reader and at the same time continuing to be more comprehensive than one might find in other introductory texts on audiology. Two new chapters have been added to this fourth edition, "Other Treatments and (Re)habilitation of Hearing and Balance Disorders" and "Role of the Speech-Language Pathologist." New introductory material has been added to the existing chapters, including environmental factors that affect the transmission of sound, signal-to-noise ratio, preparing for patient testing, cerumen management, assistive listening devices and listening aids, and status of over-the-counter hearing aids. Based on our experience that students have little, if any, information about the vestibular system and its importance to audiology clinical practice, we have reorganized the information previously covered in a separate vestibular chapter to now include vestibular anatomy, physiology, and disorders within the chapters covering auditory anatomy, physiology, and disorders. There is now a separate chapter on vestibular evaluation and bedside screenings.

This edition retains the features that worked well in previous editions, including an easy-to-read format, key learning objectives, synopses within each chapter with bulleted highlights for review, and a comprehensive glossary at the end of the book. This edition also comes with a PluralPlus companion website, which includes lecture outlines in slide format that can be used in teaching audiological concepts, the full text of Jerger and DeConde Johnson's essay on the history of audiology in the United States, and more. We are excited about all the improvements in this edition that will help students establish a strong foundation about audiology concepts and clinical practice.

PART I

# Perspectives on the Profession of Audiology



WELCOME to the fascinating world of audiology! In Part I of this textbook, we will provide you with information about the profession of audiology and the many ways in which you might be involved. We hope this part also gives you an appreciation of the rewarding aspects of being involved with audiology and helping people with hearing and balance difficulties. For those interested in speech-language pathology, nursing, physical therapy, optometry, rehabilitation counseling, or other related fields, we know that you will interact with people who have hearing loss and with audiologists, and the information in this textbook will, undoubtedly, be of use to you in your profession. We also hope that many of you will become intrigued by the possibility of joining the profession of audiology.

In Chapter 1, you will learn about the field of audiology and its professional organizations. Chapter 1 also includes an overview of the development of the profession based on input from Dr. James Jerger, a pioneer and long-time contributor in the field. Throughout the text, you will find some of his perspectives on the development of the field with set-aside boxes (Historical Vignettes). An extended version of this historical perspective by Drs. Jerger and DeConde Johnson from the second edition is available on the companion website. In Chapter 2, you will learn what is required to become an audiologist, the settings where audiologists practice, and the activities that might fill their workweek. You will become familiar with the varied paths one might take within audiology and the extensive scope of practice that defines the skills of an audiologist. Chapter 2 also presents some current demographic trends in audiology, as summarized from surveys regularly conducted by our professional organizations.

# 1 The Discipline of Audiology

**After reading this chapter, you should be able to:**

1. Define audiology and understand how audiology relates to other disciplines.
2. List some professional and student organizations related to audiology.
3. Become aware of resources from various professional websites, where you will learn more about the profession.
4. Discuss how and when audiology as a profession first began.
5. List key events that transpired over the years as the profession evolved.

Audiology is a discipline that focuses on the assessment and treatment of hearing (auditory) and balance (vestibular) disorders. More precisely, audiology is a health care profession devoted to identification, assessment, treatment/rehabilitation, and prevention of hearing and balance disorders, as well as understanding the effects of hearing loss on related communication disorders and psychosocial well-being. An audiologist is a professional who has the appropriate education and training in the country where they work. In the United States, the minimum educational requirement is a doctor of audiology (AuD) with appropriate clinical training and a license in their state to practice audiology (described more fully in Chapter 2). The United States is the only country that requires an AuD to practice audiology. Having an AuD from the United States may not qualify one to practice audiology in other countries. Other countries may require specific education and training in audiology as part of a bachelor's or master's degree program, a clinical PhD, or a specific track of qualified training (Goulios & Patuzzi, 2008; Hall, 2015; Swanepoel, 2006). Many developing countries do not have any educational or training programs in audiology; however, the requirements for education and training are likely to change as countries expand services to those with hearing loss.

Audiologists are the experts who understand the effects of hearing loss on communication and how to best improve a patient's ability to hear. Audiologists work with many other professionals and support personnel, including audiology assistants. Audiology assistants have specific training requirements and defined activities, and perform supportive tasks directed and supervised by an audiologist (American Academy of Audiology [AAA], n.d.-b; American Speech-Language-Hearing Association [ASHA], n.d.-b). The medical expert in hearing disorders is the physician. The medical specialty related to the ear is called otology, which is practiced by appropriately trained and certified otologists, also called neurotologists, otolaryngologists, or ear, nose, and throat (ENT) specialists. Audiologists also work with speech-language pathologists, who are certified and/or licensed professionals who engage in prevention, assessment, and treatment of speech and language disorders, including those who have hearing loss. See Chapter 18 for more details on the roles of the speech-language pathologist relative to working with patients with hearing loss. In addition, many audiologists are part of interdisciplinary teams, especially when it comes to the assessment and treatment of pediatric patients and patients with implantable devices, cystic fibrosis, cleft palate, speech-language disorders, or balance problems, to name a few.

## PROFESSIONAL ORGANIZATIONS IN THE UNITED STATES

The American Academy of Audiology (AAA) is the professional organization for audiologists. In 1988, AAA (often referred to as "triple A") was founded to establish an organization devoted entirely to the needs of audiologists and the interests of the audiology profession (http://www.audiology.org). Originally, AAA focused on transitioning audiology to a doctoral-level profession, which became a reality by 2007. Membership in AAA quickly skyrocketed, and, today, AAA has a membership of approximately 14,000 audiologists (American Academy of Audiology [AAA], n.d.-a). Prior to the formation of AAA, the American Speech-Language-Hearing Association (ASHA) was, and remains, a professional organization for audiologists and speech-language pathologists. The ASHA was established in 1925 as the American Academy of Speech Correction and went through several name changes, including the American Society for the Study of Disorders of Speech (1927), the American Speech Correction Association (1934), and the American Speech and Hearing Association (1947), and in 1978, it became the American Speech-Language-Hearing Association (American Speech-Language-Hearing Association [ASHA], n.d.-a). In its early years, ASHA focused on speech disorders; however, during World War II, with service personnel returning with hearing losses, ASHA expanded its mission to include assessment and treatment of those with hearing disorders.

The AAA and ASHA are both strong advocates for individuals with hearing loss and related services both at the state and national levels. These organizations each have professional certifications for audiologists: American Board of Audiology (ABA) certification through AAA and Certificate of Clinical Competence in Audiology (CCC-A) through ASHA. In addition, each of these organizations can award accreditation to academic programs that meet a set of standards: Accreditation Commission for Audiology Education (ACAE) associated with AAA and Commission on Academic Accreditation (CAA) associated with ASHA.

Audiologists may also choose to join other professional organizations. The Academy of Dispensing Audiologists (ADA) was established in 1977 to support the needs of audiologists who dispense (sell) hearing aids. The ADA later changed its name to the Academy of Doctors of Audiology (ADA) (http://www.audiologist.org) and expanded its focus to any audiologist in private practice or who wished to establish a private practice. The Educational Audiology Association (EAA) (http://www.edaud.org), formed in 1983, is a professional membership organization of audiologists and related professionals who deliver a full spectrum of hearing services to all children, particularly those in educational settings. Many audiologists are also associated with the American Auditory Society (AAS) (http://www.amauditorysoc.org) and/or the Academy of Rehabilitative Audiology (ARA) (http://www.audrehab.org). Additionally, there is a national student organization for those interested in audiology, called the Student Academy of Audiology (SAA) (http://saa.audiology.org). The SAA is devoted to audiology education, student research, professional requirements, and networking of students enrolled in audiology doctoral programs. Undergraduate students who are potentially interested in pursuing a career in audiology may also join SAA (Undergraduate Associate). Most university programs have a local chapter of SAA that is part of the national SAA. Programs may also have a chapter of National Student Speech Language Hearing Association (NSSLHA). A wealth of information about the field of audiology and a career as an audiologist can be found on the abovementioned websites.

## DEVELOPMENT OF THE PROFESSION OF AUDIOLOGY[1]

Prior to World War II, persons with hearing disorders received services by physicians and hearing aid dispensers (Martin & Clark, 2019). Audiology in the United States established its roots in 1922 with the fabrication of the first commercial audiometer (Western Electric 1-A) by Harvey Fletcher and R. L. Wegel, who were conducting pioneering research in speech communication at Bell Telephone Laboratories (Jerger, 2009). These audiometers were used, primarily, for research and in some otolaryngology practices.

Audiology as a profession began around the time of World War II, mostly because of returning service personnel who developed hearing problems from unprotected exposures to high-level noises. Initially, returning armed-service personnel were seen by otologists and speech-language pathologists, but clinical services for those with hearing loss soon evolved into a specialty practice in the United States that became known as audiology.

While the effects of excessive noise on hearing have been recognized virtually since the beginning of the industrial age, it was not until World War II that the U.S. military began to address the issues of hearing conservation with a series of regulations defining noise exposure as a hazard, setting forth conditions under which hearing protection must be employed, and requiring personnel exposed to potentially hazardous noise to have their hearing monitored. The introduction of jet aircraft into the Air Force and the Navy in the late 1940s, generating high levels of noise, was an important factor driving interest in hearing protection.

[1]Based on contributions by James Jerger and Cheryl DeConde Johnson in earlier editions. See companion website for their chapter entitled "A Brief History of Audiology in the United States."

### Historical Vignette

The first audiologist in the United States was, undoubtedly, Cordia C. Bunch. As a graduate student at the University of Iowa, late in World War I, Bunch came under the influence of Carl Seashore, a psychologist who was studying the measurement of musical aptitude, and L. W. Dean, an otolaryngologist. Together, they stimulated Bunch's interest in the measurement of hearing. Over the two decades from 1920 to 1940, Bunch carried out the first systematic studies of the relation between types of hearing loss and audiometric patterns. Bunch's pioneering efforts were published in a slender volume entitled *Clinical Audiometry*, which is now a classic in the field. In 1941, Bunch accepted an offer from the School of Speech at Northwestern University to teach courses in hearing testing and hearing disorders, as part of the education of the deaf program. While at Northwestern University, Bunch mentored Raymond Carhart, a young faculty member in speech science. In 1942, Bunch unexpectedly died at the age of 57. To continue the course in hearing testing and disorders, the Northwestern administration asked Raymond Carhart to teach the course. The rest, as they say, is history, as Carhart became another one of the early pioneers of the field.

### Historical Vignette

Attempts to exploit the residual hearing of severely and profoundly hearing-impaired persons have a history much longer than audiology. Long before there were audiometers and hearing aids, educators of the deaf were at the front lines of auditory training, using whatever tools were available. Alexander Graham Bell, inventor of the telephone and founder of the AG Bell Association, took a special interest in the possibilities of auditory training because of his wife's hearing loss. He was a strong proponent of the aural approach and lent his considerable reputation to its promulgation in the last quarter of the nineteenth century. Another early supporter of systematic training in listening was Max Goldstein, who founded the world-famous Central Institute for the Deaf in St. Louis, Missouri.

Early studies of the effects of noise on the auditory system were carried out in the 1940s and 1950s at the Naval School of Aviation Medicine, in Pensacola, Florida. Similar research programs were established at the Navy submarine base in Groton, Connecticut, and at the Navy Electronics Laboratory in San Diego, California. After World War II, audiology-specific educational programs were developed in universities to prepare professionals for clinical work, as well as becoming the stage for further research efforts that would define the practice of audiology. In the early years, audiology focused on rehabilitation, including lipreading (now called speechreading), auditory training, and hearing aids.

During the late 1960s and early 1970s, there was a focus on the development of several objective measures of the auditory system: Immittance (known then as impedance) blossomed into tympanometry for assessing middle ear disorders and acoustic reflex thresholds for differentiating/documenting conductive, sensory, and neural hearing losses. The immittance test battery is now standard in basic hearing assessments. The mid-to-late 1970s brought our attention to the clinical use of evoked electrical potentials, especially the auditory brainstem response (ABR), which provided an objective evaluation of the auditory system that was unaffected by sedation. The ABR continues to be used as a specialty test for neurologic function, and even more importantly for both newborn hearing screening and follow-up hearing threshold assessment. In the late 1970s, otoacoustic emission (OAE) testing

was developed as another objective measure of the auditory system and became an accepted part of clinical practice by the late 1980s. The clinical applicability of OAE testing was the primary impetus for states in the United States to adopt universal newborn hearing screening programs. Marion Downs of the University of Colorado, undoubtedly, had the greatest impact on the testing of pediatrics and, ultimately, the concept and realization of universal hearing screening of all newborns. Dr. Downs founded the first screening program in 1962 and never ceased in pushing for newborn hearing screening. According to the National Center for Hearing Assessment and Management (NCHAM) at Utah State University, all states and territories of America now have an Early Hearing Detection and Intervention (EHDI) program (National Center for Hearing Assessment and Management, n.d.).

The development of better-designed hearing aids and procedures for hearing aid fittings was also an important step forward in treating those with hearing loss. During the early 1950s, the transistor was developed, and its value in the design of wearable hearing aids was immediately apparent. An even greater impact on hearing aid design and miniaturization was the advent of digital signal processing, and by the 1990s, digital hearing aids were becoming the standard. Other important advances in hearing aids included microphone technology and better/smaller batteries. It is interesting to point out that prior to 1977, ASHA considered it unethical for audiologists to dispense hearing aids, except in the veterans hospitals. However, through the continuing interests and activities of audiologists directed toward dispensing of hearing aids throughout the 1970s, ASHA changed its perspective in 1979, and hearing aid dispensing soon became a large part of audiology practices. In 2017, the U.S. Congress passed legislation allowing hearing aids to be sold over-the-counter (OTC) for adults with mild to moderate degrees of hearing loss and established a 3-year time window to develop regulations and implementation. These OTC hearing aids are intended to be entry-level devices and will be available, primarily, through big box stores like Costco and CVS.

Cochlear implant (CI) systems were another milestone in audiology, beginning with the first CIs in the 1960s. Subsequently, there was a 30-year, slow-but-steady convincing of the profession that CIs were able to produce remarkable results in adults and children, and now CIs are well accepted in the audiology community. The progress of CI systems over the past three decades has been truly remarkable. The early CI systems were essentially an aid for speechreading, and few users could maintain a conversation without the aid of visual cues. However, as the number of electrodes increased and speech-coding strategies became more sophisticated, performance in the auditory-only condition improved several-fold. It is now quite reasonable to expect that a person with a CI will be able to converse, even on the telephone. Thirty years ago, few people would have predicted that this level of performance would ever be attainable.

There has been a relatively long history in vestibular disorders and testing. Bradford (1975) describes some of the early history in this area that includes the descriptions of nystagmus (reflexive eye movements) by Purkinjie (1820), discovery of the cerebellar and labyrinthine sources of vertigo by Flourens (1828), and the development of caloric testing by Barany (1915). Pioneering work in establishing the clinical use of electronystagmography (ENG) was done by Alfred Coats (e.g., Coats, 1975), Baloh and colleagues (e.g., Baloh et al., 1977), and Barber and colleagues (e.g., Barber & Stockwell, 1980). It was during this time that audiologists became involved with vestibular testing and rehabilitation. With advances in technology in the past decade, the electrode-based ENG method evolved to an infrared video camera method for recording eye movements (VNG) during the vestibular exam. Other advancements include the development of rotary chair testing that rotates the whole body and posturography with a platform that allows for tilting the body in different directions. One of the more recent clinical developments is the recording of vestibular evoked myogenic potentials (VEMP) involving the cervical muscles (cVEMP) or the ocular muscles (oVEMP) in response to loud sounds, which have been shown to be useful for assessing the

sensory organs (saccule and utricle) of the vestibular system (McCaslin & Jacobson, 2021).

Over the last 70+ years, audiology has evolved (often in parallel) along at least the following eight distinct paths:

- Development of auditory diagnostic tests (behavioral and physiological)
- Hearing aids and rehabilitation/treatment
- Pediatrics
- Auditory processing disorders (APDs)
- Hearing conservation
- Audiology in the educational (school) systems
- Tinnitus evaluation and therapy
- Development of vestibular tests and rehabilitation

The reader is referred to the comment boxes throughout this textbook for overviews of these paths. A more complete historical account of audiology in the United States has been published by Jerger (2009). In addition, Jerger and DeConde Johnson have an expanded chapter on the development of these paths in the second edition of this textbook (Jerger & DeConde Johnson, 2014), which is available in this textbook's companion website. As Jerger and DeConde Johnson (2014) concluded, "It is interesting to observe the degree to which these paths have interacted. We see the fruits of progress in the diagnostic path reflected in the development of APD testing, the impact of advances in electroacoustics and electrophysiology on universal screening procedures, the influence of cochlear implant advances on auditory training, and the influences of all on intervention with amplification, hearing conservation, tinnitus therapy, and audiology in the educational setting. These are, we believe, hallmarks of a robust and growing profession with a remarkable history" (p. 380).

## SYNOPSIS 1–1

- Audiology is a discipline that focuses on the study of normal hearing and hearing disorders, as well as vestibular (balance) assessment and rehabilitation. Audiology in the United States had its beginnings around the time of World War II.
- An audiologist is a licensed professional who practices audiology and is an expert on the effects of hearing loss on communication and psychosocial factors. Otology is the discipline primarily related to medical assessment and treatment of hearing and balance disorders and is the specialty practiced by otologists.
- The American Academy of Audiology (AAA) and the American Speech-Language-Hearing Association (ASHA) are the two main professional organizations serving their audiologist members. The AAA was founded in 1988 and is entirely run by and for audiologists.
- The national student organization for future doctoral-level audiologists is called the student Academy of Audiology (SAA). Most doctoral audiology programs have local chapters of SAA. Many undergraduate programs encourage undergraduates to enroll in student chapters.
- Audiology became a doctoral level profession by 2007, and today the AAA has approximately 14,000 members.
- Some key historical milestones in audiology include development of immittance measures (early 1970s), auditory brainstem response (ABR) measures (late 1970s), approval for audiologists to dispense hearing aids (1979), otoacoustic emission measures (1980s), digital hearing aids becoming the dominant type (1990s), and legislation allowing OTC hearing aids (2017).