PRECLINICAL SPEECH SCIENCE

Anatomy, Physiology, Acoustics, and Perception

THIRD EDITION

Thomas J. Hixon
Gary Weismer
Jeannette D. Hoit

Plural Publishing Inc.

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Preface

The third edition of *Preclinical Speech Science* is a carefully revised and expanded version of the second edition of the textbook. The revised parts include line-by-line edits of all chapters from the second edition for greater clarity, removal of certain sections (several of which are available as supplementary materials on the textbook companion website, including the scenarios of the previous edition), and addition of new material to chapters from the second edition, including text, figures, and recent references from the research literature.

This new edition also contains three new chapters, including Chapter 6 ("Speech Physiology Measurement and Analysis"), Chapter 13 ("Auditory Anatomy and Physiology"), and Chapter 14 ("Auditory Psychophysics"). Chapter 6 was added to complement Chapter 10 ("Speech Acoustic Measurement and Analysis") and Chapters 13 and 14 were added in response to suggestions made by colleagues and students, that this textbook would benefit from chapter-length material on Hearing Science. With the inclusion of these two chapters on hearing science, perhaps a more accurate title for the textbook would be *Preclinical Speech and Hearing Science*. Because this is the third edition of the text, we have chosen to retain the original title to be consistent with the previous editions.

The Workbook accompanying the third edition of this textbook has also been updated with complete sets of problems and exercises for the three new chapters, and revised exercises for all other chapters. The Workbook is a self-study resource, complete with answers to the problems and exercises.

A PluralPlus companion website also accompanies this new edition of *Preclinical Speech Science*. The website has supplementary text and figures, sound files, study guides, and instructor lecture slides.

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The formulation, writing, and production of this textbook has benefited from the talents, advice, and generosity of many people. First and foremost, we acknowledge and thank Maury Aaseng, the talented, kind, and wise creator of the beautiful images that are such an integral part of the text. Maury is our friend and colleague of these past dozen years, and hopefully of many years to come.

We acknowledge the following people, for reading and commenting on parts of the text, for discussions concerning presentation of material in the text and pointing us to relevant papers in the literature, for generosity in allowing us to use their outstanding figures in this book, and for funding significant time devoted to the preparation of the text. Thank you: Kate Bunton, Michelle Ciucci, Jim Hillenbrand, Corinne Jones, Joel Kahane, David Kuehn, Rosemary Lester-Smith, Bob Lutfi, Tim McCulloch, The Oros family, Robin Samlan, and Brad Story.

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For Nevi, Solly, and Isla:
Love thinking, reading, and knowing
You'll learn just what you don't know.
Know this way you are growing
By knowing what you don't know.

And for Tom, Pauline and Sadanand.
You know why.

1

Introduction

Welcome to *Preclinical Speech Science: Anatomy, Physiology, Acoustics, and Perception, Third Edition*. Two preliminaries are offered here. One is a discussion of the focus of the book, the other a discussion of the domains of preclinical speech science and preclinical hearing science.

FOCUS OF THE BOOK

Preclinical Speech Science: Anatomy, Physiology, Acoustics, and Perception is designed as an introduction to the fundamentals of speech and hearing science that are important to aspiring and practicing clinicians. The text is suitable for courses that cover the anatomy and physiology of speech production and swallowing, the anatomy and physiology of the hearing mechanism and auditory psychophysics, the acoustics and perception of speech, and general neuroanatomy and neurophysiology and its relevance for speech and hearing. It also includes sidetracks of clinical and historical interest, considerations of the scientific bases of clinical protocols and methodologies, and discussions of clinical personnel involved in the evaluation and management of disorders of speaking, hearing, and swallowing. This book provides up-to-date coverage of the science of speech and hearing, is user friendly to beginning students, yet integrative and translational for graduate students and practicing speech-language pathologists and audiologists. It is an outgrowth of the three authors' many years of teaching experience with several thousand undergraduate and graduate students.

The illustrations, done by the extremely talented artist Maury Aaseng, are a key feature of this book. These original illustrations, largely in full color, are supplemented by a small number of illustrations from other sources. The original illustrations were carefully chosen and drafted to convey only salient features, an approach in line with the written text.

DOMAIN OF PRECLINICAL SPEECH SCIENCE

The domain of preclinical speech science is portrayed in Figure 1–1. This domain encompasses speech production, speech acoustics, speech perception, and swallowing. Within this domain, consideration is given to levels of observation, subsystems of speech production and swallowing, and applications of data.

Levels of Observation

Speech production and swallowing are processes. They result in acoustic products (more so for speech

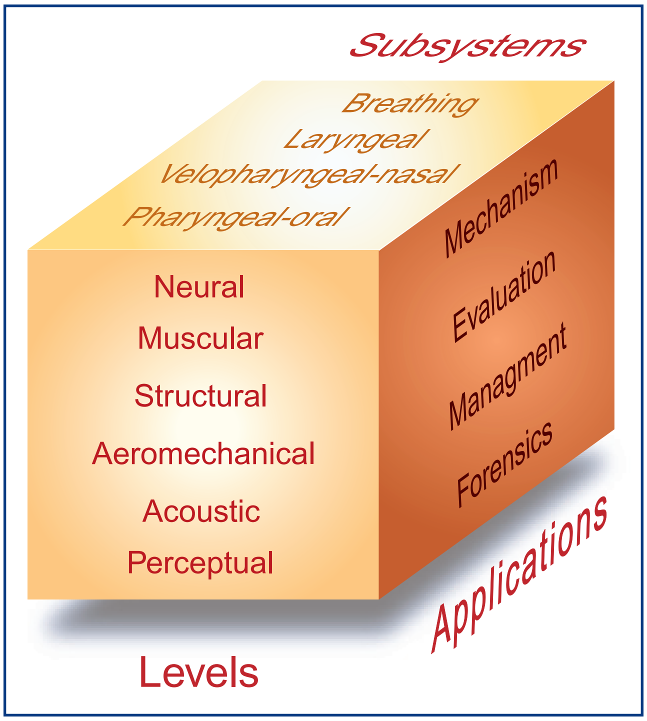

Figure 1–1. Domain of preclinical speech science.

than swallowing) and perceptual experiences. These processes, products, and experiences involve different levels of observation. Six such levels are represented in Figure 1–1: (a) neural, (b) muscular, (c) structural, (d) aeromechanical, (e) acoustic, and (f) perceptual. These levels of observation are not completely separate entities but have important interactions. These interactions are not shown in the figure but are discussed in subsequent chapters.

The neural level of observation encompasses nervous system events during speech production and swallowing. These include all events that qualify as motor planning and execution and all forms of afferent and sensory information that influence the ongoing control of speech production and swallowing. The neural level of observation pertains to the parts of the brain, spinal cord, and cranial and spinal nerves important to speech production and swallowing and to all underlying neural mechanisms, some voluntary and some automatic, some that involve awareness, and some that do not. Neural data are often derived from physical or metabolic imaging methods that reflect patterns of activation of different regions of the brain. Activation at the neural level can also be inferred from events associated with other (downstream) levels of observation.

The muscular level of observation is concerned with the influence of muscle forces on speech production and swallowing. Muscle forces are responsible for powering these two processes. Muscles are effectors that respond to control signals from the nervous system. The muscular events of speech production and swallowing are manifested in mechanical pulls and are often indexed at the periphery through the electrical activities associated with muscle contractions. Inferences about muscle activities are also made from measurements of the forces or movements generated by different parts of the speech production apparatus and swallowing apparatus. Nevertheless, there are ambiguities introduced when attempting to infer individual muscle activities from forces or movements because forces and movements are usually accomplished by groups of muscles working together. Such inferences, if they can be made at all, require a detailed knowledge of anatomy and physiology.

The structural level of observation deals with anatomical structures and movements of the speech production apparatus and swallowing apparatus. This level of observation is concerned not only with the many muscular and non-muscular structures that make up the speech apparatus, including bone, muscle, ligaments, and membranes, but also with the displacements, velocities, and accelerations/decelerations of structures and how they are timed in relation to the movements of other structures. Certain structural observations can be made with the naked eye, whereas others are hidden from view or are too rapid to be followed with the naked eye and require the use of instrumental monitoring. To the person on the street, the structural level of observation is public evidence of speech production and swallowing. Speech reading (lip reading) has its roots at this level of observation.

The structural movements of speech production and swallowing give rise to an aeromechanical level of observation. It is at this level that air comes into play. Movements of structures impart energy to the air by compressing and decompressing it and causing it to flow from one region to another. The raw airstream generated in association with the aeromechanical level is modified by structures of the speech production apparatus and swallowing apparatus that lie along various passageways. The products of the aeromechanical level are complex, rapid, and nearly continuous changes in air pressures, airflows, and air volumes. These products are usually "invisible," especially for swallowing. However, those who speak and smoke at the same time or who speak in subfreezing temperatures often provide the observer with the opportunity to visualize certain aeromechanical events.

The acoustic level of observation is fully within the public domain. Although certain aspects of swallowing may be accompanied by sounds, primacy at this level pertains to the generation of speech sounds. The raw material of the acoustic level is the sonorous, buzzlike, hisslike, and poplike sounds that result from the speaker's valving of the airstream in different ways and at different locations within the speech production apparatus. This raw material is filtered and conditioned by its passage through the apparatus and radiates from the mouth or nose, or both, in the form of very fast and nearly continuous air pressure changes experienced as sound waves. These sound waves propagate from the speaker's mouth and can be coded in terms of frequency, sound pressure level, and time and are what constitute speech, the acoustic representation of spoken language. The acoustic level is important in face-to-face communication and in the use of telephones, radios, televisions, hearing aids and cochlear implants, and various forms of recording. It is this level that makes it possible to communicate effectively around corners, through obstacles, in the dark, and over long distances.

The perceptual level of observation has somewhat different manifestations for speech and swallowing. For speech, auditory analysis of the speech (acoustic) signal allows the listener to recognize phonetic cues that are consistent with the listener's knowledge of the sound system of a language. The speaker is also a perceiver of her own speech acoustic signal, using it to check that the signal she intended is the one she produced. Visual information is another source of information for the perception of speech. Listeners, even those with normal hearing, are known to combine acoustic and visual information for the most effective perception of speech. In contrast, swallowing relies less on auditory and visual information, but is highly dependent on the more subconscious experiences of kinesthesia and proprioception (awareness of position and movement characteristics of body structures, such as the tongue and jaw). Swallowing is also guided by touch and pressure sensations (as in awareness of contact of the tongue with the hard palate), which originate in sensory receptors embedded in the skin and muscles. Taste, which is detected by specialized taste receptors on the tongue and other oral structures, and consistency of food, which is detected by tactile receptors in the pharyngeal-oral component of the speech apparatus, can also serve as perceptual information for swallowing. Of course, cognitive processes contribute to the perceptual level of observation for both speech and swallowing. Cognitive processes in speaking, swallowing and hearing are not treated in detail in this text.

Subsystems of Speech Production and Swallowing

The activities of speech production and swallowing share many of the same structural and functional components. These components can be divided, somewhat arbitrarily, into subsystems. Speech production subsystems may differ when chosen by a linguist versus a speech scientist versus a speech-language pathologist; and swallowing subsystems may differ when chosen by a swallowing scientist versus a gastroenterologist versus a speech-language pathologist. For the purposes of this book, four subsystems are used for speech production and swallowing. As illustrated in Figure 1–1, these include the (a) breathing apparatus, (b) laryngeal apparatus, (c) velopharyngeal-nasal apparatus, and (d) pharyngeal-oral apparatus. The functional significance of each of the four subsystems differs between speech production and swallowing, but each subsystem is critically important to its respective behaviors and each manifests clinical signs that can reveal abnormality.

The breathing apparatus is defined in the present context to include structures below the larynx within the neck and torso. These are, most importantly, the pulmonary apparatus (pulmonary airways and lungs) and chest wall apparatus (rib cage wall, diaphragm, abdominal wall, and abdominal content). During speech production, the breathing apparatus provides the necessary driving forces while simultaneously serving the functions of ventilation and gas exchange. During swallowing, the breathing apparatus engages in a period of apnea (breath holding) to protect the pulmonary airways and lungs from the intrusion of unwanted substances (food and liquid). The breathing apparatus is the largest of the subsystems and its role in speech production and swallowing is fundamentally important.

The laryngeal apparatus lies between the trachea (windpipe) and the pharynx (throat) and adjusts the coupling between the two. At times, the laryngeal airway is open to allow air to move in and out of the breathing apparatus, whereas at times it is adjusted to obstruct or constrict the airway. Very rapid to and fro movements of the vocal folds within the larynx create voiced sounds and give the laryngeal apparatus its colloquial label “voice box.” The larynx can also produce noisy sounds, like whisper. During swallowing, the laryngeal apparatus is active in closing the laryngeal airway to protect the pulmonary airways. Food and liquid are then able to pass over and around the larynx and into the esophagus on their way to the stomach.

The velopharyngeal-nasal apparatus consists of the upper pharynx, velum, nasal cavities, and outer nose. It is important to include the nasal portion of this subsystem because it can have a significant influence on the aeromechanical and acoustic levels of the speech production process. When breathing through the nose, the velopharyngeal-nasal airway is open. When speaking, the size of the velopharyngeal port varies, depending on the nature of the speech produced. For example, consonant sounds that require high oral air pressure are typically associated with airtight closure of the velopharyngeal port, whereas nasal consonants are produced with an open velopharyngeal port. Function of the velopharyngeal-nasal apparatus during swallowing is concerned mainly with keeping the velopharynx sealed airtight. This prevents the passage of food and liquid into the nasal cavities while substances are moved backward and downward through the oropharynx.

The pharyngeal-oral apparatus comprises the middle and lower pharynx, oral cavity, and oral vestibule. During running speech production, the apparatus is typically open during inspiration and makes different adjustments for consonant and vowel productions during expiration, including the generation of transient, voiceless, and voiced sounds and the filtering of those sounds. During swallowing, the pharyngeal-oral apparatus prepares food and liquid and propels it to the esophagus.

Applications of Data

There are many applications of data obtained about speech production and swallowing. These applications depend on who selects and defines the data and what the goals are for collecting and analyzing them. Figure 1–1 shows four important applications of data: (a) understanding mechanism, (b) evaluation, (c) management, and (d) forensics.

One application of data is the understanding of mechanism. This use provides the foundational bases for knowing how speech is produced and how swallowing is performed. Such foundational bases are important for their heuristic value in elucidating fundamental processes and principles and for differentiating normal from abnormal.

Another application of data is their use in evaluation. This use is usually practical in nature and involves quantitative determinations of the status and functional capabilities of an individual's speech production, speech, and swallowing. Evaluation first enables a determination as to whether or not abnormality exists. If abnormality does exist, then appropriate evaluation may contribute to: (a) making a diagnosis, (b) developing a rational, effective, and efficient management plan, (c) monitoring progress during the course of management, and (d) providing a reasonable prognosis as to the extent and speed of improvement to be expected. For example, a specific use of subsystems analysis in the evaluation of speech production is the determination of how individual subsystems contribute to deficits in speech intelligibility. Two individuals may have equivalent intelligibility problems as determined by formal tests but have different subsystems "explanations" for their deficits. The careful evaluation of subsystems performance can point to which parts of the speech production apparatus may be most responsible for speech intelligibility deficits and how those parts should be addressed in management. The subsystems approach to evaluation cannot be applied effectively without solid knowledge of normal structures and functions, as described in this text.

A third application of data is management. Different management strategies may be based on any of the six levels of observation and include any of the four subsystems of speech production and swallowing. Strategies may include adjusting individual variables or combinations of variables, staging the order of different interventions, and providing feedback about speech production and swallowing processes, products, and experiences. Management data provide information about outcomes and whether or not interventions are effective, efficient, and long lasting. Management data can also be used to compare and contrast different interventions to arrive at optimal choices.

The remaining application of data is their use in forensics. This application is concerned with scientific facts and expert opinion as they relate to legal issues. The speech scientist and speech-language pathologist are sometimes called on to give legal depositions or to testify in courts of law in a variety of forensic contexts. Forensic uses of data may include issues pertaining to speaker identification, speaker status under the influence of drugs or alcohol, and speaker intent at deceit, among others. Forensic uses of data may also relate to personal injury claims or malpractice claims. These may involve speech production, speech, or swallowing alone, or in different combinations, and may include adversarial depositions and testimonies of other experts. Under such circumstances, the status and capabilities of the individuals claiming personal injury or malpractice may be considered from the perspective of underlying mechanism, evaluation, and management.

DOMAIN OF PRECLINICAL HEARING SCIENCE

The domain of preclinical hearing science is portrayed in Figure 1–2. This domain encompasses audition, which serves the purpose of hearing and recognizing environmental sounds, music, speech acoustic signals, and electronically transmitted signals (as in the case of hearing aids and cochlear implants). Like the domain of preclinical speech science, consideration is given to levels of observation, subsystems, and applications of data.

Levels of Observation

Figure 1–2 shows levels of observation for audition. They include: (a) acoustic (pressure waves), (b) aeromechanical, (c) structural, (d) muscular, (e) mechanosensory, and (f) neural. This is consistent with the idea of speech production as the output and audition as the input of the speech communication process.[1]

[1]It is recognized that other forms of communication can be conceptualized in terms of output-input levels and processes. This includes sign language (gesture as output, vision as input), communication devices (e.g., language boards as output, vision as input), and speech synthesizers (synthesized speech as output, audition as input). Other examples can be imagined. This textbook does not cover these forms of communication in detail.

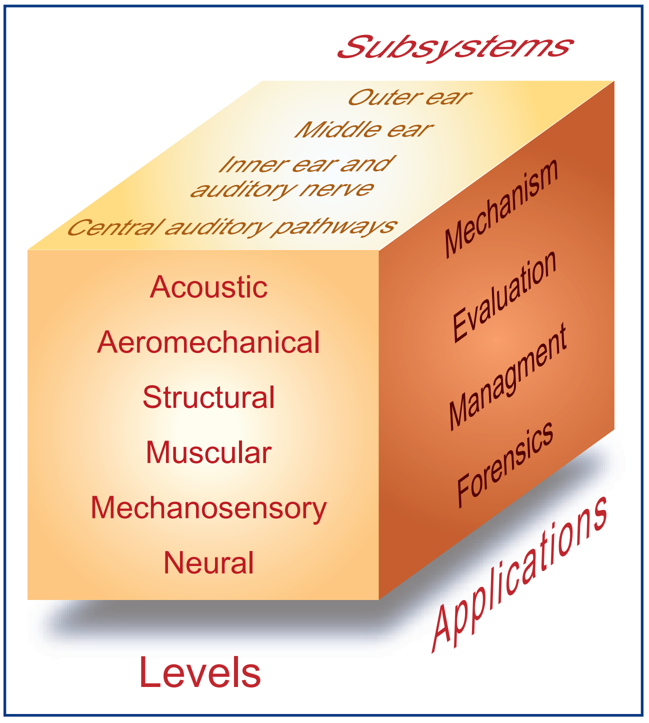

Figure 1–2. Domain of preclinical hearing science.

The acoustic level refers to the frequencies, amplitudes, and temporal characteristics of pressure waves that enter the ear at its opening to the atmosphere. As in the case of the acoustic level of speech production, the acoustic level is public. The signal can be analyzed by sophisticated instruments to extract and modify the spectral content and the way in which it varies over time. This level of observation is relevant to establishing the analysis capabilities of the human auditory system, both normal and disordered.

The aeromechanical level is important because the auditory system responds to the acoustic pressure wave (the "aero" part of the term) with mechanical vibrations of auditory structures. These structures include the tympanic membrane (the eardrum) and the ossicles, which are three tiny bones within the middle ear cavity. These mechanical vibrations replicate the vibrations in air that create pressure waves, but only to a point. The differences between auditory analysis of frequency, amplitude, and temporal characteristics and these characteristics in pressure waves reveal the analysis capabilities of the human ear.

The structural level includes the anatomy of the auditory system as well as the physiology of hearing. As in the case of the structural level of speech science, the anatomy of the auditory system is complex and interesting, and well suited to transmitting vibratory energy from the outer ear to the inner ear. Many of these structures are moving components, such as the tympanic membrane, the ossicles, the fluid within the cochlea (inner ear), and within the fluid a special membrane on which the auditory sense organs are located. A peripheral nerve is dedicated to transmission of auditory information from the cochlea to the central nervous system, and within the central nervous system complex pathways carry auditory information from the brainstem to the cortex.

The muscular level of the auditory system is simple compared with the speech production system, but still critical to hearing processes. A few muscles may cause subtle movements of the pinna (the structure attached to the head and most visible as an auditory structure), but in humans this ability has mostly disappeared. Contraction of two muscles in the middle ear, an air-filled cavity behind the tympanic membrane, stiffens the ossicles and tympanic membrane, and in doing so reduces the transmission of sound energy from the air to the cochlea. One of the muscles plays a primary role in a reflex that minimizes the possibility of damage to the cochlea when the auditory system is exposed to extremely intense sounds.

The mechanosensory level refers to the transduction of mechanical energy to neurochemical energy that is observed when fluid displacements within the cochlea (the mechanical part of the level) are transformed into neurochemical energy (the sensory part). This transformation takes place at the hair cells within the cochlea: fluid movements bend the hair cells, which cause the electrical potential of hair cells to change, which in turn releases a neurotransmitter that initiates firing of nerve fibers in the auditory nerve. The hair cells are the sensory receptors of audition, much like rods and cones within the retina are the sensory receptors for vision.

The neural level of audition includes the auditory nerve, a peripheral nerve that emerges from the cochlea and inserts into the brainstem. Inside the brainstem the fibers travel to brainstem nuclei (clusters of neuronal cell bodies), which send fibers to increasingly higher levels of the central nervous system until they reach cell bodies in the cortex. These fibers, called tracts, constitute the central auditory pathways. Fibers within the auditory nerve and nuclei and tracts that compose the auditory pathways have a tonotopic arrangement, meaning specific fibers and cells respond selectively depending on the frequencies of the incoming acoustic stimulus.

Subsystems of the Auditory System

The idea of subsystems is not frequently used to describe audition, but the concept can be easily adapted for a parallel to the speech production system. As shown in Figure 1–2, the auditory subsystems include: (a) the outer ear, (b) the middle ear, (c) the inner ear and auditory nerve, and (d) the central auditory pathways.

The outer ear includes the pinna (also called the auricle) and the external auditory meatus (the external ear canal). The structures that make up the pinna are variable across humans, and when exposed to sound pressure waves emphasize energy at certain frequencies and de-emphasize energy at other frequencies. The pinna may play a role in the localization of sound sources.

The middle ear is an air-filled cavity. It includes: (a) one surface of the three-layer tympanic membrane (eardrum), the entire membrane vibrating in response to sound energy conducted down the external ear canal, (b) the three connected ossicles (bones) that transmit vibrations of the tympanic membrane to the cochlea (an inner ear structure), (c) the opening of the auditory tube that leads to a closed tube (opened intermittently) in the pharynx, (d) two muscles that contract to stiffen the ossicles and in doing so make the transmission of sound energy from the tympanic membrane to the cochlea less efficient, and (e) segments of several nerves and blood vessels.

The inner ear contains the bony, fluid-filled cochlea, the ganglia, and cranial nerve VIII, which is composed of the auditory and vestibular nerves. Inside the snail-shaped cochlea is a membrane containing the sensory organs of hearing. This membrane and its complex structures are displaced by movement of the fluid caused by vibration of the ossicles. The inner ear also contains the vestibule where the sensory apparatus for balance is located. Vestibular structures are similar but not identical to those of the cochlea.

The central auditory pathways include a series of nuclei (the cell bodies of neurons) and fiber tracts that connect these nuclei to other parts of the brain. The pathways are dedicated to the transmission of auditory information from the brainstem to the auditory cortex. Within the cortex, several regions of cells perform increasingly complex analysis of auditory information, including the analysis resulting in the perception of speech.

Like the subsystems of speech production, the auditory subsystems are not independent and can be organized in different ways. For example, a commonly used organization includes three auditory subsystems: (a) the conductive component, (b) the sensorineural component, and (c) the central auditory pathways. The conductive component includes the outer and middle ears, the sensorineural component the cochlea and auditory nerve, and the central component the auditory pathways described above.

Applications of Data

Like speech production, the applications of data on audition serve many purposes. These purposes include: (a) understanding mechanism, (b) evaluation, and (c) management. A forensic application of audition can also be proposed, although it is clearly part of evaluation.

As stated above for speech production, knowledge of the structure and function of the auditory system is required to distinguish normal from abnormal. In addition, the knowledge is basic to the everyday professional life of speech-language pathologists and audiologists. Professionals who evaluate, diagnose, and manage communication disorders must be able to communicate with allied professionals who are not well versed in the structure and function of the auditory system and need coherent explanations of the basis of a hearing deficit. Similarly, clients and their family members are often interested in knowing the underlying science of a hearing disorder. The speech-language pathologist and audiologist who have mastered auditory structure and function can provide this information in a clear and simplified way.

The second application of data about audition is the evaluation of hearing disorders. Often the first phase of evaluation is performed by audiologists who use a variety of tests to determine the magnitude of hearing loss and the probable structure(s) responsible for the loss. Hearing disorders take many forms, which are often correlated with specific auditory subsystems. For example, an audiologist uses a range of pure tones (single-frequency acoustic events) to document the magnitude of hearing loss as a function of frequency. Depending on the pattern of hearing loss across frequencies, follow-up tests are performed to determine if the loss is in the conductive part of the mechanism, the sensorineural part, or a combination of the two. Sometimes a client shows very little hearing loss by these tests but has difficulty understanding speech. This often suggests a problem in the auditory nerve and/or central auditory pathways, and there are special tests to evaluate this possibility. These tests, and their results, cannot be understood in the absence of detailed knowledge of auditory structure and function.

The third application is management. Management of hearing problems includes the restoration, to the degree possible, of hearing function for those who have suffered hearing loss as children or adults; it also includes the provision of auditory stimulation to those born deaf or deafened by disease or accident. Hearing aids and cochlear implants are the two most common devices used in managing acquired hearing loss in children and adults (or in children who are born with hearing loss but are not deaf), and providing auditory stimulation in children born deaf or older individuals who have lost all hearing. These devices must be programmed with settings that depend on the structure and function of the diseased auditory system. The most effective programming emerges from expert knowledge of how damage to different auditory structures results in different magnitudes and patterns of hearing loss. In addition, the programming must take account of the acoustic properties of speech and how they relate to the ability to understand speech. This is because the primary purpose of any hearing device is to facilitate the understanding of speech.

Finally, an application of forensics in audition is the use of clinical tests that can detect functional hearing skills in persons who claim extensive or complete hearing loss due to accidents, disease, or other factors. This is part of the evaluation component of audition, but the potential legal implications (insurance fraud or compensation from an employer) justifies the use of the "forensic" label for this aspect of auditory evaluation.

REVIEW

Preclinical Speech Science: Anatomy, Physiology, Acoustics, and Perception is intended as an introduction to speech science and hearing science, both of fundamental importance to aspiring clinicians and practicing clinicians.

The text is suitable for different courses that cover anatomy and physiology of speech production and swallowing, hearing science, and the acoustics and perception of speech.

The material in the text is integrative and translational, applicable to both undergraduate and graduate students, and a source of continuing education and reference for practicing speech-language pathologists and audiologists.

The domain of preclinical speech and hearing science encompasses different levels of observation, different subsystems, and different applications of data.

Levels of observation in speech science include the neural, muscular, structural, aeromechanical, acoustic, and perceptual levels.

For hearing science, the levels of observation include the acoustic, structural, aeromechanical, muscular, mechanosensory, and neural.

Subsystems of speech production and swallowing include the breathing apparatus, laryngeal apparatus, velopharyngeal-nasal apparatus, and pharyngeal-oral apparatus.

Subsystems of hearing science include the outer ear, middle ear, inner ear and auditory nerve, and central auditory pathways, although an alternative and clinical set of subsystems includes the conductive, sensorineural, and auditory pathways components of the hearing mechanisms.

Applications of data include the understanding of mechanism, evaluation, management, and forensics.

Sidetracks

Throughout the book you'll find a series of sidetracks. These are short asides that relate to topics being discussed in the main text. Many of the sidetracks in the book are a bit less formal and a bit more lighthearted than the main text they complement. This is intended to enhance your reading enjoyment and to put some fun in your study of the material. We hope you enjoy reading these sidetracks as much as we enjoyed writing them.

2

Breathing and Speech Production

INTRODUCTION

The breathing apparatus moves air into and out of the body for the purpose of sustaining life as well as for performing other important functions such as speaking. It includes an energy source and passive components that couple this source to the air it moves.

This chapter begins with detailed consideration of the anatomical bases of breathing, forces and movements of breathing, control variables of breathing, neural control of breathing, and ventilation and gas exchange during tidal breathing. The latter part of the chapter is dedicated to speech breathing and selected variables that influence it.

ANATOMY OF THE BREATHING APPARATUS

The breathing apparatus is located within the torso (body trunk). A skeleton of bone and cartilage forms the framework for the breathing apparatus. This skeletal framework and the subdivisions of the breathing apparatus are considered here. The muscles of the breathing apparatus are covered under Forces of the Breathing Apparatus.

> **Coming to Terms**
>
> Terms can either enlighten you or get you into verbal quagmires. Respiratory physiologists have gone out of their way to be precise in their use of terms. They've even held conventions to iron out their differences in language. It's a good idea to take a little extra time and care when reading the early sections of this chapter. Let the lexicon of the respiratory physiologist take firm root. Don't be tempted to skip over parts just because the words in the headings look familiar to you. You may be surprised to find that a term you thought you understood actually has an entirely different meaning to a respiratory physiologist.

Skeletal Framework

The skeletal framework of the breathing apparatus is depicted in Figure 2–1. At the back of the torso, 34 irregularly shaped vertebrae (bones) form the vertebral column or backbone. The uppermost 7 of these vertebrae are termed cervical (neck), the next lower 12 are called thoracic (chest), and the next three lower groups of 5 each are referred to as lumbar, sacral, and coccygeal (collectively, abdominal). The vertebral column constitutes a back centerpost for the torso.

The ribs make up most of the upper skeletal framework. They are 12 flat, arch-shaped bones on each side of the body. The ribs slope downward from back to front along the sides of the torso, forming the rib cage and giving roundness to the framework. At the front, most of the ribs attach to bars of costal (rib) cartilage, which, in turn, attach to the sternum or breastbone. The sternum serves as a front centerpost for the rib cage. The typical rib cage includes upper pairs of ribs attached to the sternum by their own costal cartilages, lower pairs that share cartilages, and the lowest two pairs that float without front attachments.

The remainder of the upper skeletal framework is formed by the pectoral girdle (shoulder girdle). This structure is near the top of the rib cage. The front of the pectoral girdle is formed by the two clavicles (collar bones), each of which is a strut extending from the sternum over the first rib toward the side and back of the rib cage. At the back, the clavicles attach to two triangularly shaped plates, the scapulae (shoulder blades). The scapulae cover most of the upper back portion of the rib cage.

Two large, irregularly shaped coxal (hip) bones are located in the lower skeletal framework. These two bones, together with the sacral and coccygeal vertebrae, form the pelvic girdle (bony pelvis). The pelvic