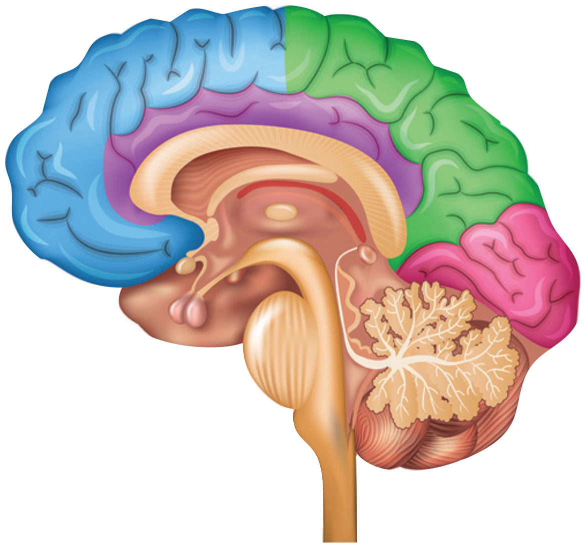

NEUROANATOMY AND NEUROPHYSIOLOGY

FOR SPEECH AND HEARING SCIENCES

SECOND EDITION

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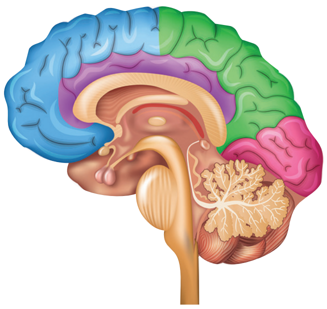

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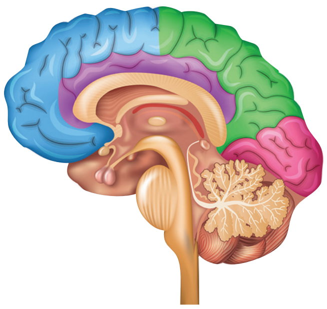


PREFACE

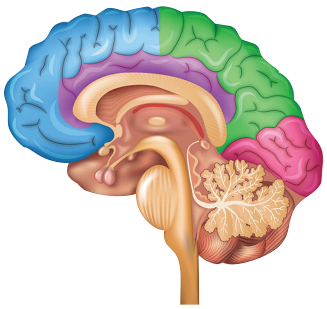
The study of the brain and its functions is at the heart of communication sciences and its disorders. There are many neurological conditions that immediately come to mind when we think of maladies affecting the brain, and the nervous system is intrinsically involved in most of the activities of our field, from the cognitive and motoric aspects of phonology or the impact of myelination on normal language development to (central) auditory processing disorder. All human actions arise from processes of the nervous system, and we can trace many of the deficits treated in our professions to some type of failure affecting this nervous system.

It is with this understanding that we sought to create this textbook and study materials. Neuroscience is the study of what is arguably the most complex phenomenon in the known universe, the nervous system. We, as humans, have brains that are uniquely complex in structure and, most important, in function. The human brain has evolved to work in complex networks that entrain multiple areas of the brain, giving it a capacity for problem-solving that outstrips our nearest evolutionary neighbors.

As audiologists, speech-language pathologists, and speech and hearing scientists we are in a position to see the inner workings of the brain firsthand through the many neuropathologies with which we are presented. The basal ganglia circuits are uniquely revealed in the tremor, hyperkinesia, and hypokinesia of conditions such as Parkinson's disease, Huntington's disease, or hepatolenticular degeneration. The impact of disease conditions such as multiple sclerosis on hearing function, cognition, and speech production can provide evidence for site of lesion activity if we are able to recognize the signs and symptoms related to the brain region affected. We are challenged on a daily basis to provide meaningful therapy to individuals who have suffered cerebrovascular accident or trauma, and we must work to provide treatment to help overcome the life-changing effects of those lesions. To do this requires a deep knowledge of this extraordinarily complex nervous system but also that the clinician develop the intention to continually learn about the nervous system and new treatments that emerge. As an example, behavioral treatments are emerging that have been shown to differentially increase the brain volume and function in areas shown to be active during attention activities, expression of compassion, and awareness of others (theory of mind). Therapies directed toward these dysfunctions could directly affect the lives of those with right hemisphere dysfunction, and the wise clinician will keep a close eye on developments such as these. To do this requires knowledge, desire, and intention. It is our deep hope that these materials can provide at least some of the motivation for a lifetime of study in neuroscience. A central component of this text is the Neuroquest software that can be accessed on the PluralPlus companion website. We owe a deep debt of gratitude to Dr. Sadanand Singh, who, many years ago as our first publisher of another book, insisted that study software was a critically important component of any text. Now, more than 20 years later, we are pleased and humbled to continue with his charge to make the current textbook as powerful a learning tool as we can.

The purpose of this textbook is to help the undergraduate and graduate student of speech-language pathology learn about the structure and function of the brain. This knowledge will aid not only in accurate clinical diagnosis but also in the correct use of evidence-based practice methods for speech therapy. There are many neurological diseases in which the primary signs and symptoms are within the domains of speech, language, or hearing disorders, so there is fertile ground for application of the knowledge acquired through study of neuroscience. We have included a number of clinical cases at the end of each chapter to prime the student's problem-solving clinical skills in his or her future profession. Most of the cases include neurological assessments that were performed over the course of treatment (sometimes even 10 years after initial neurological diagnosis), which we have included to help the reader recognize the timing of the speech or language disorder as related to the timing of the other neurological symptomatology.

This textbook is divided into 14 chapters. Chapter 1 briefly overviews the nervous system and sets the stage for studying neuroanatomy and neurophysiology by including disorders of audiology, speech, and language that students in audiology and speech-language pathology need to be aware of. Chapters 2 and 3 discuss the structure and function of cellular components of the central nervous system, including how the signals are propagated (Chapter 2) and the function of basic reflexes (Chapter 3). Chapter 4 discusses the cerebral cortex, including landmarks and components and their relation to our disciplines. Chapters 5 and 6 discuss areas and structures beneath the cortex (subcortex), including the basal ganglia, hippocampus, thalamus (Chapter 5), and brainstem (Chapter 6), as well as their associated connections to the cortex. Chapter 7 is dedicated to presentation of the cranial nerves, many of which are critical to hearing and speech. Chapters 8 and 9 discuss the cerebellum, the spinal cord, and their fiber connections. Chapter 10 focuses on the cerebrovascular supply to the brain, elaborating on the vascular supply critical for speech, language, and hearing. Chapter 11 aims to provide students with knowledge about the function for the neural control of speech and swallowing, including theoretical models of speech production. Chapter 12 is devoted to the auditory mechanism, including the auditory pathway and cortical processing of the auditory signal. Chapter 13 presents the prenatal and postnatal development of the brain and the auditory mechanism, followed by changes that occur in those two systems as a result of the aging process. Chapter 14 provides the interested reader with a review of large brain networks, with a focus on the networks associated with our professions.



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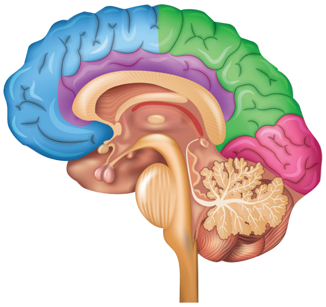
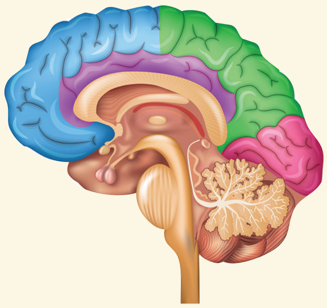


ABOUT THE AUTHORS

J. Anthony (Tony) Seikel, PhD, is emeritus faculty at Idaho State University, where he taught graduate and undergraduate courses in neuroanatomy and neuropathology over the course of his career in Communication Sciences and Disorders. He is coauthor of numerous chapters, books and research publications in the fields of speech-language pathology and audiology. His current research is examining the relationship between orofacial myofunctional disorders and oropharyngeal dysphagia.

Kostas Konstantopoulos, PhD, is an associate professor at the University of the Peloponnese, Greece, teaching neuroanatomy and all neurogenic courses. He is the first author of a textbook published in the United States about neuroimaging in neurogenic communication disorders. He currently serves as the chair for the bachelor's degree in speech and language therapy. In the past, he served as coordinator for the bachelor's degree and master's degree in speech therapy at the European University Cyprus, Cyprus. He has extensive clinical and research experience in neurogenic communication disorders spanning 20 years in various clinical settings, and 8 years of experience in clinical assessment and treatment of speech and dysphagia at the Cyprus Institute of Neurology and Genetics. Most of the case histories in the chapters of this textbook have been drawn from his files and referred from all four neurology clinics in the Cyprus Institute of Neurology and Genetics.

David G. Drumright, BS, grew up in Oklahoma and Kansas, taught electronics at DeVry for several years, then spent 20 years as a technician in acoustics and speech research. He developed many programs and devices for analysis and instruction in acoustics and speech and hearing. He has been semiretired since 2002, working on graphics and programming for courseware.



Learning Outcomes for Chapter 1

- Discuss the major structures of the central nervous system.
- Define the major structures of the peripheral nervous system.
- State the components of the neuron and their basic functions.
- State the difference between afferent and efferent systems.
- Identify the difference between volitional and reflexive actions.
- Explain the spinal reflex arc and its components.
- Discuss the relevance of reflexes to the developing infant.
- Recognize the importance of the interplay between agonist and antagonist musculature in fine motor control.
- State the role of muscle tone in maintaining a preparatory set for motor activity.

1 INTRODUCTION AND OVERVIEW

Abbreviations Used in Chapter 1

ADHD: attention deficit-hyperactivity disorder
ANS: autonomic nervous system
ANSD: auditory neuropathy spectrum disorder
(C)APD: (central) auditory processing disorder
CNS: central nervous system
DNA: deoxyribonucleic acid
EMG: electromyography
ENS: enteric nervous system
FBC: full blood count
FISH: fluorescence in situ hybridization test
GA: gestational age
NCS: nerve conduction study
NIHL: noise-induced hearing loss
PNS: peripheral nervous system
SSNL: sudden sensorineural hearing loss
VSD: ventricular septal defect

Welcome to the world of neuroscience! The nervous system is the most complex structure in nature, and perhaps in the known universe. We remain awed and humbled by this structure and its functions, and hope that we can convey a tiny bit of that to you as you begin your studies into the world of the brain.

Neuroscience is a lot like a metropolitan area: There are marvelous sites to see, but you have to choose which road to take to get to them. You might be coming from out of town, or you might live there. In either case, you find the roads that lead you where you want to go and then you take them. In many ways, this concept reflects our motivation for writing this text. We have chosen a path to your learning that will take you from an understanding of structure at the smallest levels to a knowledge of the larger structure and, ultimately, the regional functionality of that structure. We have focused on the structures of audiology and speech-language pathology in this text, much as you might choose the Museum of Modern Art over the Guggenheim if you lived in New York.

Our part of neuroscience, as members of the communication sciences and disorders community, contains some of the most important structures and functions of the brain. We do not make this claim lightly or from an arrogant point of view. Audiologists and speech-language pathologists work with people with diseases that affect the very heart of what we consider to be our most human traits. Cognitive deficits arising from dementias, such as those caused by Alzheimer's disease, rob a person of their memory, personality, and communication ability. Auditory function, which is so critical to the development of speech and language, can be severely compromised through small lesions to the temporal lobe, thalamus, or auditory pathway. Left hemisphere stroke can eliminate the ability to communicate, and right hemisphere stroke can strike at a person's ability to develop connectedness with others and even compassion. Damage to subcortical structures such as the basal ganglia can result in movement disorders that

- Discuss the role of the extrapyramidal system in fine motor control and muscle tone maintenance.
- State the role of body sensors and the cerebellum in support of skilled movement.
- Explain the role of executive functions in completing actions.
- Recognize the difference between deep and superficial sensation.
- Identify the differences among somatic, kinesthetic, and special sensations.
- Define the difference between anatomy and physiology.
- Define the differences between autonomic and somatic nervous systems.
- Identify the differences between sympathetic and parasympathetic systems.
- Define the terminology of anatomy and physiology as they relate to the study of the nervous system.
- Define specific terminology in the fields of audiology and speech-language pathology as they relate to neuropathology.

significantly alter quality of life, and damage to the right parietal lobe can result in significant deficits in the ability to attend to a stimulus or even recognize one's own body parts. All of these areas fall within our domains as audiologists and speech-language pathologists. We have felt both awed and honored to be in professions that bring us so close to the epicenter of what it is to be human. We also feel a deep responsibility to our students and their future clients. We must never forget the awesome responsibility we have to improve the lives of our clients. Welcome to the nervous system!

We begin our discussion in this chapter with an overview of the anatomy of the brain and basic functioning, followed by examination of the systems of the brain. We discuss some important details about terminology before starting our journey through the nervous system itself.

OVERVIEW OF THE NERVOUS SYSTEM

The nervous system and its proper function are essential to all of the work of our professions, whether we work with auditory function, speech, swallowing, cognition, or language. Our field is communication science, and the nervous system is all about communication.

At the most basic level, the nervous system is made up of billions of component parts termed **neurons** (also known as nerve cells), which are cells that are specialized for communication. The sheer numbers of neurons and complexity of their interactions are the means by which cognition, language, speech, and auditory processing developed in humans (Amaral & Strick, 2013).

Neurons receive information and convey it to the next neuron (Figure 1–1). Generally, neurons have a **dendrite** (the receptive component), a **soma** or body (the portion respon-

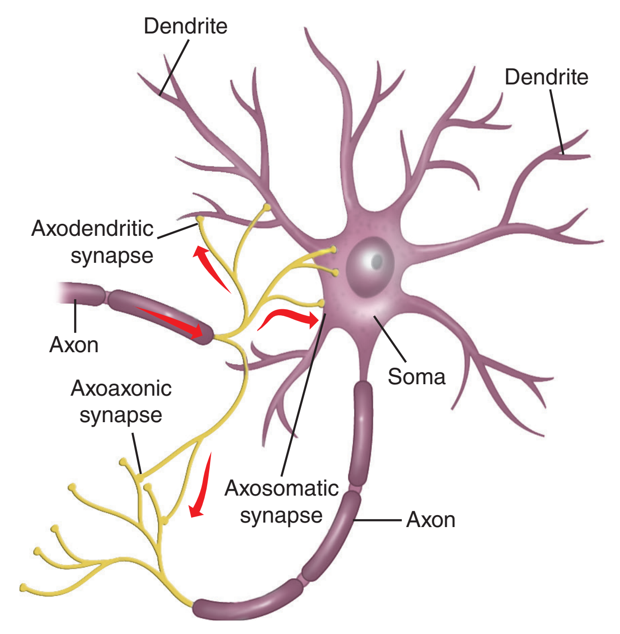


FIGURE 1–1. Information from a neuron is conveyed from the axon of that neuron to the dendrite or the body of the downstream neuron. *Source:* Adapted from Seikel, Drumright, and King (2016). *Anatomy & physiology for speech, language and hearing* (5th ed.). Cengage Learning Inc. Reproduced by permission.

sible for metabolic functions), and an **axon** (the portion responsible for exciting the next neuron). When information of sufficient strength is received at the dendrite, a **miniature excitatory postsynaptic potential** is generated that passes to a point of the axon where an action potential is generated. This action potential releases **neurotransmitter substance** into the synapse or gap between the axon and the dendrite of the next neuron in the chain, and this causes ions to pass into the dendrite, stimulating it to excitation. Thus, information can pass through the neural chain from one neuron to another, with the purpose of activating muscle, conveying sensory information, or solving some complex computational problem. We discuss generation of the action potential and communication between neurons in depth in the next chapter, but please realize that this is the basic *functional* element of the brain. With this basic process, all neurons communicate to accomplish the many tasks we demand of the nervous system.

In anatomy we refer to **organs** as groups of cells with functional unity. This holds for the anatomy of the nervous system as well. There are many types of neurons with varied functions that combine to form nuclei within the nervous system and perform specific functions. The sensory systems provide the best examples of this: The cochlear nucleus of the auditory nervous system is the first site of feature extraction for the auditory signal transduced within the cochlea. In this case, the cochlear nucleus is something of an analytical filter. The next nucleus in the chain (superior olive) is responsible for localizing sound in space. In both cases, these two **nuclei** are made up of neurons with special functions. The nervous system has many similar nuclei with wide varieties of functions, and by studying those nuclei we can start to see how the nervous system accomplishes its tasks (e.g., Baehr & Frotscher, 2012; Pickles, 2012).

As we discuss in the next section, the nervous system can be broadly broken down into the **central nervous system** (CNS) and the **peripheral nervous system** (PNS) (Tables 1–1 and 1–2). The CNS consists of the cerebral cortex and other subcortical structures, brainstem, cerebellum, and spinal cord. The PNS consists of the cranial and spinal nerves.

The **cerebral cortex** stands alone in the nervous system as the site of both voluntary action and cognition (Brodal, 2004). It is where information is processed consciously and decisions are made about action. The **cerebrum** is the home to language processing and planning, as well as execution of speech, and is the site of all complex conscious activities. In a sense, you can think of it as the awakened brain. Let's review both motor execution and sensory processing as a means of discussing the nervous system components.

Motor activity is initiated in the frontal lobe of the cerebral cortex, at an area known as the **motor strip**. As an example, your cognitive processes might provide you with the motivation to bend your finger. That intention is conveyed as a motor plan to the neurons of the brain on the motor strip that are associated with activating the muscles of the finger. The impulse to flex your finger passes out of the cerebrum on efferent projection fibers with axons that pass through the brainstem and into the spinal cord. **Efferent** neurons are those with the role of "causing an effect," as in activating a muscle. These particular fibers terminate in the thoracic region, where they synapse with neurons of the PNS, and those neurons activate muscles to cause the flexing that was planned by the cortex. This simplification ignores some very large details, but the concept holds firm: The cerebral cortex is responsible for the concept that activates the voluntary

TABLE 1–1. Major Structures of the Central Nervous System and Peripheral Nervous System

Central nervous system	Subcomponents
Cerebrum	Frontal lobe Parietal lobe Occipital lobe Temporal lobe Insular cortex Limbic system Hippocampus
Brainstem	Medulla oblongata Pons Midbrain Cerebral peduncles Brainstem pathways and nuclei
Subcortex	Thalamus Subthalamus Epithalamus Hypothalamus Basal ganglia
Cerebellum	Cerebellar cortex Cerebellar nuclei Superior, middle, inferior cerebellar peduncles
Spinal cord	Spinal cord afferent and efferent pathways
Peripheral nervous system	
Cranial nerves	Cranial nerve nuclei
Spinal nerves	Spinal nerve nuclei

TABLE 1–2. Structures of the Nervous System, Based on Complexity

Structure	Function
Glial cells	Nutrients to neurons, support, phagocytosis, myelin, long-term memory
Neuron	Communicating tissue
Single segment reflexes	Subconscious response to environment
Multisegment reflexes	Subconscious response to environment
Maturational reflexes (e.g., righting reflex)	Subconscious response to environment
Central pattern generators	Complex pattern generation utilizing sensory and motor nuclei to accomplish sequential activities; driven by sensation and utilizing combinations of more basic reflexive responses
Ganglia and nuclei	Aggregates of cell bodies with functional unity
Tracts	Aggregates of axons that transmit functionally united information; spinal cord
Structures of the brainstem	Aggregates of ganglia, nuclei, and tracts that mediate high-level reflexes and mediate the execution of cortical commands
Diencephalon	Aggregates of nuclei and tracts that mediate sensory information arriving at the cerebrum and provide basic autonomic responses for body maintenance
Cerebellum	Aggregates of nuclei, specialized neurons, and tracts that integrate somatic and special sensory information with motor planning and command for coordinated movement
Cerebrum	All conscious sensory awareness and conscious motor function, including perception, awareness, motor planning and preparation, cognitive function, attention, decision making, voluntary motor inhibition, language function, speech function

Source: Based on data of Seikel et al. (2016).

action of moving your muscles, and the PNS (in the form of spinal or cranial nerves) is responsible for direct execution.

Conscious processing follows a reverse path. If a mosquito walks on that same finger of your hand, the pressure associated with the mosquito's movement might be sufficient to activate a sensory neuron, and the impulse from that activation enters the spinal cord in an afferent neuron. **Afferent** neurons have the role of taking information from the periphery and conveying it to the CNS. In this case, the information about the mosquito will be conveyed up through the spinal cord and to nuclei within the brainstem. Those nuclei convey the sensation to the thalamus (the sensory clearinghouse at the base of the brain), which conveys the information to the somatosensory strip of the parietal lobe. In this way, sensory information at your fingertip becomes a conscious sensation in the cerebral cortex, and you can choose to move your finger to scare away the insect.

Not all actions are conscious and not all sensations reach consciousness, and that begins our discussion of everything below the level of the cerebrum. **Reflexes** are hardwired responses of the nervous system that are responsible for automated, involuntary responses to environmental or other stimuli. As an example, you likely have had experience with a physician tapping your knee to activate the patellar tendon reflex. When your knee is tapped, your leg kicks as a result of a reflexive response that we talk about in Chapter 4. For now, realize that your body is endowed with innumerable reflexes that provide involuntary responses to stimuli.

Reflexes that are present in the early postnatal period are inhibited as the cortex matures so they do not interfere with voluntary actions, but the circuits are always there and are always available if needed. Some hard-wired responses, such as those associated with the complex processes of swallowing, remain active throughout life, whereas other reflexes, such as the sucking reflex of early postnatal life, are inhibited as we gain voluntary control of the processes of eating.

Reflexes are the domain of the spinal cord and brainstem (Saper et al., 2013). The spinal cord is home to the basic **spinal reflex arc**, as well as more complex spinal reflexes. The brainstem is involved in complex reflexive and motor patterns associated with life, such as respiration, deglutition, mastication, and vomiting. This hierarchy reflects the organization of the brain, with the most basic and simple responses at the lower spinal level, the more organized responses to the environment higher in the nervous system at the brainstem level, and the highest level of response being the conscious level of the cerebral cortex.

As infants, well before we have any voluntary function, we manifest a walking reflex. It is elicited by holding an infant upright and dragging the infant's toes on a tabletop, causing stepping action to occur in the early postnatal stage. We lose that reflexive response as our nervous systems develop, but the motor pattern is retained, and our cerebral cortex uses that pattern to help us walk. To demonstrate this to yourself, actually have your cerebrum do the micromanaging. Walk slowly, intently, and focus on your feet and their movement. You will immediately notice that you lose your focus on your feet and go to another thought or sensation, and it takes a lot of effort to keep focused on the act of walking. The casual stroll of the adult does not require a lot of thought on your part: One foot puts itself in front of the other without your cortex having to micromanage the process. The cerebrum is very busy and is more than happy to allow these motor pattern subsystems to help you go about your daily life. This is automaticity.

Automaticity is supported by the ongoing and automatic control of background musculature. Similar to reflexes, background neural activity includes maintaining muscle tone that precisely counterbalances the desired activity. As an example, if you are reaching for a hidden birthday present that you need to wrap, and it is at the top of the closet just out of your reach, you will stand on your tiptoes, extend forward a little while you reach, and counteract your movement by extending your other arm and leg back to keep from losing your balance. Much of this is embedded within vestibular reflexes that you developed in the first 6 to 8 months of your life and that are also within the automatic domain. In this case, these background activities support the foreground movement. You might recall from your anatomy course the discussion about **agonists** and **antagonists**. This is that same discussion, but from a neurophysiological perspective.

Part of this background response is to maintain **muscle tone**. Balanced muscle tone provides us with the right amount of counterforce to control the agonistic movement and allows our musculature to be ready for contraction at any desired instant. In the sleep state, your muscles become flaccid, or low-tone, which is normal and natural, but when you are awake and alert, you maintain a level of muscle tone that balances the needs of your voluntary system. This tone is regulated by the indirect motor system, also known as the extrapyramidal system, a primary job of the basal ganglia and the red nucleus and their pathways. The **basal ganglia** are sets of nuclei found above the level of the brainstem that are responsible for some stereotyped movements but are also importantly involved in regulation of background movements and of muscle tone.

The **motor speech system** capitalizes on automaticity in the same way: We do not overthink these processes or we get into trouble. If we were to really focus on each movement of our articulators, we would take a very long time to say anything. Be aware of this, however: When you are learning a task, such as walking, reaching, or speaking, you will put a great deal of focus on learning the motor act, paying very close attention to what your body is telling you about the action (as we discuss in Chapter 11). The tactile, muscle, and joint **sensors** we discuss in Chapter 3 give you information about where your tongue and mandible are in space, how fast they are moving, and where they make contact. You pay attention to this *feedback* from the sensors and use that information to correct the movement so you make a more accurate attempt the next time. You learn, and then eventually you can automatize.

Motor learning is a significant feat of attending to the feedback from your body, and you get a great deal of help in the learning process from the **cerebellum**, the most densely packed structure of the CNS. The cerebellum is responsible for coordinating all motor activity and integrating the diverse inputs from the body's sensors into a cohesive map of what is happening in your body at any moment for the purpose of motor control. Again, as you reach to the top shelf of that closet, you stretch and lean forward and counterbalance your actions through opposite limb extension. This is a highly coordinated activity that requires smooth interaction of a large number of agonists and antagonists, as well as input from the muscles, joints, tactile sensors, and vestibular mechanism. All of this information gets integrated as a dynamic whole in the cerebellum, providing your motor system with the data it needs to successfully reach that birthday present on the shelf. If the vestibular system information is not integrated, you will lose your balance. If your tactile information is incorrect, you might squeeze too hard on the package, breaking its contents. If your righting reflexes are not controlled, you could extend your counterbalancing leg too far back and become unstable. The fact is that none of these problems befalls you, typically because your nervous system is continually monitoring the condition of your body relative to your motor activity, and it is continually updating and correcting those body responses to keep everything in balance with the desires of your cerebrum. You can probably guess, however, that if any one of these components fails for some reason (e.g., cerebrovascular accident), the resulting imbalance in the system will require the careful efforts of a skilled clinician to reprogram these circuits. That is why you are in this field.

Information about your body's condition at any moment travels to your cerebrum by means of pathways. Nervous system pathways (efferent and afferent) provide the superhighways for information that will be used by your CNS to control movements, have thoughts, and make sense of the world. Efferent pathways provide the means for moving muscles, once the decision has been made to do so. In Chapter 4, we introduce you to two major motor pathways (the corticospinal and corticobulbar tracts) and then provide in-depth discussion of many others in Chapter 9.

We have not talked about the complex processes of **cognition**, which are the specific and sole domain of the cerebral cortex. These root processes include memory, attention, perception, visuospatial processes, and linguistic processes. This amazing cerebrum takes these "basic" cognitive processes and uses them to get its goals accomplished through executive functions. **Executive functions** are called metacognitive processes, in that they are the processes that control the way we use our cognitive functions in problem-solving situations. For instance, if I have the sense of hunger, I must develop a plan for satisfying this need. Unless there is a box of bon-bons within easy reach, I might have to actually plan how to feed myself, perhaps including calling to see if the pizza joint is open, grabbing my money, and driving to town. All of this takes a great deal of cognitive engineering, and it depends very strongly on executive function. We talk much more about this later when we discuss cortical function.

All of the information coming to the cerebral cortex arises from sensors. The body's sensors are how we know our world. The cerebral cortex is responsible for creating a "worldview" based on its sensory input. For our purposes in the fields of audiology and speech-language pathology, the special senses associated with hearing and balance are critical elements in this whole-body image, as they provide rich information about both the movement and the environment (Goldberg et al., 2013; Hudspeth, 2013). There are general body senses and specific senses, as we discuss in Chapters 3 and 7.

General somatic sensations include both superficial and deep sensation. **Superficial sensations** are those sensed at the periphery of your body, such as pain, pressure, and temperature. **Deep sensation** includes the senses associated with muscles and their tension, tendons, muscle pain, deep vibration, and others. We are able to combine sensations below the level of the cerebral cortex to form a richer perception. One of these combinations is termed stereognosis, which is the ability to recognize ("gnosis") the shape or form of an object ("stereo") through tactile sensation alone.

There are different types of sensation, including somatic sense, kinesthetic sense, and the special senses. **Somatic sense** (body sense) includes the sensations associated with pressure (deep and light) and thermal stimulation (cold and hot). Somatic sense also includes joint position sense, muscle tension, and tendon tension. **Kinesthetic sense** is one of those combined senses, resulting in the perception of your body moving in space. **Special sense** includes the senses of hearing, vision, smell, and taste (gustation). All of these are discussed in detail later.

Intrinsic to all sensors is the specificity of stimulus. Pressure sensors of the skin will not respond to thermal stimulation, and retinal cells will not respond to auditory stimuli. Interestingly, nociceptors (pain sensors) are the same as thermal sensors, but individual sensors still differentiate between the two types of sensation. All sensors signal the nervous system in a similar way by means of a generator potential.

All somatic senses are routed through the **thalamus** on their way to the cerebral cortex. As we discuss when we examine consciousness, it is the presence of these sensory inputs that allows us to know that we exist. We "create" a perception of ourselves as a unified entity based on coordinating these inputs to form an integrated whole. The absence of sensation in a modality changes our perceptions of ourselves in space. Sensation is critically important to our well-being, and understanding of sensation and the effects of deficits is critical to the therapeutic process (Møller, 2003).

In summary:

- Neurons are cells that are specialized for communication. Neurons receive information and convey it to the next neuron. Neurons have a dendrite, soma, and axon.
- An action potential releases neurotransmitter substance into the synapse between the axon and the dendrite of the next neuron, causing ions to pass into the dendrite and stimulating it to excitation.
- Nuclei are made up of neurons with special functions.
- The CNS consists of the cerebral cortex, brainstem, cerebellum, spinal cord, and other subcortical structures. The PNS consists of the cranial and spinal nerves.
- The cerebral cortex is where information is processed consciously and decisions are made about action. Functions include auditory perception, language processing, execution of speech, and all complex conscious activities. Motor activity is initiated in the frontal lobe at the motor strip. Efferent neurons are responsible for motor activity. Sensations from the periphery of the body arise in the cortex by means of afferent nerves.
- Reflexes are hard-wired responses of the nervous system that are responsible for automated, involuntary responses to envi-

ronmental or other stimuli. Automaticity is supported by the ongoing and automatic control of background musculature. Background neural activity includes maintaining muscle tone that precisely counterbalances the desired activity. The tactile, muscle, and joint sensors provide somatic information about the position and state of the body in space. The cerebellum is responsible for coordinating all motor activity as well as for integrating the inputs from the body's sensors.

- Efferent pathways provide the means for moving muscles once the decision has been made to do so, whereas afferent pathways provide information from the body's sensors to the cortex.
- Cognition involves memory, attention, visuospatial processes, perception, and linguistic processes, which are the domain of the cerebrum.
- Somatic sense includes the sensations associated with pressure (deep and light) and thermal stimulation (cold and hot), whereas kinesthetic sense is the perception of the body moving in space. Special senses include the senses of hearing, vision, smell, and taste.

DIVISIONS OF THE NERVOUS SYSTEM

The nervous system consists of a large number of structures that work together to accomplish survival and higher function of the organism. We are predominantly symmetrical on gross examination, with left and right arms, legs, and eyes. The symmetry that you see in the mirror is reflected at the gross levels of the nervous system as well. We have two cerebral hemispheres, two cerebellar hemispheres, two thalami, and even paired pathways descending through the spinal column. We have pairs of cranial nerves serving each side of the head, and left and right spinal nerves as well. Perhaps nature "recognized" the need for redundancy, giving us symmetrical structures as backup for the times when damage occurs.

This is a good time to remind ourselves of the difference between anatomy and physiology. **Anatomy** is the study of the structure of the organism, whereas **physiology** is the study of its function. **Clinical anatomy** is the study of the pathological entity, and that often includes discussion of altered or pathological physiology. The nervous system can be viewed either as a set of structures or as a set of functions. When viewed as structures (anatomy), we divide the nervous system into central and peripheral components. The CNS consists of the cerebral cortex (or cerebrum), the brainstem, the basal ganglia, cerebellum, spinal cord, thalamus and subthalamus, nuclei and tracts within these structures, and so on. The PNS consists of the 31 spinal nerves and the 12 cranial nerves that emerge from the CNS.

The nervous system can also be organized based on function. We divide the nervous system into autonomic and somatic systems.

Autonomic Nervous System

The **autonomic nervous system** (ANS) is responsible for involuntary functions of the body, including contraction of smooth muscle, glandular secretion, and digestive and cardiac function. The ANS includes a separate subdivision, the **enteric nervous system** (ENS), which is responsible for digestive processes themselves.

The ANS has two responsive systems: sympathetic and parasympathetic. The **sympathetic system** (also known as the **thoracolumbar system** because of its relationship to the body's trunk) responds to stimulation by expending energy. If you have a close call while driving, you will very quickly notice an increase in heart rate, alertness, and sweating. You will experience increased blood pressure due to vasoconstriction, dilation of the pupils, and goose bumps. These responses are your body's way of preparing to meet some unexpected and frightening challenge, and the sympathetic system is responsible for this "flight, freeze, or fight" reaction. We now know that these physically stressful crisis moments release norepinephrine into your system in response to danger, but we also are aware that this is more than just energy expenditure. Stress takes a tremendous toll on the structures of the nervous system, literally shortening the life of the person who lives in this state constantly. The **parasympathetic system** counteracts these stress responses by slowing the heart rate, constricting the pupils, and lowering blood pressure.

The ANS is designed to maintain homeostasis of the body. You can think of it as a very complex environmental control system, much like thermostats that keep room temperature within an operationally defined limit. The values of your body's system must change to meet a crisis, and when the crisis is over, they should return to a default mode. When food enters the digestive system, a set of actions needs to take place, some resulting in muscular contraction and others resulting in secretion of enzymes. Some actions, such as esophageal peristalsis, are caused by stimulation of mechanoreceptors, whereas others are responses initiated by chemoreceptors that are sensing the need to regulate the environment by increasing or decreasing acids. The key word to keep in mind concerning the ANS is regulation: It has responsibility for keeping the systems of the body in harmony with the external environment's demands. When those demands change, the ANS changes in response. It is an elegant "operating system" for the body, and it is entirely involuntary.

The ANS arises from the prefrontal region of the cerebral cortex, as well as subcortical structures including the thalamus, hypothalamus, hippocampus, brainstem, spinal cord, and cerebellum. These represent control centers for the ANS and are connected by means of afferent (sensory) and efferent (motor) tracts.

There are peripheral components to the ANS as well. These include a pair of sympathetic trunk ganglia running external to the vertebral column, as well as ganglia (groups of