1
Overview of the Nervous System

CHAPTER OUTLINE

Overview

Welcome to *Clinical Neuroscience for Communication Disorders*. We are excited to share foundations in neuroanatomy, physiology, and contemporary neuroscience, while making connections to the everyday practices of speech–language pathologists and audiologists. Throughout this textbook, you will find clinical cases and everyday applications that connect neuroanatomy and physiology to development (both typical and disrupted), aging (both typical and disrupted), and acquired neurological disorders.

The nervous system can be divided into structures and regions that are anatomically or functionally distinct. This chapter provides an overview of the major components and their functions as well as common terminology. Everything that is mentioned here will be discussed in more detail in later chapters of the book. You can think of this as a quick tour so you know your way around the nervous system to prepare you to dive in deeper.

Major Components

The human nervous system can be broken down into two major components: the central nervous system (CNS) and the peripheral nervous system (PNS). The **central nervous system** includes the brain and spinal cord. The word "brain" commonly is used to refer to a collection of several major structures: the right and left cerebra (cerebrum), otherwise known as the two hemispheres; the brainstem; and the cerebellum. All are encased within the **cranium** (Figure 1–1). At the point at which the brainstem exits the skull through the **foramen magnum**, the structure becomes the spinal cord. The spinal cord extends down through the spinal canal, the protective "tunnel" created by the stacked vertebrae.

A slice through the CNS—whether in the brain or spinal cord—will show dark and light areas, referred to as **gray matter** and **white matter**, respectively (Figure 1–2). The gray matter is made up of **cell bodies**. The white matter is made up of extensions from those cell bodies called **axons** (discussed later; see also Chapter 3). The cell bodies generate signals that are sent down the axons to another cell. In the brain, the gray matter makes up the outer, superficial surface called the cortex (Latin: *tree bark*) as well as several collections of cell bodies (called **nuclei** or ganglia) deep in the brain. In the spinal cord, the arrangement is reversed, so the gray matter is deep (internal) and surrounded by white matter. As a general rule, gray matter processes information and white matter transmits signals.

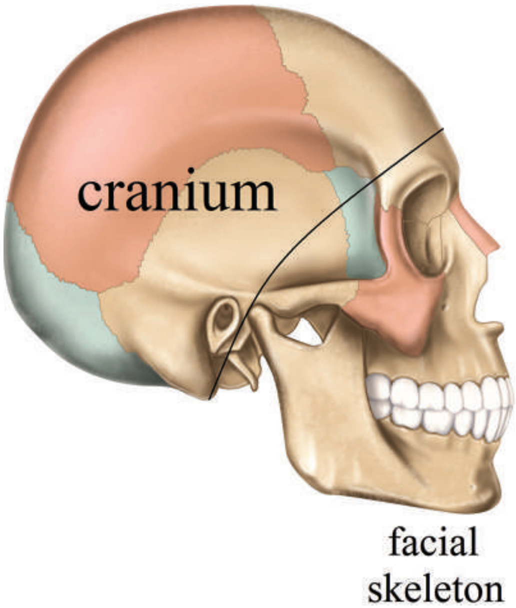

FIGURE 1–1. Cranium and facial skeleton.

The slice through the CNS also will reveal some cavities. These are the ventricles, filled with cerebrospinal fluid (CSF), which provides nutrients as well as protection. Two other structures that provide protection are the meninges and the bony encasing (Figure 1–3). The meninges (see Chapter 2) are a set of three tissue layers that cover the entire brain and spinal cord and provide a space for CSF to surround the CNS structures. The combination of the tissues and the fluid limits the movement of the brain and spinal cord. Superficial to the meninges is the bony structure. The cranium encases the brain, and the vertebral column surrounds and protects the spinal cord.

The PNS consists of all of the nerves that exit from the brainstem or spinal cord that extend out into the body (the periphery) to innervate muscles, organs, and tissues of the body (Figures 1–4 and 1–5). Twelve pairs of cranial nerves exit from the brainstem and innervate structures of the head and neck. An additional 31 pairs of spinal nerves exit from the spinal cord and innervate the structures below the neck.

The PNS can be further divided into functional subsystems. The somatic nervous system innervates skeletal muscles and is primarily responsible for conducting signals regarding body sensation and movement. The autonomic nervous system is responsible for unconscious control of body systems. It can be subdivided into the sympathetic

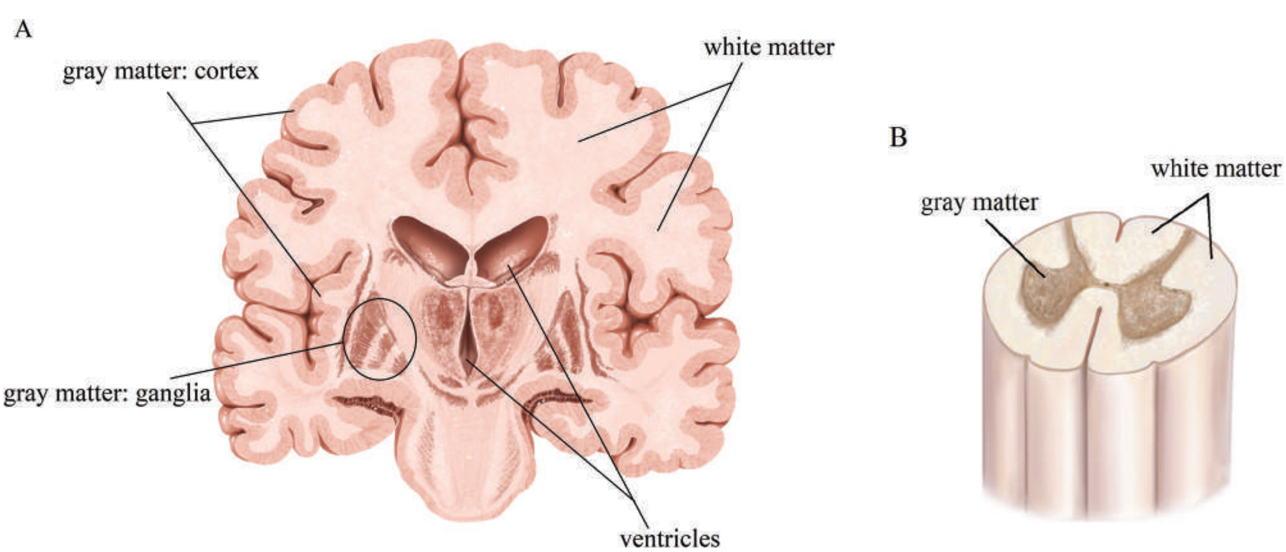

FIGURE 1–2. Gray and white matter in the brain (**A**) and spinal cord (**B**).

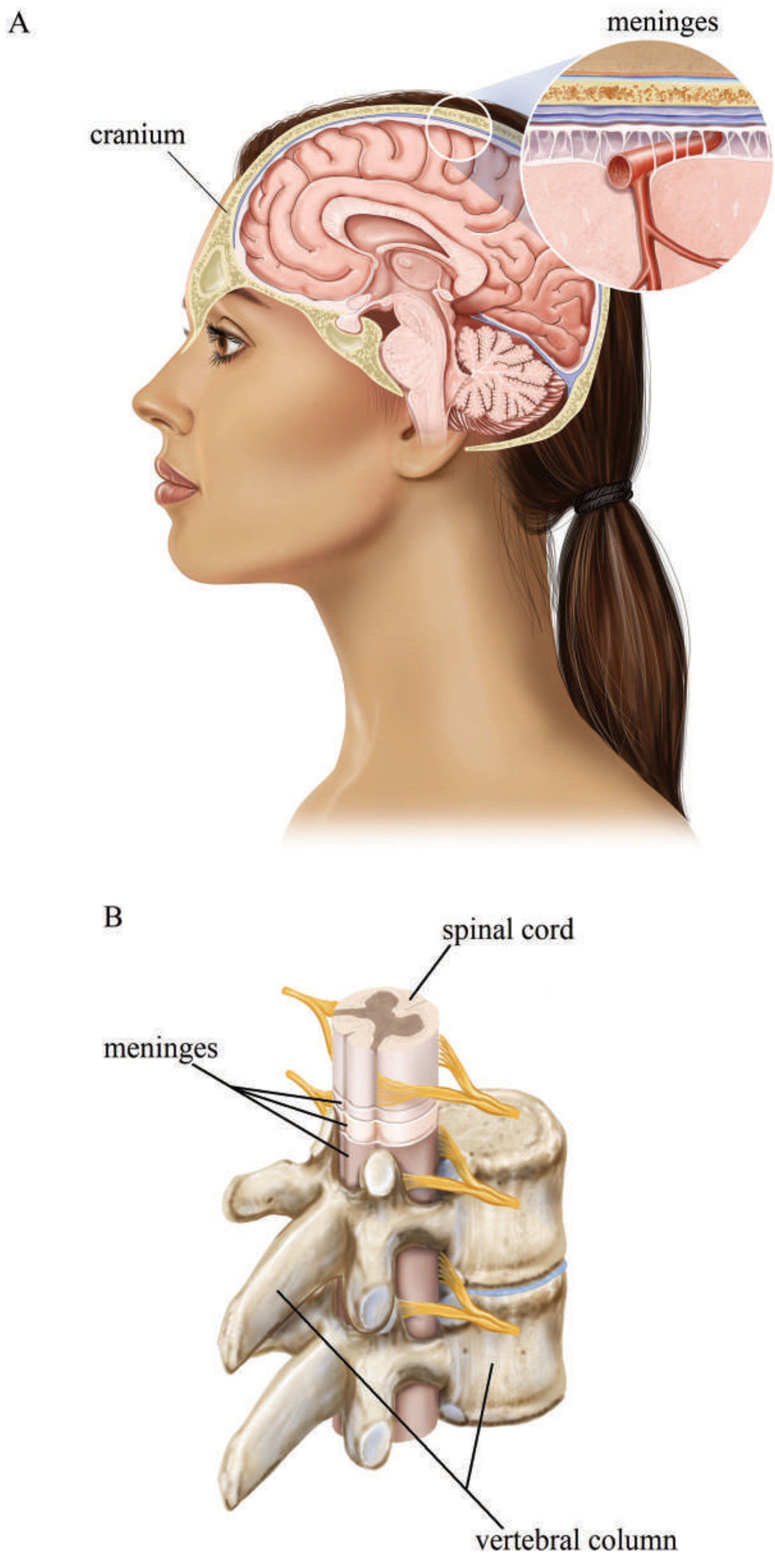

FIGURE 1–3. Meninges and bony casing for brain (**A**) and spinal cord (**B**).

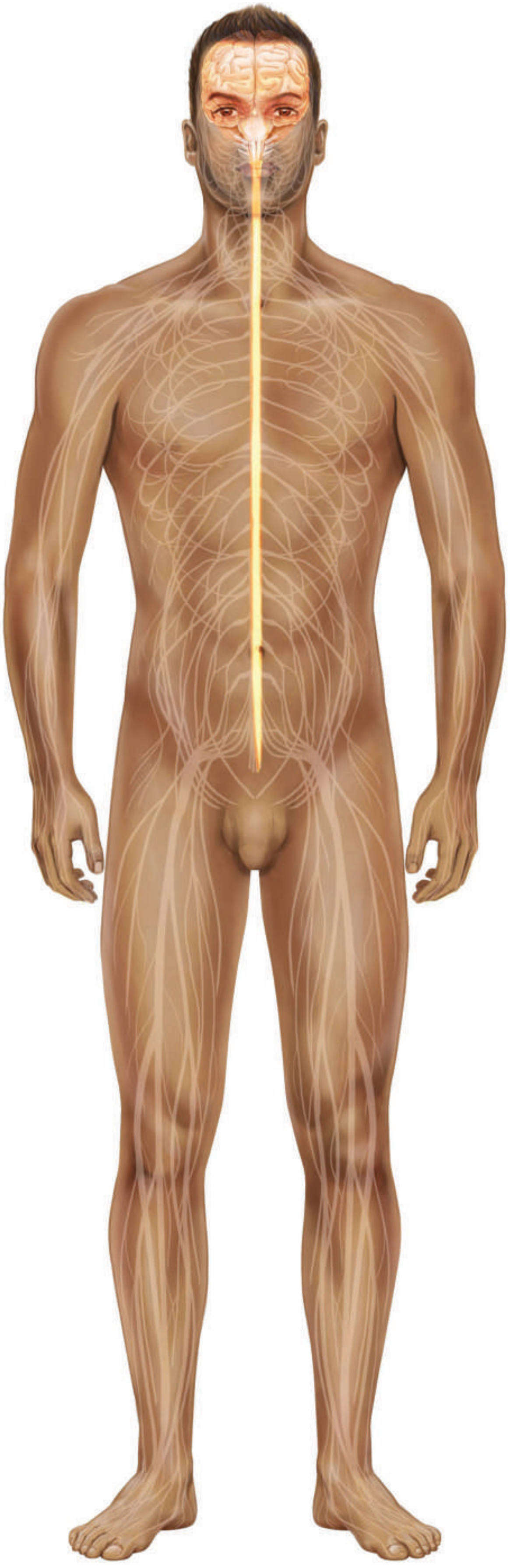

FIGURE 1–4. Peripheral nervous system. The central nervous system (brain and spinal cord) is highlighted. All nerves exiting from the brainstem and spinal cord make up the peripheral nervous system.

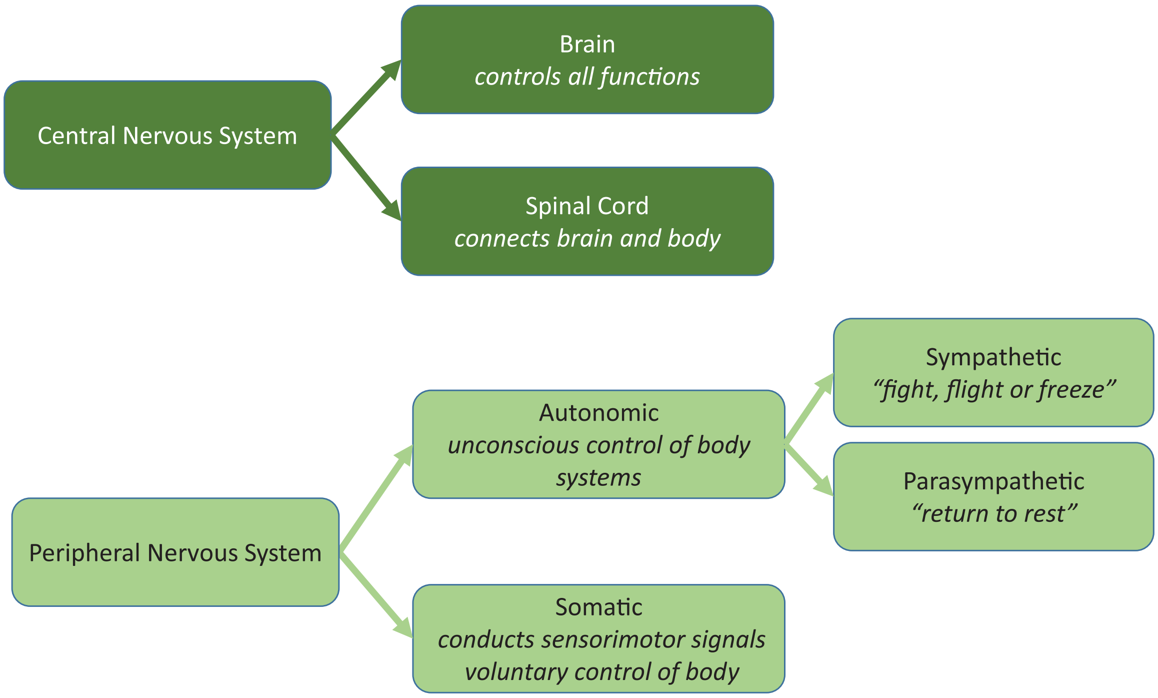

FIGURE 1–5. Schematic of the central and peripheral nervous system components.

and parasympathetic nervous systems. The sympathetic system prepares the body for "fight, flight, or freeze": When encountered with an emergency or crisis situation, the sympathetic nervous system will divert blood flow from unnecessary regions (e.g., the digestive system) to muscles and to the CNS to heighten perception, speed up response times, and facilitate muscle movements. The parasympathetic system returns the body to homeostasis (Greek: *same*, *steady*) or to baseline levels once the crisis has passed.

Box 1–1. That's Not So Funny

When you "hit your funny bone," you actually are hitting a nerve of the PNS. The ulnar nerve extends from the spinal cord and travels along the arm out to the medial arm, including the pinky and ring fingers. When you hit your elbow just right, you compress the ulnar nerve, resulting in a painful tingling sensation. Because the PNS is not protected by a bony structure, the nerves can be impacted by everyday actions.

Unlike the CNS, the PNS is not protected by either a layer of tissue or a bony structure. The nerves exit from the spinal cord and extend out to the organs, tissues, and muscles of the body.

Organization of the Nervous System

The nervous system is organized in several different ways. Along the vertical (superior–inferior) axis, there are both structurally and functionally distinct sections. In addition, there are functional differences along the horizontal (right–left) axis.

There is a hierarchy of complexity along the vertical axis. Beginning from the bottom and moving superiorly, the spinal cord primarily serves as a conduit for signals and controls only the most basic functions—reflexes. The brainstem controls autonomic and visceral systems. These are of the utmost importance for keeping your body alive, such as by regulating heart rate and respiration, but they are not part of the "thinking brain." Integration of signals begins in the brainstem, such as integration of auditory signals from the left and right ear and integration of auditory and visual signals. The diencephalon extends superiorly from the brainstem and is involved in not only relaying signals coming up from the spinal cord but also integration of signals from multiple sources (see Chapter 5). Some cognitive processing occurs in the diencephalon, although this is not well understood. Finally, the cerebrum is responsible for complex sensory and motor integration, perception, and cognitive functions such as planning, organization, reasoning, language processing, and emotions (see Chapter 14).

Organizational Systems

The hemispheres of the brain have been subdivided in multiple ways. Broadly, they are divided into lobes (frontal, parietal, occipital, and temporal; Figure 1–6), each with a variety of functions, many of which (e.g., reading, social interacting) require input and integration from multiple lobes.

Cytoarchitecture Organization

The cortex (outer gray matter of the brain) is made up of six layers of cells. The thickness of these six layers varies across regions of the brain. Layers III (cortex-to-cortex connections) and IV (thalamus-to-cortex connections) are particularly important for signaling within the cerebrum (Blumenfeld, 2010; Shipp, 2007; Figure 1–7). In 1909, Korbinian Brodmann published a numbered map of the cortex based on the cellular organization (Figure 1–8). The

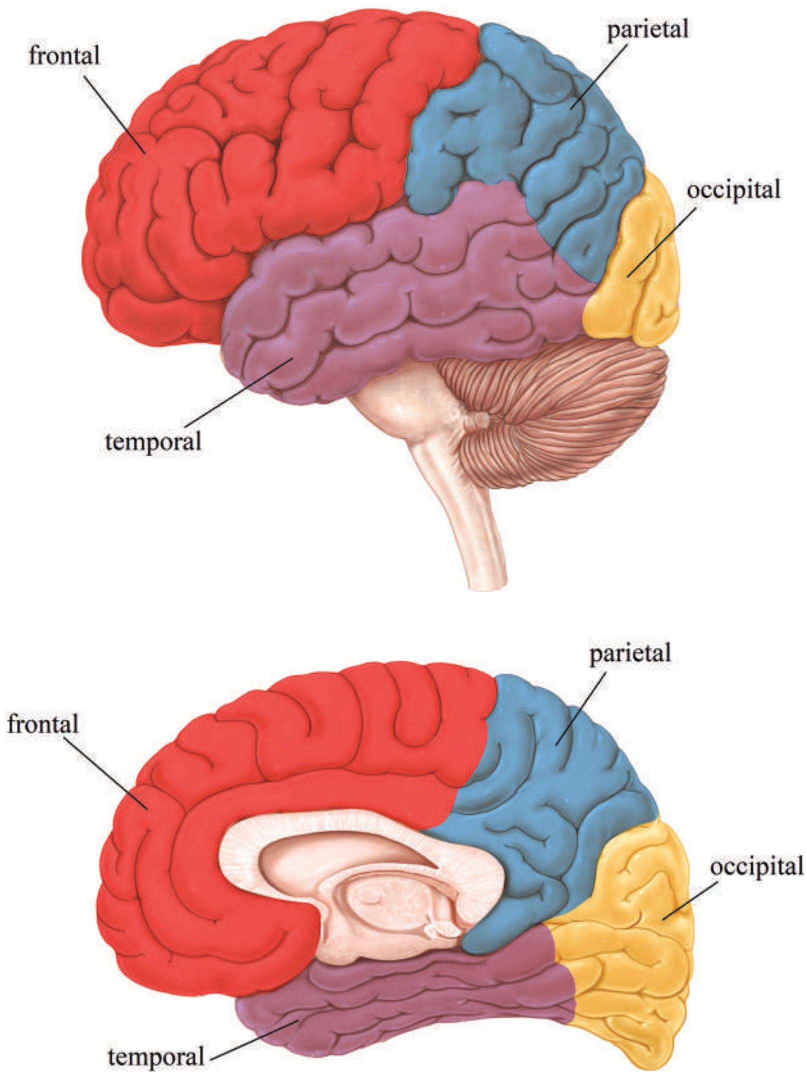

FIGURE 1–6. Lobes of the brain.

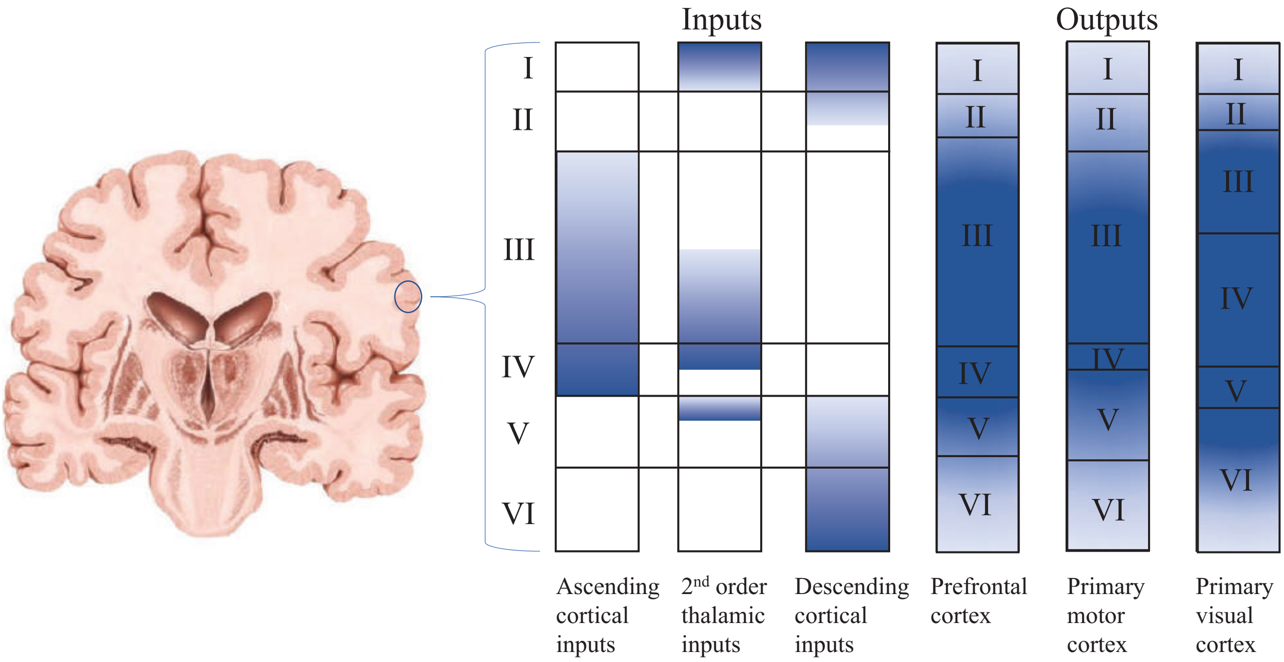

FIGURE 1–7. Cortical layers and connections.

implication of the map was that cellular organization was linked to function: Each numbered area had a different function. Although the map is not perfect, functional differences are related to cellular structures. Throughout this book, Brodmann areas are noted for areas commonly identified by the numbers.

Organization by Function

Another way to describe organization of the CNS is by function. CNS regions can be subdivided into those that control movement (motor) and body sensation (somatosensory), special senses such as visual and auditory functions, language, and higher level cognition. There are several principles that govern functional organization. First, throughout the CNS, motor areas tend to be located more anteriorly and sensory areas are located more posteriorly (see Chapter 4). Second, sensory and motor functions are controlled contralaterally. This means that the right side of the brain controls the left side of the body and vice versa. Third, the cortex contains **primary**, **secondary** (**association**), and **tertiary** (**heteromodal**) areas. **Primary regions** are the core and initial location of processing. For example, in the auditory system, all input is processed initially in the primary auditory area in the superior temporal lobe. Further processing then occurs in **association areas** where there is integration of multiple aspects of signals (e.g., pitch and intensity and duration) as well as integration across modalities (e.g., linking visual with auditory signals to determine what object is creating a sound). The heteromodal areas are characterized by multimodal inputs and functions. The highest order areas of the brain are heteromodal, such as the prefrontal cortex.

Primary processing areas are precisely organized based on a relevant principle. The organizing principle for motor and sensory areas is **somatotopy**. This means that they are arranged in reference to the body (soma). As shown in Figure 1–9, regions of the body are controlled by different areas within the primary motor and sensory areas. The resulting map, shown in Figure 1–10, is called a homunculus (Latin: *little human*). As you can see, the representation is oddly distorted, with overly large areas for the hands, lips, and tongue. This means that there are more brain cells controlling these body areas. The reason for this is discussed in more detail in Chapters 6 and 10, but it is related to the level of fine motor control and sensitivity.

Within the auditory system, regions are organized **tonotopically**, or in relation to the pitch of a sound. Low-pitched sounds are processed more anteriorly and high-pitched sounds more posteriorly. For vision, the organizing

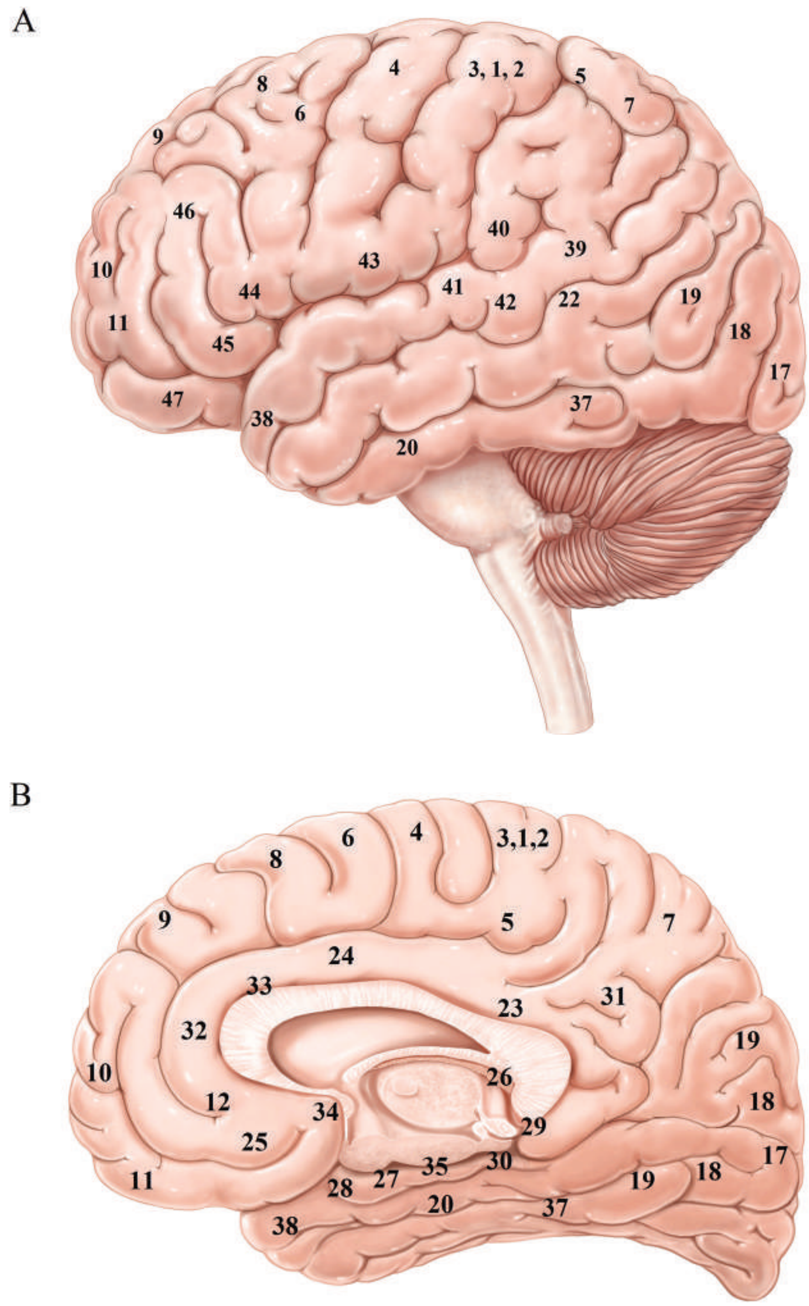

FIGURE 1–8. A. Brodmann areas shown on the lateral surface of the left hemisphere. **B.** Brodmann areas shown on the medial surface of the right hemisphere.

principle is location, called **retinotopy**. Neurons in the visual cortex are arranged based on where an image hits the retina.

Primary motor and sensory areas are relatively circumscribed, and the specific organizing principle can be mapped fairly directly onto the brain area. Thus, there are clear, reproducible maps of visual, auditory, and primary motor and somatosensory cortices. The more complex the processing, however, the less specific the maps become and the more variation there is across individuals. For example,

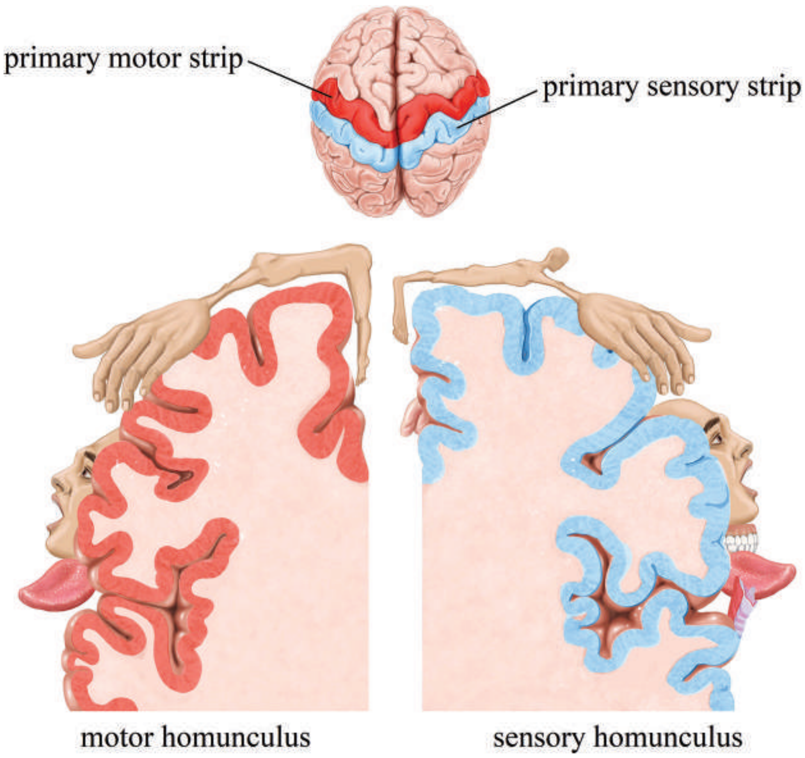

FIGURE 1–9. Coronal slice showing the cortical primary motor (*red*) and sensory (*blue*) strips.

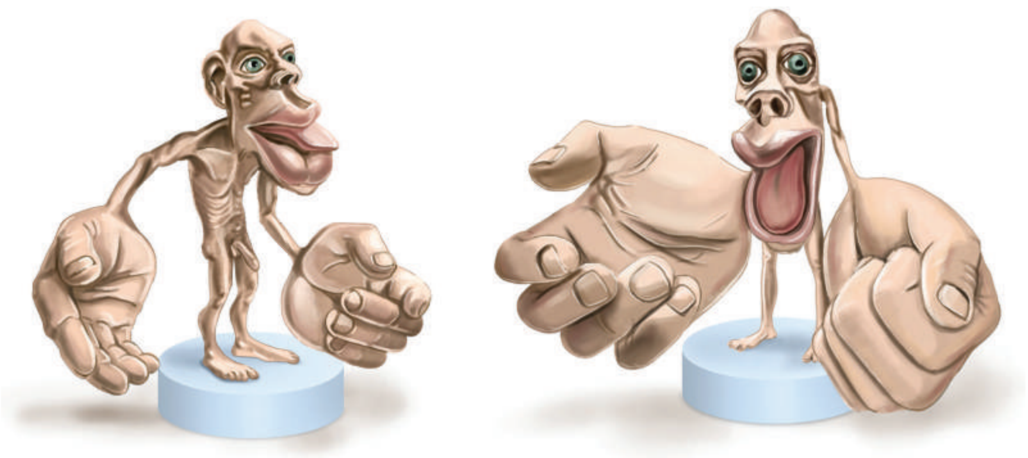

FIGURE 1–10. Sensory (*left*) and motor (*right*) homunculi.

the majority of basic language processing occurs in the left hemisphere, but it is distributed through frontal, parietal, and temporal lobes. Generally speaking, comprehension occurs more posteriorly (parietal/temporal regions) and production is controlled anteriorly (frontal lobe), but there are many connections between the areas. In addition, connections to the right hemisphere are needed to go beyond basic word and sentence-level comprehension, to understand communication that includes facial expressions, gestures, and tone of voice. Higher level cognition, such as reasoning, judgment, and insight, is controlled by the frontal lobes bilaterally, which have extensive connections to many other areas of the brain. Thus, the more complex the task, the less likely it is that there is a single area of the brain with primary control, and the more interconnectivity is needed for adequate function.

Gross organization is very similar across people, such that the functions of the lobes described previously hold for all humans without significant disruption to neural development. The organization of the motor and sensory homunculi is also consistent from person to person. Delving deeper, though, differences can occur. As explained in Chapter 10, fine motor movement practice will lead to increased space allotted to control those movements. Thus, concert pianists will have larger representations of the hand and fingers compared to an Olympic runner, who does not spend hours a day carrying out fine movements of the hands.

Terminology

Anatomical terminology is essential for establishing a common frame of reference. Learning neuroanatomy will be much easier if you have a solid understanding of a basic vocabulary. This terminology will be used to clearly indicate location and prevent misunderstandings (e.g., your left or my left?).

The terminology is used in reference to a human body in anatomical position (Figure 1–11): standing upright,

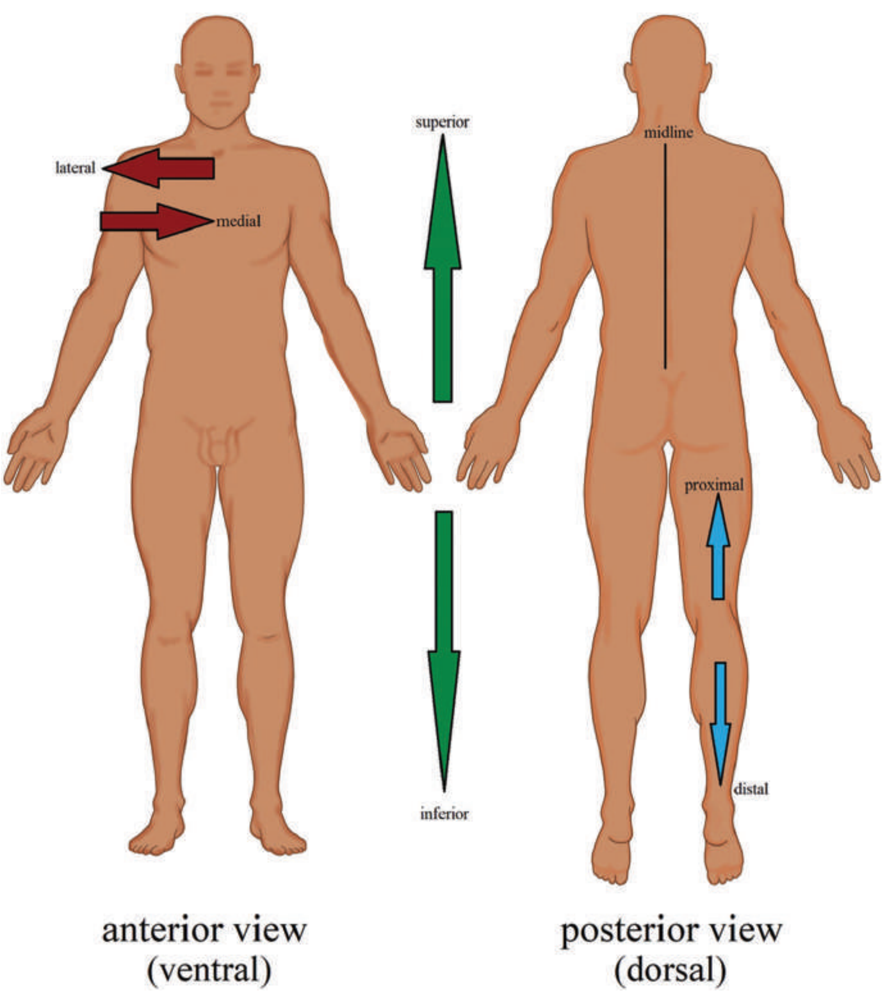

FIGURE 1–11. Anatomical position and terms of direction.

viewed from the front, with the palms facing the front. Definitions are provided in Box 1–2, and exercises are provided in the supplementary material to give you a chance to practice until you feel completely comfortable with the terms. The following terms deserve a little extra explanation to ensure clear understanding (Table 1–1):

Box 1–2. Additional Neuroanatomical Terminology

- **Gray matter:** Central nervous system tissue made up of cell bodies; appears dark in dissections
- **White matter:** Central nervous system tissue made up of axons; appears light in dissections due to the white, fatty covering called myelin that surrounds axons
- **Gyrus** (Latin: *ring*; pl. gyri): A hill or ridge; also called a convolution
- **Sulcus** (Latin: *furrow*, *wrinkle*; pl. sluci): A valley or enfolding
- **Fissure:** A valley or enfolding; usually deeper than a sulcus (but not always)
- **Cortex:** The outer layer of gray matter in the cerebral hemispheres
- **Nucleus** (pl. nuclei): A group of cell bodies—usually used to refer to structures in the central nervous system
- **Ganglion** (Greek: *tumor on a tendon* or *tissue that resembled such tumor*; pl. ganglia): A group of cell bodies—usually used to refer to structures in the peripheral nervous system
- **Fasciculus** (Latin: *little bundle*)/funiculus (Latin: *little rope*)/tract: A group of axons
- **Commissure** (Latin: *juncture*): Band of fibers/axons connecting the two sides of the nervous system
- **Projection tract:** Groups of axons that begin in the brain and extend out of the brain (i.e., to the spinal cord)
- **Association tract:** Groups of axons that lie within a hemisphere. These connect one lobe to another or one gyrus to another within a lobe.
- **Commissural tract:** Groups of axons that extend from one hemisphere to the other

Table 1–1. Terms of Position and Orientation

Superior: toward the top	**Inferior:** toward the bottom
Superficial: toward the surface	**Deep:** away from the surface
External: toward the surface	**Internal:** away from the surface
Medial: toward the midline (mesial, median)	**Lateral:** away from the midline; toward the side
Proximal: toward the point of attachment	**Distal:** away from the point of attachment
Dorsal (brain): top of head (superior) **Dorsal (body):** toward the backbone from the neck down (posterior)	**Ventral (brain):** bottom of head (inferior) **Ventral (body):** toward the belly from the neck down (anterior)
Rostral: toward the nose	**Caudal:** toward the tail
Central: toward the center	**Peripheral:** away from the center
Afferent: conducting inward or toward the central nervous system; sensory	**Efferent:** conducting outward or away from the central nervous system; motor
Ipsi-: same (ipsilateral = same side)	**Contra-:** opposite (contralateral = opposite side)