The Anatomy of the Nervous System
The Systems, Structures, and Cells That Make Up Your Nervous System

3.1 General Layout of the Nervous System
3.2 Cells of the Nervous System
3.3 Neuroanatomical Techniques and Directions
3.4 The Spinal Cord
3.5 The Five Major Divisions of the Brain
3.6 Major Structures of the Brain
In order to understand what the brain does, it is first necessary to understand what it is—to know the names and locations of its major parts and how they are connected to one another. This chapter introduces you to these fundamentals of brain anatomy.

Before you begin this chapter, I want to apologize for the lack of foresight displayed by early neuroanatomists in their choice of names for neuroanatomical structures—but, then, how could they have anticipated that Latin and Greek, universal languages of the educated in their day, would not be compulsory university fare in our time? To help you, I have provided the literal English meanings of many of the neuroanatomical terms, and I have kept this chapter as brief and to the point as possible by covering only the most important structures. Still, there is no denying that learning their names and locations will require considerable effort.

### 3.1 General Layout of the Nervous System

**Divisions of the Nervous System**

The vertebrate nervous system is composed of two divisions: the central nervous system and the peripheral nervous system (see Figure 3.1). Roughly speaking, the **central nervous system (CNS)** is the division of the nervous system that is located within the skull and spine; the **peripheral nervous system (PNS)** is the division that is located outside the skull and spine.

The central nervous system is composed of two divisions: the brain and the spinal cord. The **brain** is the part of the CNS that is located in the skull; the **spinal cord** is the part that is located in the spine.

The peripheral nervous system is also composed of two divisions: the **somatic nervous system** and the **autonomic nervous system**. The **somatic nervous system (SNS)** is the part of the PNS that interacts with the external environment. It is composed of **afferent nerves** that carry sensory signals from the skin, skeletal muscles, joints, eyes, ears, and so on, to the central nervous system, and **efferent nerves** that carry motor signals from the central nervous system to the skeletal muscles. The **autonomic nervous system (ANS)** is the part of the peripheral nervous system that regulates the body’s internal environment. It is composed of afferent nerves that carry sensory signals from internal organs to the CNS and efferent nerves that carry motor signals from the CNS to internal organs. You will not confuse the terms afferent and efferent if you remember that many words that involve the idea of going toward something—in this case, going toward the CNS—begin with an *a* (e.g., advance, approach, arrive) and that many words that involve the idea of going away from something begin with an *e* (e.g., exit, embark, escape).

The autonomic nervous system has two kinds of efferent nerves: sympathetic nerves and parasympathetic nerves. The **sympathetic nerves** are those autonomic motor nerves that project from the CNS in the lumbar (small of the back) and thoracic (chest area) regions of the spinal cord. The **parasympathetic nerves** are those autonomic motor nerves that project from the brain and sacral (lower back) region of the spinal cord. See Appendix I. (Ask your instructor to specify the degree to which you are responsible for material in the appendices.)

![FIGURE 3.1 The human central nervous system (CNS) and peripheral nervous system (PNS). The CNS is represented in red; the PNS in yellow. Notice that even those portions of nerves that are within the spinal cord are considered to be part of the PNS.](image-url)
rons (second-stage neurons) that carry the signals the rest of the way. However, the sympathetic and parasympathetic systems differ in that the sympathetic neurons that project from the CNS synapse on second-stage neurons at a substantial distance from their target organs, whereas the parasympathetic neurons that project from the CNS synapse near their target organs on very short second-stage neurons (see Appendix I).

The conventional view of the respective functions of the sympathetic and parasympathetic systems stresses three important principles: (1) that sympathetic nerves stimulate, organize, and mobilize energy resources in threatening situations, whereas parasympathetic nerves act to conserve energy; (2) that each autonomic target organ receives opposing sympathetic and parasympathetic input, and its activity is thus controlled by relative levels of sympathetic and parasympathetic activity; and (3) that sympathetic changes are indicative of psychological arousal, whereas parasympathetic changes are indicative of psychological relaxation. Although these principles are generally correct, there are significant qualifications and exceptions to each of them (see Blessing, 1997; Guyenet, 2006)—see Appendix II.

Most of the nerves of the peripheral nervous system project from the spinal cord, but there are 12 pairs of exceptions: the 12 pairs of cranial nerves, which project from the brain. They are numbered in sequence from front to back. The cranial nerves include purely sensory nerves such as the olfactory nerves (I) and the optic nerves (II), but most contain both sensory and motor fibers. The longest cranial nerves are the vagus nerves (X), which contain motor and sensory fibers traveling to and from the gut. The 12 pairs of cranial nerves and their targets are illustrated in Appendix III; the functions of these nerves are listed in Appendix IV. The autonomic motor fibers of the cranial nerves are parasympathetic.

The functions of the various cranial nerves are commonly assessed by neurologists as a basis for diagnosis. Because the functions and locations of the cranial nerves are specific, disruptions of particular cranial nerve functions provide excellent clues about the location and extent of tumors and other kinds of brain pathology.

Figure 3.2 summarizes the major divisions of the nervous system. Notice that the nervous system is a “system of twos.”
Meninges, Ventricles, and Cerebrospinal Fluid

The brain and spinal cord (the CNS) are the most protected organs in the body. They are encased in bone and covered by three protective membranes, the three meninges (pronounced “men-ING-ees”). The outer meninx (which, believe it or not, is the singular of meninges) is a tough membrane called the dura mater (tough mother). Immediately inside the dura mater is the fine arachnoid membrane (spiderweblike membrane). Beneath the arachnoid membrane is a space called the subarachnoid space, which contains many large blood vessels and cerebrospinal fluid; then comes the innermost meninx, the delicate pia mater (pious mother), which adheres to the surface of the CNS.

Also protecting the CNS is the cerebrospinal fluid (CSF), which fills the subarachnoid space, the central canal of the spinal cord, and the cerebral ventricles of the brain. The central canal is a small central channel that runs the length of the spinal cord; the cerebral ventricles are the four large internal chambers of the brain: the two lateral ventricles, the third ventricle, and the fourth ventricle (see Figure 3.3). The subarachnoid space, central canal, and cerebral ventricles are interconnected by a series of openings and thus form a single reservoir.

Cerebrospinal fluid supports and cushions the brain. These functions are all too apparent to patients who have had some of their cerebrospinal fluid drained away; they suffer raging headaches and experience stabbing pain each time they jerk their heads.

Cerebrospinal fluid is continuously produced by the choroid plexuses—networks of capillaries (small blood vessels) that protrude into the ventricles from the pia mater. The excess cerebrospinal fluid is continuously absorbed from the subarachnoid space into large blood-filled spaces, or dural sinuses, which run through the dura mater and drain into the large jugular veins of the neck. Figure 3.4 illustrates the absorption of cerebrospinal fluid from the subarachnoid space into the large sinus that runs along the top of the brain between the two cerebral hemispheres.

Occasionally, the flow of cerebrospinal fluid is blocked by a tumor near one of the narrow channels that link the ventricles—for example, near the cerebral aqueduct, which connects the third and fourth ventricles. The resulting buildup of fluid in the ventricles causes the walls of the ventricles, and thus the entire brain, to expand, producing a condition called hydrocephalus (water head). Hydrocephalus is treated by draining the excess fluid from the ventricles and trying to remove the obstruction.

Blood–Brain Barrier

The brain is a finely tuned electrochemical organ whose function can be severely disturbed by the introduction of certain kinds of chemicals. Fortunately, there is a mechanism that impedes the passage of many toxic substances from the blood into the brain: the blood–brain barrier. This barrier is a consequence of the special structure of cerebral blood vessels. In the rest of the body, the cells that
compose the walls of blood vessels are loosely packed; as a result, most molecules pass readily through them into surrounding tissue. In the brain, however, the cells of the blood vessel walls are tightly packed, thus forming a barrier to the passage of many molecules—particularly proteins and other large molecules (Abbott, Rönnbäck, & Hannson, 2005). The degree to which recreational and therapeutic drugs can influence brain activity depends on the ease with which they penetrate the blood–brain barrier (Löschler & Potschka, 2005).

The blood–brain barrier does not impede the passage of all large molecules. Some large molecules that are critical for normal brain function (e.g., glucose) are actively transported through cerebral blood vessel walls. Also, the blood vessel walls in some areas of the brain allow certain large molecules to pass through them unimpeded; for example, sex hormones, which have difficulty permeating some parts of the brain, readily enter neurons involved in sexual behavior.
Most of the cells of the nervous system are of two fundamentally different types: neurons and glial cells. Their anatomy is discussed in the following two subsections.

**Anatomy of Neurons**

Neurons are cells that are specialized for the reception, conduction, and transmission of electrochemical signals. They come in an incredible variety of shapes and sizes (see Migliore & Shepherd, 2005; Nelson, Sugino, & Hempel, 2006); however, many are similar to the one illustrated in Figures 3.5 and 3.6.

**Figure 3.5** The major external features of a typical neuron.
**Endoplasmic reticulum.** A system of folded membranes in the cell body; rough portions (those with ribosomes) play a role in the synthesis of proteins; smooth portions (those without ribosomes) play a role in the synthesis of fats.

**Cytoplasm.** The clear internal fluid of the cell.

**Ribosomes.** Internal cellular structures on which proteins are synthesized; they are located on the endoplasmic reticulum.

**Golgi complex.** A system of membranes that packages molecules in vesicles.

**Nucleus.** The spherical DNA-containing structure of the cell body.

**Mitochondria.** Sites of aerobic (oxygen-consuming) energy release.

**Microtubules.** Tubules responsible for the rapid transport of material throughout neurons.

**Synaptic vesicles.** Spherical membrane packages that store neurotransmitter molecules ready for release near synapses.

**Neurotransmitters.** Molecules that are released from active neurons and influence the activity of other cells.

**FIGURE 3.6** The major internal features of a typical neuron.
External Anatomy of Neurons  Figure 3.5 is an illustration of the major external features of one type of neuron. For your convenience, the definition of each feature is included in the illustration.

Internal Anatomy of Neurons  Figure 3.6 is an illustration of the major internal features of one type of neuron. Again, the definition of each feature is included in the illustration.

Neuron Cell Membrane  The neuron cell membrane is composed of a lipid bilayer—two layers of fat molecules (see Figure 3.7). Embedded in the lipid bilayer are numerous protein molecules that are the basis of many of the cell membrane’s functional properties. Some membrane proteins are channel proteins, through which certain molecules can pass; others are signal proteins, which transfer a signal to the inside of the neuron when particular molecules bind to them on the outside of the membrane.

Classes of Neurons  Figure 3.8 illustrates a way of classifying neurons that is based on the number of processes (projections) emanating from their cell bodies. A neuron with more than two processes extending from its cell body is classified as a multipolar neuron; most neurons are multipolar. A neuron with one process extending from its cell body is classified as a unipolar neuron, and a neuron with two processes extending from its cell body is classified as a bipolar neuron. Neurons with short axons or no axon at all are called interneurons; their function is to integrate the neural activity within a single brain structure, not to conduct signals from one structure to another.

In general, there are two kinds of gross neural structures in the nervous system: those composed primarily of cell bodies and those composed primarily of axons. In the central nervous system, clusters of cell bodies are called nuclei (singular nucleus); in the peripheral nervous system, they are called ganglia (singular ganglion). (Note that the word nucleus has two different neuroanatomical meanings; it is a structure in the neuron cell body and a cluster of cell bodies in the CNS.) In the central nervous system, bundles of axons are called tracts; in the peripheral nervous system, they are called nerves.

Glial Cells: The Forgotten Majority  Neurons are not the only cells in the nervous system. Glial cells are found throughout the nervous system, and they outnumber neurons by 10 to 1.

There are several kinds of glial cells (Fields & Stevens-Graham, 2002). Oligodendrocytes, for example, are glial cells with extensions that wrap around the axons of some neurons of the central nervous system. These extensions are rich in myelin, a fatty insulating substance, and the myelin sheaths that they form increase the speed and efficiency of axonal conduction. A similar function is performed in the peripheral nervous system by Schwann cells, a second class of glial cells. Oligodendrocytes and Schwann cells are illustrated in Figure 3.9. Notice that each Schwann cell constitutes one myelin segment, whereas each oligodendrocyte provides several myelin segments, often on more than one axon. Another important difference between Schwann cells and oligodendrocytes is that only Schwann cells can guide axonal regeneration (regrowth) after damage. That is why effective axonal regeneration in the mammalian nervous system is restricted to the PNS.

Microglia are a third class of glial cells. Microglia are smaller than other glia—thus their name. They respond
3.2 Cells of the Nervous System

Myelination in the Peripheral Nervous System

Myelination in the Central Nervous System

FIGURE 3.8 A unipolar neuron, a bipolar neuron, a multipolar neuron, and an interneuron.

FIGURE 3.9 The myelination of CNS axons by an oligodendrocyte and the myelination of PNS axons by Schwann cells.
to injury or disease by multiplying, engulfing cellular debris, and triggering inflammatory responses.

**Astrocytes** are a fourth class of glial cells. They are the largest glial cells and they are so named because they are star-shaped (*astron* means “star”). The extensions of some astrocytes cover the outer surfaces of blood vessels that course through the brain; they also make contact with neuron cell bodies (see Figure 3.10). These particular astrocytes play a role in allowing the passage of some chemicals from the blood into CNS neurons and in blocking other chemicals (Abbott, Rönnbäck, & Hansson, 2006).

For decades, it was assumed that the function of astrocytes was merely to provide support for neurons—providing them with nutrition, clearing waste, and forming a physical matrix to hold neural circuits together (*glia* means “glue”). But this limited view of the role of astrocytes is rapidly changing, thanks to a series of remarkable findings. Astrocytes have been shown to send and receive signals from neurons and other glial cells, to control the establishment and maintenance of synapses between neurons, to modulate neural activity, and to participate in glial circuits (Volterra & Meldolesi, 2005). Now that the first wave of discoveries has focused neuroscientific attention on astrocytes and other glial cells, appreciation of their role in nervous system function should grow rapidly. These underappreciated supporting players are moving closer to center stage. Their possible role in various nervous system disorders is under intensive investigation.

### 3.3 Neuroanatomical Techniques and Directions

This section of the chapter first describes a few of the most common neuroanatomical techniques. Then, it explains the system of directions that neuroanatomists use to describe the location of structures in vertebrate nervous systems.

**Neuroanatomical Techniques**

The major problem in visualizing neurons is not their minuteness. The major problem is that neurons are so tightly packed and their axons and dendrites so intricately intertwined that looking through a microscope at unprepared neural tissue reveals almost nothing about them. The key to the study of neuroanatomy lies in preparing neural tissue in a variety of ways, each of which permits a clear view of a different aspect of neuronal structure, and then combining the knowledge obtained from each of the preparations. This point is illustrated by the following neuroanatomical techniques.

**Golgi Stain**  The greatest blessing to befall neuroscience in its early years was the accidental discovery of the **Golgi stain** by Camillo Golgi (pronounced “GOLE-jee”), an Italian physician, in the early 1870s. Golgi was trying to stain the meninges, by exposing a block of neural tissue to potassium dichromate and silver nitrate, when he noticed an amazing thing. For some unknown reason, the silver chromate created by the chemical reaction of the two substances Golgi was using invaded a few neurons in each slice of tissue and stained each invaded neuron entirely black. This discovery made it possible to see individual neurons for the first time, although only in silhouette (see Figure 3.11). Stains that totally dye all neurons on a slide reveal nothing of their structure because the neurons are so tightly packed.
Nissl Stain Although the Golgi stain permits an excellent view of the silhouettes of the few neurons that take up the stain, it provides no indication of the number of neurons in an area or the nature of their inner structure. The first neural staining procedure to overcome these shortcomings was the Nissl stain, which was developed by Franz Nissl, a German psychiatrist, in the 1880s. The most common dye used in the Nissl method is cresyl violet. Cresyl violet and other Nissl dyes penetrate all cells on a slide, but they bind effectively only to structures in neuron cell bodies. Thus, one can estimate the number of cell bodies in an area by counting the number of Nissl-stained dots. Figure 3.12 is a photograph of a slice of brain tissue stained with cresyl violet. Notice that only the layers composed mainly of neuron cell bodies are densely stained.

Electron Microscopy A neuroanatomical technique that provides information about the details of neuronal structure is electron microscopy (pronounced “my-CROSS-uh-pee”). Because of the nature of light, the limit of magnification in light microscopy is about 1,500 times, a level of magnification that is insufficient to reveal the fine anatomical details of neurons. Greater detail can be obtained by first coating thin slices of neural tissue with an electron-absorbing substance that is taken up by different parts of neurons to different degrees, then passing a beam of electrons through the tissue onto a photographic film. The result is an electron micrograph, which captures neuronal structure in exquisite detail (see Figure 4.10 on page 88). A scanning electron microscope provides spectacular electron micrographs in three dimensions (see Figure 3.13 on page 62), but it is not capable of as much magnification as a conventional electron microscope.
Neuroanatomical Tracing Techniques

Neuroanatomical tracing techniques are of two types: anterograde (forward) tracing methods and retrograde (backward) tracing methods. Anterograde tracing methods are used when an investigator wants to trace the paths of axons projecting away from cell bodies located in a particular area. The investigator injects into the area one of several chemicals commonly used for anterograde tracing—chemicals that are taken up by cell bodies and then transported forward along their axons to their terminal buttons. After a few days, the brain is removed and sliced; the slices are then treated to reveal the locations of the injected chemical.

Retrograde tracing methods work in reverse; they are used when an investigator wants to trace the paths of axons projecting into a particular area. The investigator injects into the area one of several chemicals commonly used for retrograde tracing—chemicals that are taken up by terminal buttons and then transported backward along their axons to their cell bodies. After a few days, the brain is removed and sliced; the slices are then treated to reveal the locations of the injected chemical.

**Directions in the Vertebrate Nervous System**

It would be difficult for you to develop an understanding of the layout of an unfamiliar city without a system of directional coordinates: north–south, east–west. The same goes for the nervous system. Thus, before introducing you to the locations of major nervous system structures, I will describe the three-dimensional system of directional coordinates used by neuroanatomists.

Directions in the vertebrate nervous system are described in relation to the orientation of the spinal cord. This system is straightforward for most vertebrates, as Figure 3.14 indicates. The vertebrate nervous system has three axes: anterior–posterior, dorsal–ventral, and medial–lateral. First, anterior means toward the nose end (the anterior end), and posterior means toward the tail end (the posterior end); these same directions are sometimes referred to as rostral and caudal, respectively. Second, dorsal means toward the surface of the back or the top of the head (the dorsal surface), and ventral means toward the surface of the chest or the bottom of the head (the ventral surface). Third, medial means toward the midline of the body, and lateral means away from the midline toward the body’s lateral surfaces.

We humans complicate this simple three-axis (anterior–posterior, ventral–dorsal, medial–lateral) system of neuroanatomical directions by insisting on walking around on our hind legs. This changes the orientation of our cerebral hemispheres in relation to our spines and brain stems.

You can save yourself a lot of confusion if you remember that the system of vertebrate neuroanatomical directions was adapted for use in humans in such a way that the terms used to describe the positions of various body surfaces are the same in humans as they are in more typical, non-upright vertebrates. Specifically, notice that the top
of the human head and the back of the human body are both referred to as dorsal even though they are in different directions, and the bottom of the human head and the front of the human body are both referred to as ventral even though they are in different directions (see Figure 3.15). To circumvent this complication, the terms superior and inferior are often used to refer to the top and bottom of the primate head, respectively.

Proximal and distal are two other common directional terms. In general, proximal means “close,” and distal means “far.” Specifically, with regard to the peripheral nervous system, proximal means closer to the CNS, and distal means farther from the CNS—for example, the nerve terminals of the shoulders are proximal to those of the fingers.

In the next few pages, you will be seeing drawings of sections (slices) of the brain cut in one of three different planes: horizontal sections, frontal (also termed coronal) sections, and sagittal sections. These three planes are illustrated in Figure 3.16. A section cut down the center of the brain, between the two hemispheres, is called a midsagittal section. A section cut at a right angle to any long, narrow structure, such as the spinal cord or a nerve, is called a cross section.

This is a good place for you to pause to scan your brain. Are you ready to proceed to the structures of the brain and spinal cord? Test your grasp of the preceding sections of this chapter by drawing a line between each term in the left column and the appropriate word or phrase in the right column. The correct answers are provided below. Before proceeding, review material related to your incorrect answers.

1. myelin a. gaps
2. soma b. cone-shaped region
3. axon hillock c. packaging membranes
4. Golgi complex d. fatty substance
5. ribosomes e. neurotransmitter storage
6. synapses f. cell body
7. glial cells g. PNS clusters of cell bodies
8. synaptic vesicles h. protein synthesis
9. astrocytes i. the forgotten majority
10. ganglia j. CNS myelinators
11. oligodendrocytes k. black
12. Golgi stain l. largest glial cells
13. dorsal m. caudal
14. posterior n. top of head

Scan Your Brain answers: (1) d, (2) f, (3) b, (4) c, (5) h, (6) a, (7) i, (8) e, (9) l, (10) g, (11) j, (12) k, (13) n, (14) m.
Chapter 3  ■  The Anatomy of the Nervous System

3.4  The Spinal Cord

In the first three sections of this chapter, you learned about the divisions of the nervous system, the cells that compose it, and some of the neuroanatomical techniques that are used to study it. This section begins your ascent of the human CNS by focusing on the spinal cord. The final two sections of the chapter focus on the brain.

In cross section, it is apparent that the spinal cord comprises two different areas (see Figure 3.17): an inner H-shaped core of gray matter and a surrounding area of white matter. Gray matter is composed largely of cell bodies and unmyelinated interneurons, whereas white matter is composed largely of myelinated axons. (It is the myelin that gives the white matter its glossy white sheen.) The two dorsal arms of the spinal gray matter are called the dorsal horns, and the two ventral arms are called the ventral horns.

Pairs of spinal nerves are attached to the spinal cord—one on the left and one on the right—at 31 different levels of the spine. Each of these 62 spinal nerves divides as it nears the cord (see Figure 3.17), and its axons are joined to the cord via one of two roots: the dorsal root or the ventral root.

All dorsal root axons, whether somatic or autonomic, are sensory (afferent) unipolar neurons with their cell bodies grouped together just outside the cord to form the dorsal root ganglia (see Figure 3.17). Many of their synaptic terminals are in the dorsal horns of the spinal gray matter (see Figure 3.18). In contrast, the neurons of the ventral root are motor (efferent) multipolar neurons with their cell bodies in the ventral horns. Those that are part of the somatic nervous system project to skeletal muscles; those that are part of the autonomic nervous system project to ganglia, where they synapse on neurons that in turn project to internal organs (heart, stomach, liver, etc.). See Appendix I.

3.5  The Five Major Divisions of the Brain

A necessary step in learning to live in an unfamiliar city is learning the names and locations of its major neighborhoods or districts. Those who possess this information can easily communicate the general location of any destination in the city. This section of the chapter introduces you to the five “neighborhoods,” or divisions, of the brain—for much the same reason.

To understand why the brain is considered to be composed of five divisions, it is necessary to understand its early development (see Swanson, 2000). In the vertebrate embryo, the tissue that eventually develops into the CNS is recognizable as a fluid-filled tube (see Figure 3.19). The first indications of the developing brain are three swellings that occur at the anterior end of this tube. These three swellings eventually develop into the adult forebrain, midbrain, and hindbrain.

Before birth, the initial three swellings in the neural tube become five (see Figure 3.19). This occurs because the forebrain swelling grows into two different swellings, and so does the hindbrain swelling. From anterior to posterior, the five swellings that compose the developing brain at birth are the telencephalon, the diencephalon, the...
Now that you have learned the five major divisions of the brain, it is time to introduce you to their major structures. This section of the chapter begins its survey of brain structures in the myelencephalon, then ascends through the other divisions to the telencephalon. The brain structures introduced and defined in this section are boldfaced but are not included in the Key Terms list at the end of the chapter. Rather, they are arranged according to their locations in the brain in Figure 3.30 on page 72.

Here is a reminder before you delve into the anatomy of the brain: The directional coordinates are the same for the brain stem as for the spinal cord, but they are rotated by 90° for the forebrain.

**Mesencephalon (or midbrain), the metencephalon, and the myelencephalon** (encephalon means “within the head”). These swellings ultimately develop into the five divisions of the adult brain. As a student, I memorized their order by remembering that the telencephalon is on the top and the other four divisions are arrayed below it in alphabetical order.

Figure 3.20 illustrates the locations of the telencephalon, diencephalon, mesencephalon, metencephalon, and myelencephalon in the adult human brain. Notice that in humans, as in other higher vertebrates, the telencephalon (the left and right cerebral hemispheres) undergoes the greatest growth during development. The other four divisions of the brain are often referred to collectively as the **brain stem**—the stem on which the cerebral hemispheres sit. The myelencephalon is often referred to as the **medulla**.

**Myelencephalon**

Not surprisingly, the **myelencephalon** (or **medulla**), the most posterior division of the brain, is composed largely of tracts carrying signals between the rest of the brain and the body. An interesting part of the myelencephalon from a psychological perspective is the **reticular formation** (see Figure 3.21 on page 66). It is a complex network of about 100 tiny nuclei that occupies the central core of the brain stem from the posterior boundary of the myelencephalon to the anterior boundary of the midbrain. It is so named because of its netlike appearance (*reticulum* means “little net”). Sometimes, the reticular formation is referred to as the **reticular activating system** because parts of it seem to play a role in arousal. However, the various nuclei of the reticular formation are involved in a
damage also produces a variety of cognitive deficits suggests that the functions of the cerebellum are not restricted to sensorimotor control.

**Mesencephalon**

The *mesencephalon*, like the metencephalon, has two divisions. The two divisions of the mesencephalon are the tectum and the tegmentum (see Figure 3.22). The **tectum** (roof) is the dorsal surface of the midbrain. In mammals, the tectum is composed of two pairs of bumps, the **colliculi** (little hills). The posterior pair, called the **inferior colliculi**, have an auditory function; the anterior pair, called the **superior colliculi**, have a visual function. In lower vertebrates, the function of the tectum is entirely visual; thus, the tectum is referred to as the **optic tectum**.

The **tegmentum** is the division of the mesencephalon ventral to the tectum. In addition to the reticular formation and tracts of passage, the tegmentum contains three colorful structures that are of particular interest to biopsychologists: the periaqueductal gray, the substantia nigra, and the red nucleus (see Figure 3.22). The variety of functions—including sleep, attention, movement, the maintenance of muscle tone, and various cardiac, circulatory, and respiratory reflexes. Accordingly, referring to this collection of nuclei as a system can be misleading.

**Metencephalon**

The *metencephalon*, like the myelencephalon, houses many ascending and descending tracts and part of the reticular formation. These structures create a bulge, called the **pons**, on the brain stem’s ventral surface. The pons is one major division of the metencephalon; the other is the cerebellum (little brain)—see Figure 3.21. The **cerebellum** is the large, convoluted structure on the brain stem’s dorsal surface. It is an important sensorimotor structure; cerebellar damage eliminates the ability to precisely control one’s movements and to adapt them to changing conditions. However, the fact that cerebellar...
periaqueductal gray is the gray matter situated around the cerebral aqueduct, the duct connecting the third and fourth ventricles; it is of special interest because of its role in mediating the analgesic (pain-reducing) effects of opiate drugs. The substantia nigra (black substance) and the red nucleus are both important components of the sensorimotor system.

**Diencephalon**

The diencephalon is composed of two structures: the thalamus and the hypothalamus (see Figure 3.23). The thalamus is the large, two-lobed structure that constitutes the top of the brain stem. One lobe sits on each side of the third ventricle, and the two lobes are joined by the massa intermedia, which runs through the ventricle. Visible on the surface of the thalamus are white lamina (layers) that are composed of myelinated axons.

The thalamus comprises many different pairs of nuclei, most of which project to the cortex. Some are sensory relay nuclei—nuclei that receive signals from sensory receptors, process them, and then transmit them to the appropriate areas of sensory cortex. For example, the lateral geniculate nuclei, the medial geniculate nuclei, and the ventral posterior nuclei are important relay stations in the visual, auditory, and somatosensory systems, respectively. But it is now clear that the sensory relay nuclei are not one-way streets; they all receive feedback signals from the very areas of cortex to which they project (Cudeiro & Sillito, 2006). The general organization of the thalamus is illustrated in Appendix V.

The hypothalamus is located just below the anterior thalamus (hypo means “below”)—see Figure 3.24 on page 68. It plays an important role in the regulation of several motivated behaviors. It exerts its effects in part by regulating the release of hormones from the pituitary gland, which dangles from it on the ventral surface of the brain. The literal meaning of pituitary gland is “snot gland”; it was discovered in a gelatinous state behind the nose of an unembalmed cadaver and was incorrectly assumed to be the main source of nasal mucus.

In addition to the pituitary gland, two other structures appear on the inferior surface of the hypothalamus: the optic chiasm and the mammillary bodies (see Figure 3.24). The optic chiasm is the point at which the optic nerves from each eye come together. The X shape is created because some of the axons of the optic nerve decussate (cross over to the other side of the brain) via the optic chiasm. The decussating fibers are said to be contralateral (projecting from one side of the body to the other), and the non-decussating fibers are said to be ipsilateral (staying on the same side of the body). The mammillary bodies, which are often considered to be part of the hypothalamus, are a pair of spherical nuclei located on the inferior surface of the hypothalamus, just behind the pituitary. The mammillary bodies and the other nuclei of the hypothalamus are illustrated in Appendix VI.

**Telencephalon**

The telencephalon, the largest division of the human brain, mediates the brain’s most complex functions. It initiates voluntary movement, interprets sensory input, and mediates
sulcus). The ridges between fissures and sulci are called gyri (singular gyrus). It is apparent in Figure 3.25 that the cerebral hemispheres are almost completely separated by the largest of the fissures: the longitudinal fissure. The cerebral hemispheres are directly connected by a few tracts spanning the longitudinal fissure; these hemisphere-connecting tracts are called cerebral commissures. The largest cerebral commissure, the corpus callosum, is clearly visible in Figure 3.25.

As Figures 3.25 and 3.26 indicate, the two major landmarks on the lateral surface of each hemisphere are the central fissure and the lateral fissure. These fissures partially divide each hemisphere into four lobes: the frontal lobe, the parietal lobe (pronounced “pa-RYE-e-tal”), the temporal lobe, and the occipital lobe (pronounced “ok-SIP-i-tal”). Among the largest gyri are the precentral gyri, the postcentral gyri, and the superior temporal gyri in the frontal, parietal, and temporal lobes, respectively.

Cerebral Cortex The cerebral hemispheres are covered by a layer of tissue called the cerebral cortex (cerebral bark). In humans, the cerebral cortex is deeply convoluted (furrowed)—see Figure 3.25. The convolutions have the effect of increasing the amount of cerebral cortex without increasing the overall volume of the brain. Not all mammals have convoluted cortices; most mammals are lissencephalic (smooth-brained). It was once believed that the number and size of cortical convolutions determined a species’ intellectual capacities; however, the number and size of cortical convolutions appear to be related more to body size. Every large mammal has an extremely convoluted cortex.

The large furrows in a convoluted cortex are called fissures, and the small ones are called sulci (singular sulcus).
different functions. Still, it is useful at this early stage of your biopsychological education to get a general idea of various functions of areas within each lobe.

The main function of the occipital lobes is quite straightforward: We humans rely heavily on the analysis of visual input to guide our behavior, and the occipital cortex and large areas of adjacent cortex perform this function. There are two large functional areas in each parietal lobe: The postcentral gyrus analyzes sensations from the body (e.g., touch), whereas the remaining areas of cortex in the posterior parts of the parietal lobes play roles in perceiving the location of both objects and our own bodies and in directing our attention. The cortex of each temporal lobe has three general functional areas: the superior temporal gyrus is involved in hearing and language; the inferior temporal cortex identifies complex visual patterns; and the medial portion of temporal cortex (which is not visible from the usual side view) is important for certain kinds of memory. Lastly, each frontal lobe has two distinct functional areas: the precentral gyrus and adjacent frontal cortex have a motor function, whereas the frontal cortex anterior to motor cortex performs complex cognitive functions, such as planning response sequences, evaluating the outcomes of potential patterns of behavior, and assessing the significance of the behavior of others.

About 90% of human cerebral cortex is neocortex (new cortex); that is, it is six-layered cortex of relatively recent evolution (Douglas & Martin, 2004). By convention, the layers of neocortex are numbered I through VI, starting at the surface. Figure 3.27 on page 70 illustrates two adjacent sections of neocortex. One has been stained with a Nissl stain to reveal the number and shape of its cell bodies; the other has been stained with a Golgi stain to reveal the silhouettes of a small proportion of its neurons.

Three important characteristics of neocortical anatomy are apparent from the sections in Figure 3.27. First, it is apparent that there are two fundamentally different kinds of cortical neurons: pyramidal (pyramid-shaped) cells and stellate (star-shaped) cells. Pyramidal cells are large multipolar neurons with pyramid-shaped cell bodies, a large dendrite called an apical dendrite that extends from the apex of the pyramid straight toward the cortex surface, and a very long axon. In contrast, stellate cells are small star-shaped interneurons (neurons with short axons or no axon). Second, it is apparent that the six layers of neocortex differ from one another in terms of the size and density of their cell bodies and the relative proportion of pyramidal and stellate cell bodies that they contain. Third, it is apparent that many long axons and dendrites course vertically (i.e., at right angles to the cortical layers) through the neocortex. This vertical flow of information is the basis of the neocortex’s columnar organization; neurons in a given vertical column of neocortex often form a mini-circuit that performs a single function (Laughlin & Sejnowski, 2003).

It is important to understand that the cerebral lobes are not functional units. It is best to think of the cerebral cortex as a flat sheet of cells that just happens to be divided into lobes because pressure causes it to be folded in on itself during development. Thus, it is incorrect to think that a lobe has a single function or that adjacent areas of cortex that happen to lie in two different lobes necessarily have
A fourth important characteristic of neocortical anatomy is not apparent in Figure 3.27: Although all neocortex is six-layered, there are variations in the thickness of the respective layers from area to area (Brown & Bowman, 2002; Passingham, Stephan, & Kotter, 2002). For example, because the stellate cells of layer IV are specialized for receiving sensory signals from the thalamus, layer IV is extremely thick in areas of sensory cortex. Conversely, because the pyramidal cells of layer V conduct signals from the neocortex to the brain stem and spinal cord, layer V is extremely thick in areas of motor cortex.

The hippocampus is one important area of cortex that is not neocortex—it has only three major layers (see Förster, Ahao, & Frotscher, 2006). The hippocampus is located at the medial edge of the cerebral cortex as it folds back on itself in the medial temporal lobe (see Figure 3.25). This folding produces a shape that is, in cross section, somewhat reminiscent of a sea horse (hippocampus means “sea horse”).

The Limbic System and the Basal Ganglia

Although much of the subcortical portion of the telencephalon is taken up by axons projecting to and from the neocortex, there are several large subcortical nuclear groups. Some of them are considered to be part of either the limbic system or the basal ganglia motor system. Don’t be misled by the word system in these contexts; it implies a level of certainty that is unwarranted. It is not entirely clear exactly what these hypothetical systems do, exactly which structures should be included in them, or even whether it is appropriate to view them as unitary systems. Nevertheless, if not taken too literally, the concepts of limbic system and basal ganglia motor system provide a useful means of conceptualizing the organization of several subcortical structures.

The limbic system is a circuit of midline structures that circle the thalamus (limbic means “ring”). The limbic system is involved in the regulation of motivated behaviors—including the four Fs of motivation: fleeing, feeding, fighting, and sexual behavior. (This joke is as old as biopsychology itself, but it is a good one.) In addition to several structures about which you have already read (e.g., the mammillary bodies and the hippocampus), major structures of the limbic system include the amygdala, the fornix, the cingulate cortex, and the septum.

Let’s begin tracing the limbic circuit (see Figure 3.28) at the amygdala—the almond-shaped nucleus in the anterior temporal lobe (amygdala means “almond” and is pronounced “a-MIG-dah-lah”)—see Swanson & Petrovich (1998). Posterior to the amygdala is the hippocampus, which runs beneath the thalamus in the medial temporal lobe. Next in the ring are the cingulate cortex and the fornix. The cingulate cortex is the large strip of cortex in the cingulate gyrus on the medial surface of the cerebral hemispheres, just superior to the corpus callosum; it encircles the dorsal thalamus (cingulate means “encircling”). The fornix, the major tract of the limbic
system, also encircles the dorsal thalamus; it leaves the dorsal end of the hippocampus and sweeps forward in an arc coursing along the superior surface of the third ventricle and terminating in the septum and mammillary bodies (fornix means “arc”). The septum is a midline nucleus that is located at the anterior tip of the cingulate cortex. Several tracts connect the septum and mammillary bodies with the amygdala and hippocampus, thereby completing the limbic ring.

The basal ganglia are illustrated in Figure 3.29. As we did with the limbic system, let’s begin our examination of the basal ganglia with the amygdala, which is considered to be part of both systems. Sweeping out of each amygdala, first in a posterior direction and then in an anterior direction, is the long tail-like caudate (caudate means “tail-like”). Each caudate forms an almost complete circle; in its center, connected to it by a series of fiber bridges, is the putamen (pronounced “pew-TAY-men”). Together, the caudate and the putamen, which both have a striped appearance, are known as the striatum (striped structure). The remaining structure of the basal ganglia is the pale circular structure known as
the globus pallidus (pale globe). The globus pallidus is located medial to the putamen, between the putamen and the thalamus.

The basal ganglia play a role in the performance of voluntary motor responses. Of particular interest is a pathway that projects to the striatum from the substantia nigra of the midbrain. Parkinson’s disease, a disorder that is characterized by rigidity, tremors, and poverty of voluntary movement, is associated with the deterioration of this pathway. Another part of the basal ganglia that is currently of particular interest to biopsychologists is the nucleus accumbens, which is in the medial portion of the ventral striatum (see Figure 3.29). The nucleus accumbens is thought to play a role in the rewarding effects of addictive drugs and other reinforcers.

Figure 3.30 summarizes the major brain divisions and structures—whose names have appeared in boldface in this section.

**FIGURE 3.30** Summary of major brain structures. This display contains all the brain anatomy key terms that appear in boldface in Section 3.6.
If you have not previously studied the gross anatomy of the brain, your own brain is probably straining under the burden of new terms. To determine whether you are ready to proceed, scan your brain by labeling the following mid-sagittal view of a real human brain. You may find it challenging to switch from color-coded diagrams to a photograph of a real brain.

The correct answers are provided below. Before proceeding, review material related to your errors and omissions. Notice that Figure 3.30 includes all the brain anatomy terms that have appeared in bold type in this section and thus is an excellent review tool.

1. __________________________ lobe
2. __________________________ gyrus
3. ____________________________
4. ____________________________
5. ____________________________
6. ____________________________
7. ____________________________ colliculus
8. ____________________________ body
9. ____________________________
10. ____________________________ ventricle
11. ____________________________
12. ____________________________
13. ____________________________
14. ____________________________
Figure 3.31 concludes this chapter, for reasons that too often get lost in the shuffle of neuroanatomical terms and technology. I have included it here to illustrate the beauty of the brain and the art of those who study its structure. I hope you are inspired by it. I wonder what thoughts its neural circuits once contained.

**FIGURE 3.31** The art of neuroanatomical staining. This slide was stained with both a Golgi stain and a Nissl stain. Clearly visible on the Golgi-stained pyramidal neurons are the pyramid-shaped cell bodies, the large apical dendrites, and numerous dendritic spines. Less obvious here is the long, narrow axon that projects from each pyramidal cell body off the bottom of this slide. (Courtesy of Miles Herkenham, Unit of Functional Neuroanatomy, National Institute of Mental Health, Bethesda, MD.)

**Themes Revisited**

This chapter contributed relatively little to the development of the book’s themes; that development was temporarily slowed while you were being introduced to the key areas and structures of the human brain. A knowledge of fundamental neuroanatomy will serve as the foundation of discussions of brain function in subsequent chapters. However, the clinical implications theme did arise three times: in discussions of the importance of the cranial nerves in neurological diagnosis, the role of blockage of cerebral aqueducts in hydrocephalus, and the involvement of damage to the pathway from the substantia nigra to the striatum in Parkinson’s disease. Also, the thinking clearly tab warned you not to fall into the trap of thinking of the lobes of the cerebral cortex as functional units or of thinking of the limbic structures and basal ganglia as systems.
Think about It

1. Which of the following extreme positions do you think is closer to the truth? (a) The primary goal of all psychological research should be to relate psychological phenomena to the anatomy of neural circuits. (b) Psychologists should leave the study of neuroanatomy to neuroanatomists.

2. Perhaps the most famous mistake in the history of biopsychology was made by Olds and Milner (see Chapter 15). They botched an electrode implantation in the brain of a rat, and the tip of the stimulation electrode ended up in an unknown structure. When they subsequently tested the effects of electrical stimulation of this unknown structure, they made a fantastic discovery: The rat seemed to find the brain stimulation extremely pleasurable. In fact, the rat would press a lever for hours at an extremely high rate if every press produced a brief stimulation to its brain through the electrode. If you had accidentally stumbled on this intracranial self-stimulation phenomenon, what neuroanatomical procedures would you have used to identify the stimulation site and the neural circuits involved in the pleasurable effects of the stimulation?

Key Terms

3.1 General Layout of the Nervous System
- Central nervous system (CNS) (p. 52)
- Peripheral nervous system (PNS) (p. 52)
- Somatic nervous system (SNS) (p. 52)
- Afferent nerves (p. 52)
- Efferent nerves (p. 52)
- Autonomic nervous system (ANS) (p. 52)
- Sympathetic nerves (p. 52)
- Parasympathetic nerves (p. 52)
- Cranial nerves (p. 53)
- Meninges (p. 54)
- Dura mater (p. 54)
- Arachnoid membrane (p. 54)
- Subarachnoid space (p. 54)
- Pia mater (p. 54)
- Cerebrospinal fluid (CSF) (p. 54)
- Central canal (p. 54)
- Cerebral ventricles (p. 54)
- Choroid plexuses (p. 54)
- Blood–brain barrier (p. 54)

3.2 Cells of the Nervous System
- Multipolar neuron (p. 58)
- Unipolar neuron (p. 58)
- Bipolar neuron (p. 58)
- Interneurons (p. 58)
- Nuclei (p. 58)
- Ganglia (p. 58)
- Tracts (p. 58)
- Nerves (p. 58)
- Glial cells (p. 58)
- Oligodendrocytes (p. 58)
- Myelin (p. 58)
- Myelin sheaths (p. 58)
- Schwann cells (p. 58)
- Microglia (p. 58)
- Astrocytes (p. 60)

3.3 Neuroanatomical Techniques and Directions
- Golgi stain (p. 60)
- Nissl stain (p. 61)
- Electron microscopy (p. 61)
- Anterior (p. 62)
- Posterior (p. 62)
- Dorsal (p. 62)
- Ventral (p. 62)
- Medial (p. 62)
- Lateral (p. 62)
- Superior (p. 63)
- Inferior (p. 63)
- Proximal (p. 63)
- Distal (p. 63)
- Horizontal sections (p. 63)
- Frontal sections (p. 63)
- Sagittal sections (p. 63)
- Cross section (p. 63)

3.4 The Spinal Cord
- Gray matter (p. 64)
- White matter (p. 64)
- Dorsal horns (p. 64)
- Ventral horns (p. 64)
- Dorsal root ganglia (p. 64)

3.5 The Five Major Divisions of the Brain
- Brain stem (p. 65)

3.6 Major Structures of the Brain
- Sensory relay nuclei (p. 67)
- Decussate (p. 67)
- Contralateral (p. 67)
- Ipsilateral (p. 67)
- Sulci (p. 68)
- Pyramidal cells (p. 69)
- Stellate cells (p. 69)
- Columnar organization (p. 69)