

PROLOGUE

## Asha's Story

The headaches began without warning. A pounding, intense pain just over Asha's left temple. Asha just couldn't seem to shake it—the pain was unrelenting. She was uncharacteristically tired, too.

But your author Sandy's friend Asha, then a 32-year-old university professor, chalked up her constant headache and fatigue to stress and exhaustion. After all, the end of her demanding first semester of teaching and research was drawing near. Still, Asha had always been very healthy

and usually tolerated stress well. She didn't drink or smoke. And no matter how late she stayed up working on her lectures and research proposals, she still got up at 5:30 every morning to work out at the university gym.

There were other, more subtle signs that something was wrong. Asha's husband, Paul, noticed that she had been behaving rather oddly in recent weeks. For example, at Thanksgiving dinner, Asha had picked up a knife by the wrong end and tried to cut her turkey with the handle instead of the blade. A few hours later, Asha had made the same mistake trying to use scissors: She held the blades and tried to cut with the handle.

Asha laughed these incidents off, and for that matter, so did Paul. They both thought she was simply under too much stress. And when Asha occasionally got her words mixed up, neither Paul nor anyone else was terribly surprised. Asha was born in India, and her first language was Tulu. Although Asha was extremely fluent in English, she often got English phrases slightly wrong—like the time she said that it was "storming cats and birds" instead of "raining cats and dogs."

There were other odd lapses in language. "I would say something, thinking it was correct," Asha recalled, "and people would say to me, 'What



are you saying?' I wouldn't realize I was saying something wrong. I would open my mouth and just nonsense would come out. But it made perfect sense to me. At other times, the word was on the tip of my tongue—I knew I knew the word, but I couldn't find it. I would fumble for the word, but it would come out wrong. Sometimes I would slur words, like I'd try to say 'Saturday,' only it would come out 'salad day.'"

On Christmas morning, Paul and Asha were with Paul's family, opening presents. Asha walked over to Paul's father to look at the pool cue he had received as a gift. As she bent down, she fell forward onto her father-in-law. At first, everyone thought Asha was just joking around. But then she fell to the floor, her body stiff. Seconds later, it was apparent that Asha had lost consciousness and was having a seizure.

Asha remembers nothing of the seizure or of being taken by ambulance to the hospital intensive care unit. She floated in and out of consciousness for the first day and night. One scan showed some sort of blockage in Asha's brain. Another scan revealed a large white spot on the left side of her brain. At only 32 years of age, Asha had suffered a stroke—brain damage caused by a disruption of the blood flow to the brain.

#### IN THIS CHAPTER:

INTRODUCTION: Neuroscience and Behavior

The Neuron: The Basic Unit of Communication

The Nervous System and the Endocrine System: Communication Throughout the Body

A Guided Tour of the Brain

Specialization in the Cerebral Hemispheres

PSYCH FOR YOUR LIFE: Maximizing Your Brain's Potential

She remained in the hospital for 12 days. It was only after Asha was transferred out of intensive care that both she and Paul began to realize just how serious the repercussions of the stroke were. Asha couldn't read or write and had difficulty comprehending what was being said. Although she could speak, she could not name even simple objects, such as a tree,

a clock, or her doctor's tie. In this chapter, you will discover why the damage to Asha's brain impaired her ability to perform simple behaviors, like naming common objects. ~



Neuroscience and Behavior Even simple behaviors, such as laughing and talking while running with a friend, involve the harmonious integration of multiple internal signals and body processes. What kinds of questions might neuroscientists ask about the common behaviors shown here?

**biological psychology** The specialized branch of psychology that studies the relationship between behavior and bodily processes and systems; also called *biopsychology* or *psychobiology*.

**neuroscience** The study of the nervous system, especially the brain.

**neuron** A highly specialized cell that communicates information in electrical and chemical form; a nerve cell.

**sensory neuron** The type of neuron that conveys information to the brain from specialized receptor cells in sense organs and internal organs; also called *afferent neuron*.

**motor neuron** The type of neuron that signals muscles to contract; also called *efferent neuron*.

**interneuron** The type of neuron that communicates information from one neuron to the next.

**cell body** The part of a cell that processes nutrients and provides energy for the neuron to function; contains the cell's nucleus; also called the *soma*.

#### **INTRODUCTION:**

## Neuroscience and Behavior

As we discussed in Chapter 1, **biological psychology** is the scientific study of the biological bases of behavior and mental processes. One important area of study within biological psychology is **neuroscience**—the scientific study of the brain and the rest of the nervous system. Neuroscience has become increasingly important in the field of psychology, impacting virtually every area of research (Schwartz & others, 2016). Thus, you'll see references to important neuroscience findings throughout this text.

This chapter will lay an important foundation for the rest of the book by helping you develop an understanding of the nervous system and its relationship to behavior. We'll start by looking at *neurons*, the basic cells of the nervous system. We'll consider the organization of the nervous system and a closely linked communication network, the *endocrine system*. We'll then move on to a guided tour of the brain and explore how certain brain areas are specialized to handle different functions. In Psych for Your Life, at the end of the chapter, we'll describe how the brain responds to environmental stimulation by literally altering its physical structure. And we'll return to Asha's story and tell you how she fared after her stroke.

## The Neuron

THE BASIC UNIT OF COMMUNICATION

**KEY THEME** 

Information in the nervous system is transmitted by specialized cells, called neurons.

#### ■ KEY QUESTIONS

- What are the basic components of the neuron, and what are their functions?
- What are glial cells, and what is their role in the nervous system?
- What is an action potential, and how is it produced?

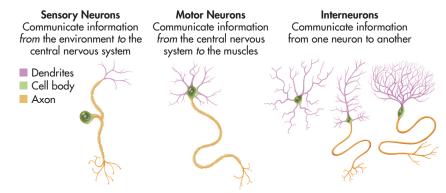
Communication throughout the nervous system takes place via **neurons**—cells that are highly specialized to receive and transmit information from one part of the body to another. Most neurons, especially those in your brain, are extremely small. A bit of brain tissue no larger than a grain of rice contains about 10,000 neurons! Your entire brain contains an estimated 90 *billion* neurons.

Neurons vary greatly in size and shape, reflecting their specialized functions (see Figure 2.1). There are three basic types of neurons, each communicating different kinds of information. Sensory neurons, also called *afferent neurons*, convey information about the environment, such as light or sound, from specialized receptor cells in the sense organs to the brain. Sensory neurons also carry information from the skin and internal organs to the brain. Motor neurons, also called *efferent neurons*, communicate information to the muscles and glands of the body. Simply blinking your eyes activates thousands of motor neurons. Finally, interneurons communicate information *between* neurons. By far, most of the neurons in the human nervous system are interneurons. Many interneurons connect to other interneurons.

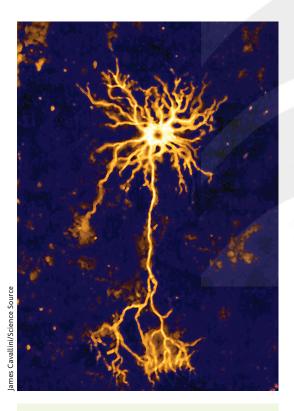
One type of neuron deserves special mention. *Mirror neurons* are not structurally different from other motor neurons. They are a distinct type of motor neuron that becomes activated both when individuals perform a motor act *and* when they observe the same motor act done by another individual (Cook & others, 2014; Rizzolatti & Sinigaglia, 2016).

#### Characteristics of the Neuron

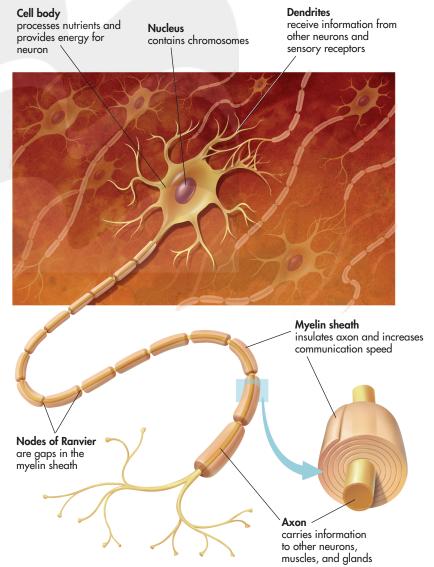
Most neurons have three basic components: a *cell body, dendrites,* and an *axon* (see Figure 2.2). The **cell body,** also called the *soma,* contains structures that manufacture proteins and process nutrients, providing the energy the neuron needs to function. The cell body also contains the *nucleus,* which in turn contains the cell's genetic material—twisted strands of DNA called *chromosomes.* 



**FIGURE 2.1** Types of Neurons Neurons differ in size, shape, and complexity. The distinctive shapes of neurons reflect their specialized functions. Shown here are a few representative neuron types. Virtually all neurons have three basic parts: a *cell body*, an *axon*, and *dendrites*. In most neurons, the dendrites project from the cell body, but in sensory neurons, the dendrites extend from the opposite end of the axon, as shown here.



**FIGURE 2.2** The Parts of a Typical Neuron The drawing at right shows the location and function of key parts of a neuron. The photograph above, taken with a specialized microscope, clearly shows multiple dendrites and a single long axon projecting from the cell body.



**dendrites** The multiple short fibers that extend from a neuron's cell body and receive information from other neurons or from sensory receptor cells.

**axon** The long, fluid-filled tube that carries a neuron's messages to other body areas.

glial cells or glia (GLEE-ull) The support cells that assist neurons by providing structural support, nutrition, and removal of cell wastes; glial cells manufacture myelin.

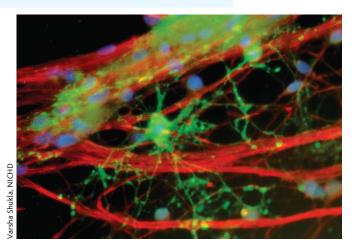
myelin sheath (MY-eh-lin) A white, fatty covering wrapped around the axons of some neurons that increases their communication speed.

action potential A brief electrical impulse by which information is transmitted along the axon of a neuron.

**stimulus threshold** The minimum level of stimulation required to activate a particular neuron.

resting potential The state in which a neuron is prepared to activate and communicate its message if it receives sufficient stimulation.

Glial Cells There are many different kinds of glial cells, or *glia*. They play an active role in brain functioning (Fields, 2013). This colored micrograph shows the first stages of myelin formation by an *oligodendrocyte* (green). Like a spider spinning a web, the oligodendrocyte sends tendrils out to neighboring axons (red) and wraps layers of myelin around them in a spiral-shaped pattern.



Short, branching fibers, called **dendrites**, extend from the cell bodies of most neurons. The term *dendrite* comes from a Greek word meaning "tree." And, the intricate branching of the dendrites does often resemble the branches of a tree. Dendrites *receive* messages from other neurons or specialized cells. Dendrites with many branches have a greater surface area, which increases the amount of information the neuron can receive. Some neurons have thousands of dendrites.

The **axon** is a single, elongated tube that extends from the cell body in most, though not all, neurons. (Some neurons do not have axons.) Axons carry information *from* the neuron *to* other cells in the body, including other neurons, glands, and muscles. In contrast to the potentially large number of dendrites, a neuron has only one axon exiting from the cell body. However, many axons have branches near their tips that allow the neuron to communicate information to more than one target.

Axons can vary enormously in length. Most axons are very small; some are no more than a few thousandths of an inch long. Other axons are quite long. For example, the longest axon in your body is that of the motor neuron that controls your big toe. This axon extends from the base of your spine into your foot. If you happen to be a seven-foot-tall basketball player, this axon could be four feet long! For most of us, though, this axon is closer to three feet long.

#### Glial Cells

Along with neurons, the human nervous system is made up of other specialized cells, called **glial cells** or simply **glia** (see photo). Glial cells are abundant in the human brain. *Glia* is Greek for "glue," and although they don't actually glue neurons together, glia do provide structural support for neurons throughout the nervous system.

There are several different kinds of glial cells, each with its own specialized function (Fields, 2013). For example, *oligodendrocytes* in the brain and *Schwann cells* in the rest of the nervous system form the **myelin sheath**, a white fatty covering that is wrapped around the axons of some, but not all, neurons. In much the same way that insulating plastic on electrical wires prevents interference when wires contact each other, myelin helps insulate one axon from the axons of other neurons. Rather than forming a continuous coating of the axon, however, the myelin sheath occurs in segments that are separated by small gaps. The small gaps are called the *nodes of Ranvier*, or simply *nodes* (see Figure 2.2). Neurons whose axons are wrapped in myelin communicate their messages up to 50 times faster than do unmyelinated neurons (Fields, 2013). Myelin formation may also be involved in learning new motor behaviors (Long & Corfas, 2014; McKenzie & others, 2014).

The importance of myelin becomes readily apparent when it is damaged. For example, *multiple sclerosis* is a disease that involves the degeneration of patches of the myelin sheath. This degeneration causes the transmission of neural messages to be

slowed or interrupted, resulting in disturbances in sensation and movement. Muscle weakness, loss of coordination, and blurred vision are among the more common symptoms of multiple sclerosis.

## Communication Within the Neuron THE ACTION POTENTIAL

Essentially, the function of neurons is to transmit information throughout the nervous system. But exactly *how* do neurons transmit information? We'll first describe communication *within* a neuron, and then, in the following section, we'll describe communication *between* neurons.

In general, messages are gathered by the dendrites and cell body and then transmitted along the axon in the form of a brief electrical impulse called an **action potential**. The action potential is produced by the movement of electrically charged particles, called *ions*, across the membrane of the axon. Some ions are negatively charged, while others are positively charged.

Think of the axon membrane as a gatekeeper that carefully controls the balance of positive and negative ions on the interior and exterior of the axon. As the gatekeeper, the axon membrane opens and closes ion channels that allow ions to flow into and out of the axon

Each neuron requires a minimum level of stimulation from other neurons or sensory receptors to activate it. This minimum level of stimulation is called the neuron's **stimulus threshold**. While waiting for sufficient stimulation to activate it, the neuron is said to be *polarized*. This means that there is a difference in the electrical charge between the inside and the outside of the axon.

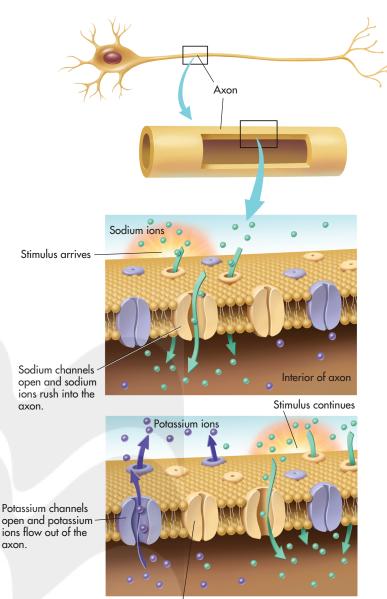
More specifically, there is a greater concentration of negative ions inside the neuron. Thus, the axon's interior is more negatively charged than is the exterior fluid surrounding the axon. The negative electrical charge is about –70 millivolts (thousandths of a volt) (see Figure 2.4 on the next page). The –70 millivolts is referred to as the neuron's **resting potential**.

In this polarized, negative-inside/positive-outside condition, there are different concentrations of two particular ions: sodium and potassium. While the neuron is in resting potential, the fluid surrounding the axon contains a larger concentration of *sodium* ions than does the fluid within the axon. The fluid within the axon contains a larger concentration of *potassium* ions than is found in the fluid outside the axon.

An action potential is triggered when the neuron is sufficiently stimulated by other neurons or sensory receptors. First, the neuron depolarizes: At each successive axon segment, sodium ion channels open for a mere thousandth of a second. The sodium ions rush to the axon interior from the surrounding fluid, and then the sodium ion channels close. Less than a thousandth of a second later, the potassium ion channels open, allowing potassium to flow out of the axon and into the fluid surrounding it. Then the potassium ion channels close (see Figure 2.3). This sequence of depolarization and ion movement continues down the entire length of the axon.

As this ion exchange occurs, the relative balance of positive and negative ions separated by the axon membrane changes. The electrical charge on the inside of the axon momentarily changes to a positive charge of about +30 millivolts. The result is a brief positive electrical impulse that progressively occurs at each segment down the axon—the action potential.

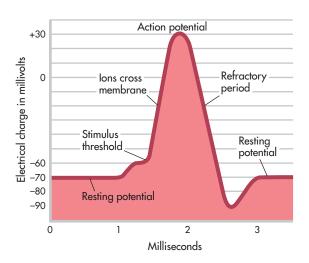
Although it's tempting to think of the action potential as traveling in much the same way as electricity travels through a wire, that's *not* what takes place in the neuron. The axon is actually a poor conductor of electricity. At each successive segment of the axon, the action potential is *regenerated* in the



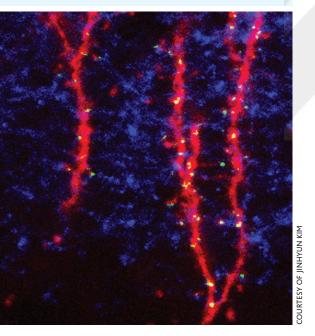
The first sodium channels have closed, but those farther down the axon open, continuing the process of depolarization along the axon.

## **FIGURE 2.3** Communication Within the Neuron: The Action Potential These drawings depict the ion channels in the membrane of a

FIGURE 2.4 Electrical Changes During an Action Potential This graph shows the changing electrical charge of the neuron during an action potential. When the neuron depolarizes and ions cross the axon membrane, the result is a brief positive electrical impulse of +30 millivolts—the action potential. During the refractory period, the neuron reestablishes the resting potential negative charge of -70 millivolts and then is ready to activate again.



The Brain Capturing a Thought In the brain, as in the rest of the nervous system, information is transmitted by electrical impulses that speed from one neuron to the next (Kim & others, 2012). In this striking image, you can clearly see the synaptic connections (bright yellow dots) between the axons of the presynaptic or "sending" neurons (blue) and the dendrites of the postsynaptic or "receiving" neurons (red).



**synapse** (SIN-aps) The point of communication between two neurons.

**synaptic** gap (sin-AP-tick) The tiny space between the axon terminal of one neuron and the dendrite of an adjoining neuron.

same way in which it was generated in the previous segment—by depolarization and the movement of ions.

Once the action potential is started, it is *self-sustaining* and continues to the end of the axon. In other words, there is no such thing as a partial action potential. Either the neuron is sufficiently stimulated and an action potential occurs or the neuron is not sufficiently stimulated and an action potential does not occur. This principle is referred to as the *all-or-none law*.

After the action potential, the neuron enters a *refractory period*, lasting a thousandth of a second or less, during which the neuron cannot "fire," or

generate another action potential. Instead, the neuron *repolarizes* and reestablishes the negative-inside/positive-outside condition. Like depolarization, repolarization occurs progressively at each segment down the axon. This process reestablishes the *resting potential* conditions so that the neuron is capable of firing again (see Figure 2.4).

Action potentials are generated in mere thousandths of a second. Thus, a single neuron can potentially generate hundreds of neural impulses per second. Just how fast do neural impulses zip around your body? The fastest neurons in your body communicate at speeds of up to 270 miles per hour. In the slowest neurons, messages creep along at about 2 miles per hour. This variation in communication speed is due to two factors: the axon diameter and the myelin sheath. The larger the axon's diameter, the faster it conducts action potentials. And myelinated neurons communicate much faster than unmyelinated neurons because the action potential "jumps" from node to node rather than progressing down the entire length of the axon.

## **Communication Between Neurons**

**BRIDGING THE GAP** 

#### KEY THEME

Communication between neurons takes place at the synapse, the junction between two adjoining neurons.

#### ■ KEY QUESTIONS

- How is information communicated at the synapse?
- What is a neurotransmitter, and what is its role in synaptic transmission?
- What are seven important neurotransmitters, and how do psychoactive drugs affect synaptic transmission?

The primary function of a neuron is to communicate information to other cells, most notably other neurons. The point of communication between two neurons is called the **synapse**. At this communication junction, the message-*sending* neuron is referred to as the *presynaptic neuron*. The message-*receiving* neuron is called the *post-synaptic neuron*. For cells that are specialized to communicate information, neurons have a surprising characteristic: They don't touch each other. The presynaptic and postsynaptic neurons are separated by a tiny, fluid-filled space, called the **synaptic gap**, which is only 20 to 40 nanometers wide. How small is that? For comparison, the thickness of a single sheet of paper is about 100,000 nanometers.

How do neurons communicate? In most cases, when the presynaptic neuron is activated, it generates an action potential that travels to the end of the axon.

At the end of the axon are several small branches called **axon terminals**. Floating in the interior fluid of the axon terminals are tiny sacs called **synaptic vesicles** (see **Figure 2.5**). The synaptic vesicles hold special chemical messengers manufactured by the neuron, called **neurotransmitters**.

When the action potential reaches the axon terminals, some of the synaptic vesicles "dock" on the axon terminal membrane and then release their neurotransmitters into the synaptic gap. These chemical messengers cross the synaptic gap and attach to *receptor sites* on the dendrites of the receiving or postsynaptic neuron. This journey across the synaptic gap takes just a few millionths of a second. The entire process of transmitting information at the synapse is called **synaptic transmission**.

What happens to the neurotransmitter molecules after they've attached to the receptor sites of the postsynaptic neuron? Most often, they detach from the receptor and are reabsorbed by the presynaptic neuron so they can be recycled and used again. This process is called **reuptake**. Reuptake also occurs with many of the neurotransmitters that failed to attach to a receptor and were left floating in the synaptic gap. Neurotransmitter molecules that are not reabsorbed or that remain attached to the receptor site are broken down or destroyed by enzymes.

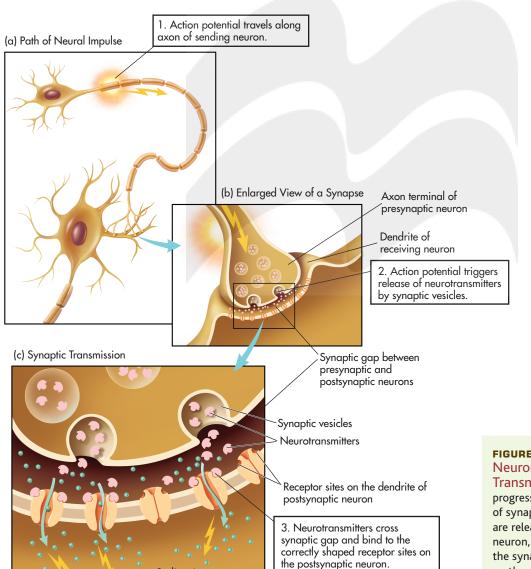
**axon terminals** The branches at the end of the axon that contain tiny pouches, or sacs, called synaptic vesicles.

synaptic vesicles (sin-AP-tick VESS-ickullz) The tiny pouches or sacs in axon terminals that contain chemicals called neurotransmitters.

**neurotransmitters** Chemical messengers manufactured by a neuron.

**synaptic transmission** (sin-AP-tick) The process through which neurotransmitters are released by one neuron, cross the synaptic gap, and affect adjoining neurons.

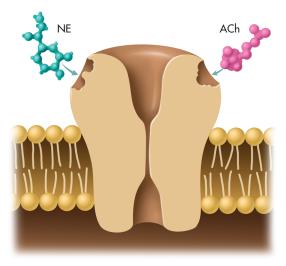
**reuptake** The process by which neurotransmitter molecules detach from a post-synaptic neuron and are reabsorbed by a presynaptic neuron so they can be recycled and used again.



Sodium ions

FIGURE 2.5 Communication Between Neurons: The Process of Synaptic Transmission Follow the steps in this progressive graphic to trace the sequence of synaptic transmission. Neurotransmitters are released by the sending, or presynaptic, neuron, cross the tiny fluid-filled space called the synaptic gap, and attach to receptor sites on the receiving, or postsynaptic, neuron.

rigure 2.6 Neurotransmitter and Receptor Site Shapes Each neurotransmitter has a chemically distinct shape. Like a key in a lock, a neurotransmitter must perfectly fit the receptor site on the receiving neuron for its message to be communicated. In this figure, NE is the abbreviation for the neurotransmitter norepinephrine, and ACh is the abbreviation for acetylcholine.



Some neurons produce only one type of neurotransmitter, but others manufacture three or more. Each neurotransmitter has a chemically distinct shape. Like a key in a lock, a neurotransmitter's shape must precisely match that of a receptor site on the postsynaptic neuron for the neurotransmitter to affect that neuron (see Figure 2.6). And, the postsynaptic neuron can have many differently shaped receptor sites on its dendrites and other surfaces. Thus, a given neuron may be able to receive several different neurotransmitters.

Depending upon the receptor to which it binds, a neurotransmitter communicates either an excitatory or an inhibitory message to a postsynaptic neuron. An *excitatory message* increases the likelihood that the postsynaptic neuron will activate and generate an action potential. An *inhibitory message* decreases the likelihood that the postsynaptic neuron will activate.

When released by a presynaptic neuron, neurotransmitters cross hundreds, even thousands, of synaptic gaps. Each released neurotransmitter will attach to a receptor site on an intertwined dendrite of an adjacent neuron. Because the receiving neuron can have thousands of dendrites that intertwine with the axon terminals of many presynaptic neurons, the number of potential synaptic interconnections between neurons is truly mind-boggling. Each neuron in the brain communicates directly with an average of 1,000 other neurons (Hyman, 2005). However, some specialized neurons have as many as 100,000 connections with other neurons. Thus, there are up to 100 *trillion* synaptic interconnections in your brain (Eroglu & Barres, 2010). That's the number 10 followed by 13 zeros!

Acetylcholine: Turning Back the Clock with Botox Wanting to look younger for his wedding, 35-year-old Joshua Baggett signed up for Botox injections to tighten the skin on his face. How does Botox eliminate facial wrinkles? Botox injections contain very minute amounts of botulinum, a toxin that causes muscle paralysis around the injection site by blocking the release of acetylcholine from motor neurons. Because the muscles can't contract, the skin smooths out, and facial wrinkles are diminished or eliminated.



### Neurotransmitters and Their Effects

Your ability to perceive, feel, think, move, act, and react depends on the delicate balance of neurotransmitters in your nervous system. Yet neurotransmitters are present in only infinitesimal amounts in brain tissue—roughly equivalent to a pinch of salt dissolved in an Olympic-sized swimming pool.

Specific neurotransmitters are associated with particular psychological processes and problems (see **Table 2.1**). However, the connection between a particular neurotransmitter and a particular effect is *not* a simple one-to-one relationship. Most behaviors are the result of the complex interaction of different neurotransmitters. Furthermore, neurotransmitters sometimes have different effects in different areas of the brain.

## **Important Neurotransmitters**

**Acetylcholine**, the first neurotransmitter discovered, is found in all motor neurons. It stimulates muscles to contract, including the heart and stomach muscles. Whether it is as simple as the flick of an eyelash or as complex as a back flip, all movement involves acetylcholine.

Acetylcholine is also found in many neurons in the brain, and it is important in memory, learning, and general intellectual functioning. People with *Alzheimer's disease*, which is characterized by progressive loss of memory and deterioration of intellectual functioning, have a severe depletion of several neurotransmitters in the brain, most notably acetylcholine.

acetylcholine (uh-seet-ull-KO-leen) Neurotransmitter that causes muscle contractions and is involved in learning and memory.

**dopamine** (DOPE-uh-meen) Neurotransmitter involved in the regulation of bodily movement, thought processes, and rewarding sensations.

**serotonin** (ser-uh-TONE-in) Neurotransmitter involved in sensory perceptions, sleep, and emotions.

The neurotransmitter **dopamine** is involved in movement, attention, learning, and pleasurable or rewarding sensations. Evidence suggests that the addictiveness of many drugs, including cocaine and nicotine, is related to their ability to increase dopamine activity in the brain (Volkow & others, 2011a, 2011b).

The degeneration of the neurons that produce dopamine in one brain area causes *Parkinson's disease*, which is characterized by rigidity, muscle tremors, poor balance, and difficulty in initiating movements. Symptoms can be alleviated by a drug called *L-dopa*, which converts to dopamine in the brain.

The neurotransmitters **serotonin** and **norepinephrine** are found in many different brain areas. Serotonin is involved in sleep, sensory perceptions, moods, and emotional states, including depression (Deneris & Wyler, 2012). Some antidepressant drugs, like *Prozac*, increase the availability of serotonin in certain brain regions. Norepinephrine is implicated in the activation of neurons throughout the brain and helps the body gear up in the face of danger or threat.

The most abundant neurotransmitters in the brain are two closely related neurotransmitters, **glutamate** and **gamma-aminobutyric acid**, abbreviated **GABA**. In a delicate balancing act, glutamate conveys *excitatory* messages and GABA communicates *inhibitory* messages. Like a dimmer switch, GABA regulates the level of neural activity in the brain. Too much GABA impairs learning, motivation, and movement, but too little GABA can lead to seizures (McCarthy, 2007). Alcohol makes people feel relaxed and less inhibited partly by increasing GABA activity and decreasing glutamate, reducing overall brain activity.

Glutamate is involved in learning, memory, and sensory processes (Morris, 2013). Too much glutamate can overstimulate the brain, causing seizures and cell death. Glutamate is also implicated in Alzheimer's disease, neurological diseases, and schizophrenia.

Endorphins are another important class of neuro-transmitter. Chemically similar to morphine, heroin, and other opioid drugs, endorphins are hundreds of times more potent and are released in response to stress, trauma, and pain. Endorphins are implicated in the pain-reducing effects of *acupuncture*, an ancient Chinese medical technique that involves inserting needles at various locations in the body (Kemmer, 2007; Zhao, 2008). Also associated with positive mood, endorphins may cause "runner'shigh" (see photo).

# How Drugs Affect Synaptic Transmission

Much of what is known about different neurotransmitters has been learned from observing the effects of drugs and other substances. Many drugs, especially those that affect moods or behavior, work by affecting the normal functioning of neurotransmitters in the synapses (Volkow & others, 2011a, 2011b).

Some drugs increase or decrease the amounts of neurotransmitters released by neurons. For example, the venom of a black widow spider bite causes acetylcholine to be released continuously by motor neurons, causing severe muscle spasms. Drugs may also affect the length of time the neurotransmitters remain in the synaptic gap, either increasing or decreasing the amount available to the post-synaptic receptor.

#### TABLE 2.1

#### **Summary of Important Neurotransmitters**

Neurotransmitter	Primary Roles	
Acetylcholine	Learning, memory Muscle contractions	
Dopamine	Movement Thought processes Rewarding sensations	
Serotonin	Emotional states Sleep Sensory perception	
Norepinephrine	Physical arousal Learning, memory Regulation of sleep	
Glutamate	Excitatory messages	
GABA	Inhibitory messages	
Endorphins	Pain perception Positive emotions	

The "Endorphin Rush" of Runner's High "Runner's high" is the rush of euphoria that many people experier

euphoria that many people experience after intense aerobic exercise, especially running or cycling. In an ingenious experiment by German neuroscientist Henning Boecker and his colleagues (2008), elite male runners were injected with a radioactively tagged chemical that bonded to opioid receptors in the brain. After two hours of endurance running, PET scans showed the highest levels of natural endorphin production in brain regions known to be involved in positive emotions. The scans also showed that endorphin activity was positively correlated with subjective experience: The more intense the euphoria experienced by the individual runner, the higher the level of endorphin activity in his brain.

**norepinephrine** (nor-ep-in-EF-rin) Neurotransmitter involved in learning, memory, and regulation of sleep; also, a hormone manufactured by adrenal glands.

**glutamate** Neurotransmitter that usually communicates an excitatory message.

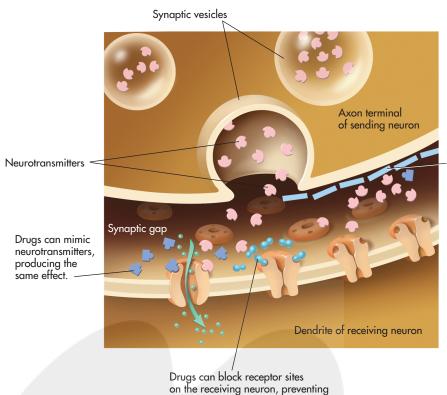
#### GABA (gamma-aminobutyric acid)

Neurotransmitter that usually communicates an inhibitory message.

**endorphins** (en-DORF-inz) Neurotransmitters that regulate pain perceptions.

## FIGURE 2.7 How Drugs Affect Synaptic Transmission

Drugs affect brain activity by interfering with neurotransmitter functioning in the synapse.
Drugs may also affect synaptic transmission by increasing or decreasing the amount of a particular neurotransmitter that is produced.



the neurotransmitter's effect.

Drugs can block reuptake of the neurotransmitter, increasing the neurotransmitter's effect.





Review the process of neural communication by completing the Video Activity: The Neuron: Basic Units of Communication.

**agonist** A drug or other chemical substance that binds to a receptor site and triggers a response in the cell.

**antagonist** A drug or other chemical substance that blocks a receptor site and inhibits or prevents a response in the receiving cell.

One way in which drugs can prolong the effects of the neurotransmitters is by blocking the reuptake of the neurotransmitters by the sending neuron. For example, the antidepressants Prozac, Zoloft, and Paxil are *selective serotonin reuptake inhibitors*, also called *SSRIs*. These medications inhibit the reuptake of serotonin, increasing the availability of serotonin in the brain. Similarly, the illegal drug cocaine produces its exhilarating rush by interfering with the reuptake of dopamine (Volkow & others, 2011a, b).

Drugs can also mimic specific neurotransmitters. An **agonist** is a drug or other chemical that binds to a receptor and facilitates synaptic transmission. Often, agonist drugs are chemically similar to a specific neurotransmitter and produce the same effect. For example, nicotine is a stimulant because it is chemically similar to acetylcholine. It occupies acetylcholine receptor sites, stimulating skeletal muscles and causing the heart to beat more rapidly.

Alternatively, a drug can act as an **antagonist** by *blocking* the effect of neurotransmitters. A drug may fit into receptor sites and prevent neurotransmitters from acting. For example, the drug *curare*, used in poison arrows by native hunters in South America, blocks acetylcholine receptor sites, causing virtually instantaneous paralysis. The brain sends signals to the motor neurons, but the muscles can't respond because the motor neuron receptor sites are blocked by the curare. Similarly, the drug *naloxone* is an opioid antagonist. By blocking endorphin receptors, it can quickly reverse the effects of heroin, oxycodone, or other opioid drugs (Rich & others, 2011). **Figure 2.7** summarizes the effects of drugs on synaptic transmission.



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# The Nervous System and the Endocrine System

COMMUNICATION THROUGHOUT THE BODY

#### **■ KEY THEME**

Two major communication systems in the body are the nervous system and the endocrine system.

#### ■ KEY QUESTIONS

- What are the divisions of the nervous system, and what are their functions?
- How is information transmitted in the endocrine system, and what are its major structures?
- How do the nervous and endocrine systems interact to produce the fight-or-flight response?

Specialized for communication, up to 1 *trillion* neurons are linked throughout your body in a complex, organized communication network called the **nervous system**. The human nervous system is divided into two main divisions: the *central nervous system* and the *peripheral nervous system* (see Figure 2.8). For even simple behaviors to occur, such as curling your toes or scratching your nose, these two divisions must function as a single, integrated unit. Yet each of these divisions is highly specialized and performs different tasks.

The neuron is the most important transmitter of messages in the central nervous system. In the peripheral nervous system, communication occurs along **nerves**, which are made up of large bundles of neuron axons. Unlike neurons, many nerves are large enough to be seen easily with the unaided eye.

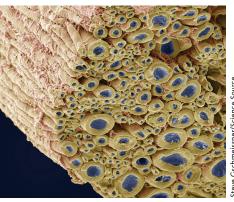
## The Central Nervous System

The **central nervous system (CNS)** includes the brain and the spinal cord. The central nervous system is so critical to your ability to function that it is entirely protected by bone—the brain by your skull and the spinal cord by your spinal column. Surrounding and protecting the brain and the spinal cord are three layers of membranous tissues, called the *meninges*. As an added measure of protection, the brain and spinal cord are suspended in *cerebrospinal fluid* to protect them from being jarred. Cerebrospinal fluid also fills four hollow cavities in the brain, called *ventricles*. The inner surfaces of the ventricles are lined with *neural stem cells*, specialized cells that generate neurons in the developing brain (see Chapter 9).

The central nervous system is the central processing center—every action, thought, feeling, and sensation you experience is processed through the central nervous system. The most important element of the central nervous system is, of course, the brain, which acts as the command center. We'll take a tour of the human brain in a later section.

The spinal cord handles both incoming and outgoing messages. Sensory receptors send messages along sensory nerves to the spinal cord, then up to the brain. To activate muscles, the brain sends signals down the spinal cord that are relayed out along motor nerves to the muscles.

Although most behaviors are controlled by your brain, **spinal reflexes** are simple, automatic behaviors that occur without any brain involvement. For example, the *withdrawal reflex* occurs when



#### FIGURE 2.8 The Nervous System

The nervous system is a complex, organized communication network that is divided into two main divisions: the central nervous system (shown in blue) and the peripheral nervous system (shown in yellow).



**nervous system** The primary internal communication network of the body; divided into the central nervous system and the peripheral nervous system.

**nerves** Bundles of neuron axons that carry information in the peripheral nervous system.

**central nervous system (CNS)** The division of the nervous system that consists of the brain and spinal cord.

**spinal reflexes** Simple, automatic behaviors that are processed in the spinal cord.

Nerves and Neurons Are Not the Same A cross section of a peripheral nerve is shown in this electron micrograph. The nerve is composed of bundles of axons (blue) wrapped in the myelin sheath (yellow). In the peripheral nervous system, myelin is formed by a type of glial cell called Schwann cells, shown here as a pinkish coating around the axons.

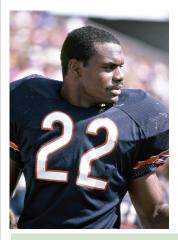


#### IN FOCUS

### Concussions, Cumulative Impacts, and CTE

Although encased in bone and cushioned by cerebrospinal fluid, the brain is highly susceptible to injury. Just a quarter inch of bone and membranes protect the brain from harm. A sharp blow to the head or a shock wave from an explosion can cause the brain to shake, twist, or literally crash into the skull. And, just as an eggshell will not protect a raw egg from damage when the egg is shaken, a helmet may not protect the brain from injury in an impact.

When an impact disrupts normal brain functioning, a *traumatic brain injury* (or *TBI*) may be diagnosed. A *concussion* is the most common, and mildest, type of TBI, affecting more than 1 million people every year in the United States alone (Rabinowitz & others, 2014). Auto accidents, falls, and sports injuries are the most common causes of concussion.





The Ravages of CTE Football player Dave Duerson became a successful businessman after years of playing for the NFL. But as his emotions and behavior became erratic, his business and marriage failed. Troubled by severe headaches, memory problems, depression, and impulses he couldn't control, Duerson suspected he might have developed CTE (Nowinski, 2013). Just before committing suicide, Duerson texted his ex-wife, asking her to donate his brain to the Boston University Center for the Study of Traumatic Encephalopathy. Researchers there found the telltale signs of brain damage (brown coloring) in several regions of Dave Duerson's brain (right) (McKee & others, 2013). Duerson's advanced CTE probably contributed to his depression and suicide.

(I) Michael J. Minardi/Getty Images (r) Ann C McKee, MD Professor of Neurology and Pathology, VA Boston Healthcare System and Boston University School of Medicine Concussions can cause physical damage and disrupt many aspects of brain function. As the brain twists or bounces, axons are sheared, myelin is damaged, and brain chemistry is disrupted. Although damage may not be evident on a CT or MRI scan, it's obvious in the behavioral manifestations of concussion: loss of consciousness, dizziness, blurred or double vision, slurred speech and memory loss, and other symptoms (Guay & others, 2016).

Most people recover from concussions without complications. However, repeated concussions can lead to a serious brain disease called *chronic traumatic encephalopathy*, or *CTE*. CTE is a progressive, degenerative brain disease that can be diagnosed only after death (Hay & others, 2016). Symptoms include depression and anxiety, poor judgment and lack of impulse control, and problems with memory, concentration, and attention. Ultimately, CTE leads to dementia and death (Gavett & others, 2011).

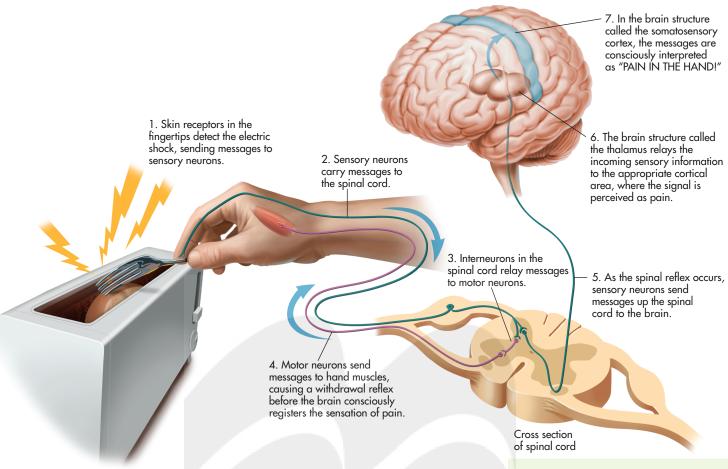
To date, CTE has been diagnosed primarily in professional athletes, especially football and hockey players who were known to have suffered multiple concussions. But researchers now suspect that CTE can result from less severe but repetitive brain injuries. Thomas Owens was a popular, academically successful 21-year-old college football player with no history of depression who committed suicide after complaining of stress. Owens had never been diagnosed with a concussion or head injury, but his brain showed clear signs of CTE. Neurologists believe that it was caused by the thousands of low-impact hits his brain had absorbed over years of playing middle school, high school, and college football (Schwarz, 2010).

A new study provides evidence for this view that it may be the cumulative impact of repeated blows to the head, rather than concussions alone, that leads to CTE and other abnormalities in brain functioning in later life. Philip Montenigro and his colleagues (2016) found a positive correlation between athletes' estimated cumulative number of hits and symptoms of depression and cognitive and behavioral problems in later life. This correlation was stronger than that between diagnosed concussions and problems in later life.

Researchers hope that future work will help identify ways to protect athletes, especially young athletes, against the worst effects of head impacts. As CTE researcher and neurologist Robert Stern (2016) observed, "We need to take very seriously the notion that hitting your head over and over again may have long-term consequences."

you touch a painful stimulus, such as something hot or sharp. As shown in Figure 2.9, this simple reflex involves a loop of rapid communication among *sensory neurons*, which communicate sensation to the spinal cord; *interneurons*, which relay information within the spinal cord; and *motor neurons*, which signal the muscles to react.

Spinal reflexes are crucial to your survival. The additional few seconds that it would take you to consciously process sensations and decide how to react could result in serious injury. Spinal reflexes are also important as indicators that the neural



pathways in your spinal cord are working correctly. That's why physicians test spinal reflexes during neurological examinations by tapping just below your kneecap for the knee-jerk spinal reflex.

## The Peripheral Nervous System

The **peripheral nervous system** is the other major division of your nervous system. The *peripheral* nervous system comprises all the nerves outside the central nervous system that extend to the outermost borders of your body, including your skin. The communication functions of the peripheral nervous system are handled by its two subdivisions: the *somatic nervous system* and the *autonomic nervous system*.

The **somatic nervous system** communicates sensory information received by sensory receptors along sensory nerves *to* the central nervous system. And, it carries messages *from* the central nervous system along motor nerves to perform voluntary muscle movements. When you turn a page of this book, for example, messages from the brain are communicated down the spinal cord and then out to the muscles via the somatic nervous system.

The other subdivision of the peripheral nervous system is the **autonomic nervous system**, which regulates *involuntary* functions, such as heartbeat, blood pressure, breathing, and digestion. These processes occur with little or no conscious involvement. This is fortunate, because if you had to mentally command your heart to beat or your stomach to digest the food you had for lunch, it would be difficult to focus your attention on anything else.

FIGURE 2.9 A Spinal Reflex A spinal reflex is a simple, involuntary behavior that is processed in the spinal cord without brain involvement. If you accidentally shock yourself by using a metal fork to pry a bagel out of a plugged-in toaster, you'll instantly pull your hand away from the painful stimulus—an example of the withdrawal reflex. The sequence shown here illustrates how the withdrawal reflex can occur before the brain processes the conscious perception of pain.

**peripheral nervous system** (per-IF-er-ull) The division of the nervous system that includes all the nerves lying outside the central nervous system.

**somatic nervous system** The subdivision of the peripheral nervous system that communicates sensory information to the central nervous system and carries motor messages from the central nervous system to the muscles.

**autonomic nervous system** (aw-toe-NAHM-ick) The subdivision of the peripheral nervous system that regulates involuntary functions.

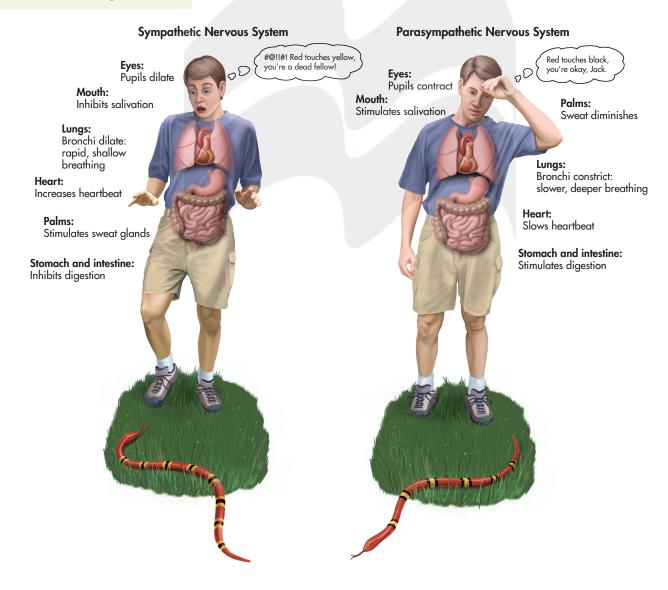
**sympathetic nervous system** The branch of the autonomic nervous system that produces rapid physical arousal in response to perceived emergencies or threats.

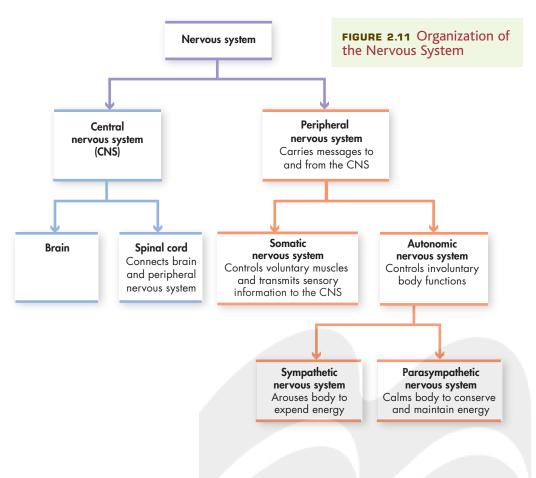
FIGURE 2.10 The Sympathetic and Parasympathetic Branches of the Autonomic Nervous System Hikers in the southern United States memorize a simple rhyme to distinguish the venomous coral snake (red stripes touch yellow stripes) from its harmless mimic, a scarlet king snake (red stripes touch black stripes). Arousal of the sympathetic nervous system (left) prepares the hiker to fight or flee from the dangerous snake. When the hiker realizes that the snake is harmless (right), the parasympathetic nervous system calms the body and gradually restores normal functioning.

However, the autonomic nervous system is not completely self-regulating. By engaging in physical activity or purposely tensing or relaxing your muscles, you can increase or decrease autonomic activity. Emotions and mental imagery also influence your autonomic nervous system.

The involuntary functions regulated by the autonomic nervous system are controlled by two different branches: the *sympathetic* and *parasympathetic nervous systems*. These two systems control many of the same organs in your body but cause them to respond in opposite ways (see **Figure 2.10**). In general, the sympathetic nervous system *arouses* the body to expend energy, and the parasympathetic nervous system *calms* the body to conserve energy.

The **sympathetic nervous system** is the body's emergency system, rapidly activating bodily systems to meet threats or emergencies. When you are frightened, your breathing accelerates, your heart beats faster, digestion stops, and the bronchial tubes in your lungs expand. All these physiological responses increase the amount of oxygen available to your brain and muscles. Your pupils dilate to increase your field of vision, and your mouth becomes dry, because salivation stops. These and other bodily changes collectively represent the *fight-or-flight response*—they physically prepare you to fight or to flee from a perceived danger. We'll discuss the fight-or-flight response in greater detail in the chapters on emotion and stress.





While the sympathetic nervous system mobilizes your body's physical resources, the **parasympathetic nervous system** conserves and maintains your physical resources. It calms you down after an emergency. Acting much more slowly than the sympathetic nervous system, the parasympathetic nervous system gradually returns your body's systems to normal.

Although the sympathetic and parasympathetic nervous systems produce opposite effects, they act together, keeping the nervous system in balance (see Figure 2.11). Each division handles different functions, yet the whole nervous system works in unison so that both automatic and voluntary behaviors are carried out smoothly.

Activating the Sympathetic Nervous System When the sympathetic nervous system activates in humans, tiny muscles in the skin contract, which elevates your hair follicles, producing the familiar sensation of "goose bumps" and making your hair stand on end. A similar process takes place in many mammals, making the fur

or hair bristle, with rather spectacular

Life on white/Alamy

results in this kitten.

## The Endocrine System

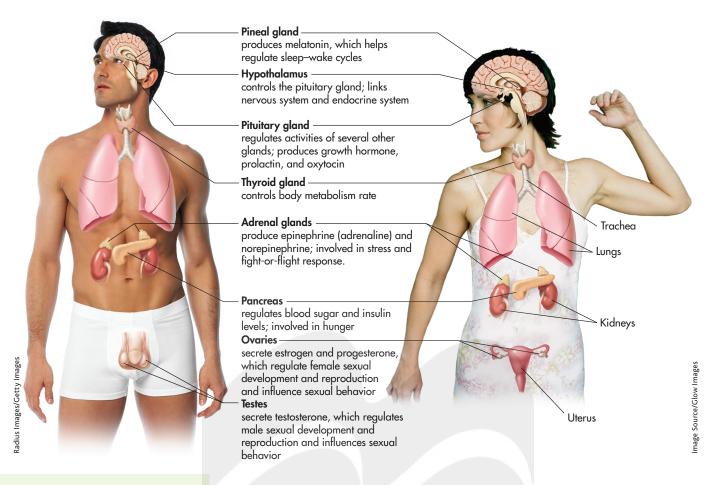
The **endocrine system** is made up of glands that are located throughout the body (see **Figure 2.12** on the next page). Like the nervous system, the endocrine system uses chemical messengers to transmit information from one part of the body to another. Although the endocrine system is not part of the nervous system, it interacts with the nervous system in important ways.

Endocrine glands communicate information from one part of the body to another by secreting messenger chemicals called **hormones** into the bloodstream. The hormones circulate throughout the bloodstream until they reach specific hormone receptors on target organs or tissue. Hormones regulate physical processes and influence behavior. For example, metabolism, growth rate, digestion, blood pressure,

parasympathetic nervous system The branch of the autonomic nervous system that maintains normal bodily functions and conserves the body's physical resources.

endocrine system (EN-doe-krin) The system of glands, located throughout the body, that secrete hormones into the bloodstream.

**hormones** Chemical messengers secreted into the bloodstream primarily by endocrine glands.



#### FIGURE 2.12 The Endocrine System

The endocrine system and the nervous system are directly linked by the hypothalamus in the brain, which controls the pituitary gland. In turn, the pituitary releases hormones that affect the hormone production of several other endocrine glands. Shown here are the location and main functions of several important endocrine glands.

**pituitary gland** (pih-TOO-ih-tare-ee) The endocrine gland attached to the base of the brain that secretes hormones affecting the function of other glands as well as hormones that act directly on physical processes.

**oxytocin** Hormone involved in reproduction, social motivation, and social behavior.

and sexual development and reproduction are all regulated by the endocrine hormones. Hormones are also involved in emotional responses and stress.

Endocrine hormones are closely linked to the workings of the nervous system. For example, the release of hormones may be stimulated or inhibited by certain parts of the nervous system. In turn, hormones can promote or inhibit the generation of nerve impulses. Finally, some hormones and neurotransmitters are chemically identical. The same molecule can act as a hormone in the endocrine system and as a neurotransmitter in the nervous system.

Endocrine system communication is much slower than the rapid transmission of information in the nervous system. Endocrine glands secrete hormones into the bloodstream, and it takes a few seconds for the hormones to be delivered to their target organs.

The signals that trigger the secretion of hormones are regulated by the brain, primarily by a brain structure called the *hypothalamus*, which serves as the main link between the endocrine system and the nervous system. The hypothalamus directly regulates the release of hormones by the **pituitary gland**, a pea-sized gland just under the brain. The pituitary's hormones, in turn, regulate the production of other hormones by many of the glands in the endocrine system.

The pituitary gland also produces some hormones that act directly. For example, the pituitary produces *growth hormone*, which stimulates normal skeletal growth during childhood. The pituitary gland can also secrete endorphins to reduce the perception of pain. In nursing mothers, the pituitary produces *prolactin*, the hormone that stimulates milk production.

Another important hormone, **oxytocin**, is produced by the hypothalamus and released into the bloodstream by the pituitary gland. Breastfeeding is an example

of the complex interaction among behavior, the nervous system, and the endocrine system. In nursing mothers, nerve impulses from sensory receptors in the skin are sent to the hypothalamus, which signals the release of oxytocin. Oxytocin produces the "let down" reflex, causing stored milk to begin flowing. During childbirth, oxytocin signals the uterus to contract.

Oxytocin also has psychological effects (Carter, 2014). It promotes bonding between reproductive partners and between parent and infant, and even between dogs and owners (Nagasawa & others, 2015). Early research found that it also promotes empathy, trust among group members, and sensitivity to social cues (see Miller, 2013). These findings gave oxytocin the reputation as "the love hormone," but oxytocin is actually involved in *many* different aspects of social motivation and behavior. In some circumstances, oxytocin can promote aggression or other antisocial behavior (de Dreu & others, 2011; Olff & others, 2013). And, other researchers have found that some people respond to oxytocin with increased social anxiety, rather than increased feelings of trust (Bartz & others, 2011; Olff & others, 2013).

The **adrenal glands** produce hormones that are involved in the human stress response and play a key role in the fight-or-flight response, described earlier. When activated, the sympathetic nervous system stimulates the adrenal glands, which produce *epinephrine* and *norepinephrine*. (You may be more familiar with the word *adrenaline*, which is another name for epinephrine.)

Epinephrine and norepinephrine cause physical arousal and act as neurotransmitters, stimulating activity at the synapses in the sympathetic nervous system. If it takes you a long while to calm down after an upsetting experience, it's because of the lingering effects of epinephrine and norepinephrine—an example of the long-lasting effects of hormones.

Also important are the **gonads**, or sex organs—the *ovaries* in women and the *testes* in men. In women, the ovaries secrete the hormones *estrogen* and *progesterone*. In men, the testes secrete male sex hormones called *androgens*, the most important of which is *testosterone*. Testosterone is also secreted by the adrenal glands in both males and females. In both males and females, the sex hormones influence sexual development, sexual behavior, and reproduction. They also affect brain structure and function (Lombardo & others, 2012; McEwen & others, 2012).



Go to LaunchPad to test your understanding of The Nervous and Endocrine Systems with LearningCurve.

## A Guided Tour of the Brain

#### ■ KEY THEME

The brain is a highly complex, integrated, and dynamic system of interconnected neurons.

#### ■ KEY QUESTIONS

- What are neural pathways, and why are they important?
- What are functional and structural plasticity?
- What is neurogenesis, and what is the evidence for its occurrence in the adult human brain?

The most complex mass of matter in the universe sits right behind your eyes and between your two ears—your brain. Not even the Internet can match the human brain for speed and sophistication of information transmission. On average, the human brain represents only about 2 percent of the body's weight, yet consumes 20 percent of the body's energy.

**adrenal glands** The pair of endocrine glands that are involved in the human stress response.

**gonads** The endocrine glands that secrete hormones that regulate sexual characteristics and reproductive processes; *ovaries* in females and *testes* in males.

#### MYTH SCIENCE

Is it true that oxytocin is the "love hormone," making people more trusting and empathic?

The Human Brain Weighing roughly three pounds, the human brain is about the size of a small cauliflower and has the consistency of tofu. Although your brain makes up only about 2 percent of your total body weight, it uses some 20 percent of the oxygen your body needs while at rest (Rachle, 2015). The oxygen is used in breaking down glucose to supply the brain with energy.



off Tompkinson/Scie

positron emission tomography (PET) scan An imaging technique that provides

color-coded images of brain activity by tracking the brain's use of a radioactively tagged compound, such as glucose, oxygen, or a drug.

magnetic resonance imaging (MRI) A noninvasive imaging technique that produces highly detailed images of the body's structures and tissues, using electromagnetic signals generated by the body in response to magnetic fields.

Our knowledge of the brain has benefited immensely from the development of sophisticated scanning techniques, described in Focus on Neuroscience, "Imaging the Brain." In this part of the chapter, we'll take you on a guided tour of the human brain. As your tour guides, our goal here is not to tell you everything that is known or suspected about the human brain. Such an endeavor would take an entire library rather than a single chapter in a college textbook. Instead, our first goal is to familiarize you with the basic organization and structures of the brain. Our second goal is to give you a sense of how the brain works. In later chapters, we'll add to your



#### 🌄 FOCUS ON NEUROSCIENCE

## Imaging the Brain

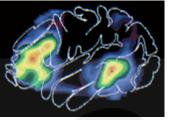
Brain-scan images have become so commonplace in popular media that it's easy to forget just how revolutionary brain-imaging technology has been in the field of psychology (Mather & others, 2013a, 2013b; Poldrack, 2017). Here, we'll look at four commonly used brainimaging techniques and examine how they're used in psychological research.

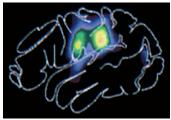
Positron-emission tomography (PET) is based on the fact that increased activity in a particular brain region is associated with increased blood flow and energy consumption in that region. A small amount of a relatively harmless, radioactive substance is injected into the person's bloodstream, and the PET scanner tracks how much of the radioactive substance is used in thousands of different brain regions. A computer analyzes the data, producing color-coded images of the brain's activity.

Magnetic resonance imaging (MRI) does not involve invasive procedures such as injections of radioactive substances. While a person lies in a magnetic tube, his or her brain is bombarded with powerful but harmless magnetic fields. A computer analyzes the electromagnetic signals generated by brain-tissue molecules in response to the magnetic fields. The result is a series of digital images, each a detailed "slice" of the brain's structures. MRI scans are also routinely used to produce detailed images of other body parts, such as joints, spine, or organs.

Functional MRI (fMRI) combines the ability to produce a detailed image of the brain's structures with the capacity to track the brain's activity or functioning (K. Smith, 2012). While the person lies in the MRI scanner, a powerful computer tracks the electromagnetic signals that are generated by changes in the brain's metabolic activity, such as increased blood flow to a particular brain region. By measuring the ebb and flow of oxygenated blood in the brain, an fMRI produces a series of scans that show detailed moment-by-moment "movies" of the brain's changing activity in specific structures or regions.

**Diffusion MRI (dMRI)** is a new scanning method that tracks the movement of water molecules in the brain along the myelinated axons connecting one part of the brain to another. This technique allows neuroscientists to produce detailed three-dimensional images of the brain's neural pathways (Chi, 2014; Glasser & others, 2016; Van Essen & Glasser, 2016). The most commonly used methods are diffusion tensor imaging (DTI), and a more advanced method, diffusion spectrum imaging (DSI).





Unpracticed

**Practiced** 

Positron emission tomography (PET) PET scans provide colorcoded images of the brain's activity. Red and yellow colors highlight areas with the highest level of activity, while green and blue colors indicate lower levels of brain activity. These scans show the brain regions active while participants learned a new language task (left) and performing the language task after it had been well learned (right).

Dr. Marcus E. Raichle, Professor of Radiology & Neurology/ Washington University School of Medicine

#### **Limitations of Brain-Imaging Studies**

Neuroscientists and psychologists use brain imaging technology in many different kinds of research, and we'll highlight its use throughout this text. You'll often also see brain scans in the media, sometimes used to illustrate claims that the source for particular characteristics or behaviors has been found in the brain (Poldrack & Farah, 2015). Nevertheless, brain-imaging research has several limitations (Poldrack & others, 2017; Satel & Lilienfeld, 2013).

When you consider the results of brain-imaging studies, including those presented in this textbook, keep the following points in mind:

- 1. Brain-imaging studies usually involve a small number of participants. Because of the limited availability and the high cost of the technology, many brain-imaging studies have fewer than a few dozen participants. With any research involving a small number of participants, caution must be exercised in generalizing results to a wider population (Button & others, 2013; Poldrack & others, 2017).
- 2. Brain imaging studies tend to focus on simple aspects of behavior. Even seemingly simple tasks involve the smooth coordination of multiple brain regions. As Jerome Kagan (2008) observes, "[a]n event as simple as the unexpected sound of a whistle activates 24 different brain areas." Thus, it's naïve to think that complex psychological or behavioral functions can be mapped to a single brain center (Coltheart, 2013; Mather & others, 2013b).

knowledge of the brain as we discuss the brain's involvement in specific psychological processes.

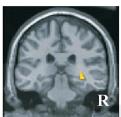
To begin, it's important to note that the brain generally does not lend itself to simple explanations. Although we will identify the functions that are associated with particular brain regions, remember that specific functions seldom correspond neatly to a single, specific brain site. Most psychological processes, especially complex ones, involve *multiple* brain structures and regions (Breakspear, 2017). Even seemingly simple tasks—such as carrying on a conversation, catching

functional magnetic resonance imaging

(fMRI) A noninvasive imaging technique that uses magnetic fields to map brain activity by measuring changes in the brain's blood flow and oxygen levels.

**diffusion MRI (dMRI)** A noninvasive imaging technique that maps neural connections in the brain by tracking the movement of water molecules along myelinated axons.





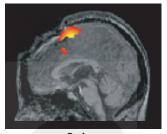
Magnetic resonance imaging (MRI) MRI scans produce digital images showing a detailed "slice" of the brain's structures. Here, yellow dots highlight a brain region, the *hippocampus*, that was significantly larger in experienced London taxi drivers, known for their encyclopedic memory of London streets, than in control participants (Maguire & others, 2000, 2006). The size of the region was also positively correlated with the length of time the participants had been driving taxis: The longer the individual had been driving a taxi, the larger the hippocampus (Woollett & others, 2009).

 $Hippocampus, Vol.\ 16,\ 2006,\ p.\ 1097.\ Reprinted\ with\ permission\ of\ Wiley-Liss,\ Inc.,\ a\ subsidiary\ of\ John\ Wiley\ \&\ Sons,\ Inc.$ 

- 3. Brain imaging may not increase understanding of a psychological process. For example, although brain imaging might point to a particular brain structure as being involved in, say, fear or romantic love, knowing this may not advance our understanding of the psychological experience of fear or romantic love (Decety & Cacioppo, 2010).
- 4. Brain imaging is not necessarily a more "scientific" explanation. As psychologist Paul Bloom (2006) points out, "[f]unctional MRI seems more like 'real' science than many of the other things that psychologists are up to. It has all the trappings of work with great laboratory credibility: big, expensive, and potentially dangerous machines, hospitals and medical centers, and a lot of people in white coats." To be truly useful, brain imaging of a particular behavior must be interpreted within the context of existing psychological knowledge about the behavior (Beck, 2010; Kihlstrom, 2010).

#### Looking at Brain-Scan Images

What should you notice when you look at the brain-scan images in this text? First, read the text description so you understand the task or condition being measured. Second, read the brain-scan caption for specific details or areas to notice. Third, carefully compare the treatment scan with the control scan if both are shown. Fourth, keep the limitations of brain-scan technology in mind. Finally, remember that human experience is much too complex to be captured by a single snapshot of brain activity (Miller, 2010).



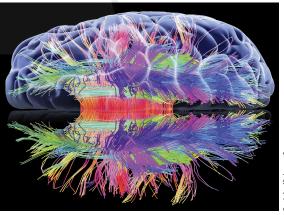


**Patient** 

**Controls** 

Functional MRI (fMRI) fMRI combines the ability to produce a detailed image of the brain's structures with the capacity to track the brain's functioning. Here, fMRI was used to record the brain activity of a woman in a vegetative state (Owen & others, 2006). Researchers asked her to imagine playing tennis and other tasks. The scans above compare her brain activity to that of normal volunteers ("controls") performing the same tasks. In both, regions known to be involved in movement and spatial navigation were active. The fMRI scans confirmed that the patient was conscious of her surroundings and able to respond to spoken commands.

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Pasi eka/Scie

Diffusion MRI (dMRI) dMRI tracks the movement of water through brain tissue to provide detailed, three-dimensional images of the brain's neural pathways (Chu, 2014; Van Essen & Glasser, 2016). Overlaid on a model of the human brain, this dMRI scan clearly shows the intricate neural conections in the left and right cerebral hemisphers. The neural fibers of the *corpus callosum*, which connects the two hemispheres of the brain, are shown in red.

#### MYTH SCIENCE

Is it true that even simple behaviors and abilities involve the activation of multiple parts of the brain?

## MYTH SCIENCE

Is it true that you only use 10% of your brain?

The human brain produces in 30 seconds as much data as the Hubble Space Telescope has produced in its lifetime.

-Konrad Kording (2013)

We've always known that our brains control our behavior, but not that our behavior could control and change the structure of our brains.

—Fred Gage (2007)

**functional plasticity** The brain's ability to shift functions from damaged to undamaged brain areas.

**structural plasticity** The brain's ability to change its physical structure in response to learning, active practice, or environmental influences.

**neurogenesis** The development of new neurons.

a ball, or watching a movie—involve the smoothly coordinated synthesis of information among many different areas of your brain (Turk-Browne, 2013). Thus, contrary to what some people claim, it's *not* true that you "use only 10 percent of your brain." Imagine how well you would function if you lost even a third of your brain tissue, much less 90 percent. As neuroscientist Barry Gordon (2008) observes, "we use virtually every part of the brain, and the brain is active almost all the time."

How is information shared among these multiple brain regions? Even though we'll talk about brain centers and structures that are involved in different aspects of behavior, the best way to think of the brain is as an *integrated system*.

The estimated 90 billion neurons of the human brain are linked by millions of miles of neural connections. Many brain functions involve the activation of *neural pathways* that link different brain structures (Jbabdi & Behrens, 2012; Park & Friston, 2013). Neural pathways are formed by groups of neuron cell bodies in one area of the brain that project their axons to other brain areas (Seung, 2012). These neural pathways form communication networks and circuits that link different brain areas. Mapping the information highways of the human brain is the ambitious goal of *The Human Connectome Project*, which aims to combine brain-imaging data from hundreds of participants (Glasser & others, 2016). Apparently, patterns of brain connectivity are different for every individual—as unique as a fingerprint (Finn & others, 2015).

## The Dynamic Brain PLASTICITY AND NEUROGENESIS

Before embarking on our tour, we need to describe one last important characteristic of the brain: its remarkable capacity to change in response to experience. Until the mid-1960s, neuroscientists believed—and taught—that by early adulthood the brain's physical structure was *hardwired* or fixed for life. But today it's known that the brain's physical structure is literally sculpted by experience (Knobloch & Jessberger, 2011). The brain's ability to change function and structure is referred to as *neuroplasticity*, or simply *plasticity*. (The word *plastic* originally comes from a Greek word, *plastikos*, which means the quality of being easily shaped or molded.)

One form of plasticity is **functional plasticity**, which refers to the brain's ability to shift functions from damaged to undamaged brain areas. Depending on the location and degree of brain damage, stroke or accident victims often need to "relearn" once-routine tasks such as speaking, walking, and reading. If the rehabilitation is successful, undamaged brain areas gradually assume the ability to process and execute the tasks (Pascual-Leone & others, 2005).

But the brain can do more than just shift functions from one area to another. **Structural plasticity** refers to the brain's ability to physically change its structure in response to learning, active practice, or environmental stimulation.

Even subtle changes in your environment or behavior can lead to structural changes in the brain. For example, just seven days after learning how to juggle, young adults showed a measurable increase in gray matter in brain regions involved in perceiving, remembering, and anticipating complex visual motions (Driemeyer & others, 2008). So did senior citizens (Boyke & others, 2008). Even mental activity changes the brain: 10 weeks of foreign-language training resulted in measurable changes in the amount of gray matter in the hippocampus, a brain structure associated with memory formation (Bellander & others, 2016). In another study, tiny structural changes in one brain region were detected after study participants spent just two hours playing a new video game that involved spatial learning and memory (Sagi & others, 2012).

An even more dramatic example of the brain's capacity to change is **neurogenesis**—the development of new neurons. For many years, scientists believed that people and mammals did not experience neurogenesis after birth

(Kempermann, 2012a). With the exception of birds, tree shrews, and some rodents, it was thought that the mature brain could lose neurons but could not grow new ones.

It's now known, however, that thousands of new neurons are generated every day in adult mammals, including adult humans (Eriksson & others, 1998; Spalding & others, 2013). In humans, neurogenesis appears to be limited to two brain regions: the hippocampus and the *olfactory bulb*, which is responsible for odor perception. These newly generated neurons are incorporated into existing neural networks, possibly playing a key role in learning and memory (Kempermann, 2012b; Marín-Burgin & others, 2012).

Environmental factors affect neurogenesis. Stress, exercise, environmental complexity, and even social status have been shown to influence the rate of neurogenesis in monkeys, birds, and mice (Glasper & others, 2012; Kuipers & others, 2014; Sakalem & others, 2017). In laboratory animals, learning new behaviors enhances the survival of new neurons (Shors, 2014).

In the next section, we'll begin our guided tour of the brain. Following the general sequence of the brain's development, we'll start with the structures at the base of the brain and work our way up to more complicated brain regions, which are responsible for complex mental activity.

#### The Brainstem

#### HINDBRAIN AND MIDBRAIN STRUCTURES

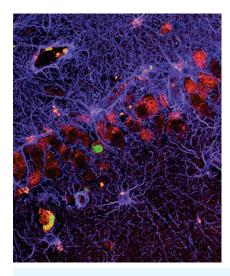
#### ■ KEY THEME

The brainstem includes the hindbrain and midbrain, located at the base of the brain.

#### KEY QUESTIONS

- Why does damage to one side of the brain affect the opposite side of the body?
- What are the key structures of the hindbrain and midbrain, and what are their functions?

The major regions of the brain are illustrated in Figure 2.13, which can serve as a map to keep you oriented during our tour. At the base of the brain lie the hindbrain and, directly above it, the midbrain. Combined, the structures of the hindbrain and midbrain make up the brain region called the **brainstem**.



#### Neurogenesis in the Adult Human Brain New neurons, shown in green, can be seen amid already established neurons, shown in red. In one area of the adult hippocampus, researchers found that each cubic centimeter of brain tissue contained from 100 to 300 new neurons (Eriksson & others, 1998). A later study by Kristy Spalding and her colleagues (2013) confirmed that more than a thousand new neurons are generated each day, even in older adults.

Photo courtesy Fred H. Gage, The Salk Institute, San Diego

**brainstem** A region of the brain made up of the hindbrain and the midbrain.

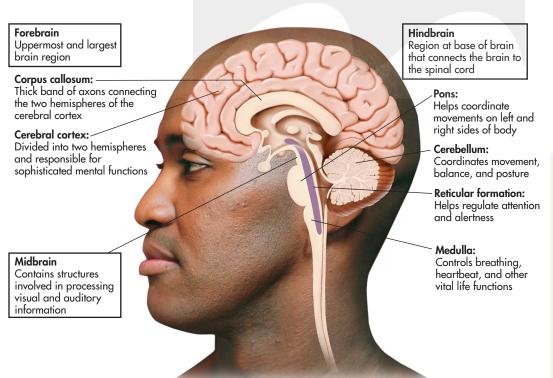


FIGURE 2.13 Major Regions of the Brain Situated at the base of the brain, the hindbrain's functions include coordinating movement and posture, regulating alertness, and maintaining vital life functions. The midbrain helps process sensory information. In combination, the hindbrain and the midbrain comprise the brainstem. The forebrain is the largest brain region and is involved in more sophisticated behaviors and mental processes.

Jupiter Images/Photos.com/Alamy

#### The Hindbrain

The **hindbrain** connects the spinal cord with the rest of the brain. Sensory and motor pathways pass through the hindbrain to and from regions that are situated higher up in the brain. Sensory information coming in from one side of the body crosses over at the hindbrain level, projecting to the opposite side of the brain. And outgoing motor messages from one side of the brain also cross over at the hindbrain level, controlling movement and other motor functions on the opposite side of the body. This is referred to as *contralateral organization*.

Contralateral organization accounts for why people who suffer strokes on one side of the brain experience muscle weakness or paralysis on the opposite side of the body. For example, Asha, whom you met in the Prologue, suffered only minor damage to motor control areas in her brain. However, because the stroke occurred on the *left* side of her brain, what muscle weakness she did experience was localized on the *right* side of her body, primarily in her right hand.

Three structures make up the hindbrain—the medulla, the pons, and the cerebellum. The **medulla** is situated at the base of the brain directly above the spinal cord. It is at the level of the medulla that ascending sensory pathways and descending motor pathways crisscross to the contralateral side of the body.

The medulla plays a critical role in basic life-sustaining functions. It contains centers that control such vital autonomic functions as breathing, heart rate, and blood pressure. The medulla also controls a number of vital reflexes, including swallowing, coughing, vomiting, and sneezing. Because the medulla is involved in such critical life functions, damage to this brain region can rapidly prove fatal.

Above the medulla is a swelling of tissue called the **pons**, which represents the uppermost level of the hindbrain. Bulging out behind the pons is the large **cerebellum**. On each side of the pons, a large bundle of axons connects it to the cerebellum. The word *pons* means "bridge," and the pons is a bridge of sorts: Information from various other brain regions located higher up in the brain is relayed to the cerebellum via the pons. The pons also contains centers that play an important role in regulating breathing.

The cerebellum functions in the control of balance, muscle tone, and coordinated muscle movements. It is also involved in the learning of habitual or automatic movements and motor skills, such as typing, writing, or backhanding a tennis ball.

Jerky, uncoordinated movements can result from damage to the cerebellum. Simple movements, such as walking or standing upright, may become difficult or impossible. The cerebellum is also one of the brain areas affected by alcohol consumption, which is why a person who is intoxicated may stagger and have difficulty walking a straight line or standing on one foot.

At the core of the medulla and the pons is a network of neurons called the **reticular formation**, or the *reticular activating system*, which is composed of many groups of specialized neurons that project up to higher brain regions and down to the spinal cord. The reticular formation plays an important role in regulating attention and sleep.

#### The Midbrain

The **midbrain** is an important relay station that contains centers involved in the processing of auditory and visual sensory information. Auditory sensations from the left and right ears are processed through the midbrain, helping you orient toward the direction of a sound. The midbrain is also involved in processing visual information, including eye movements, helping you visually locate objects and track their movements. After passing through the midbrain level, auditory information and visual information are relayed to sensory processing centers farther up in the forebrain region, which will be discussed shortly.

A midbrain area called the **substantia nigra** is involved in motor control and contains a large concentration of dopamine-producing neurons. *Substantia nigra* means "dark substance," and as the name suggests, this area is darkly pigmented. The substantia nigra is part of a larger neural pathway that helps prepare other brain regions to initiate organized movements or actions. In the section

**hindbrain** A region at the base of the brain that contains several structures that regulate basic life functions.

medulla (muh-DOOL-uh) A hindbrain structure that controls vital life functions such as breathing and circulation.

**pons** A hindbrain structure that connects the medulla to the two sides of the cerebellum; helps coordinate and integrate movements on each side of the body.

**cerebellum** (sair-uh-BELL-um) A large, twosided hindbrain structure at the back of the brain; responsible for muscle coordination and maintaining posture and equilibrium.

**reticular formation** (reh-TICK-you-ler) A network of nerve fibers located in the center of the medulla that helps regulate attention, arousal, and sleep; also called the reticular activating system.

midbrain The middle and smallest brain region, involved in processing auditory and visual sensory information.

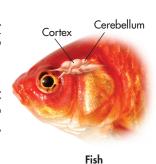
**substantia nigra** (sub-STAN-she-uh NYE-gruh) An area of the midbrain that is involved in motor control and contains a large concentration of dopamine-producing neurons.

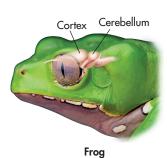
**forebrain** The largest and most complex brain region, which contains centers for complex behaviors and mental processes; also called the *cerebrum*.

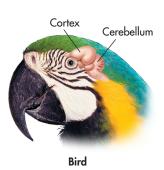
**cerebral cortex** (suh-REE-brull or SAIR-uh-brull) The wrinkled outer portion of the forebrain, which contains the most sophisticated brain centers.

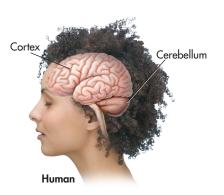
**cerebral hemispheres** The nearly symmetrical left and right halves of the cerebral cortex.

corpus callosum A thick band of axons that connects the two cerebral hemispheres and acts as a communication link between them.









on neurotransmitters, we noted that Parkinson's disease involves symptoms of abnormal movement, including difficulty initiating a particular movement. Many of those movement-related symptoms are associated with the degeneration of dopamine-producing neurons in the substantia nigra.

FIGURE 2.14 The Cerebral Cortex

The brains of these different animal species have many structures in common, including a cerebellum and cortex. However, the proportion devoted to the cortex is much greater in mammals than in fish, amphibians, or birds.

#### The Forebrain

#### **■ KEY THEME**

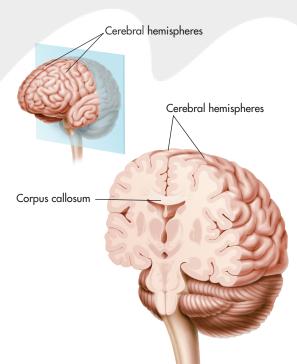
The forebrain includes the cerebral cortex and the limbic system structures.

#### **□** KEY OUESTIONS

- What are the four lobes of the cerebral cortex, and what are their functions?
- What is the limbic system?
- What functions are associated with the thalamus, hypothalamus, hippocampus, and amygdala?

Situated above the midbrain is the largest region of the brain: the **forebrain**. In humans, the forebrain represents about 90 percent of the brain. In **Figure 2.14**, you can

see how the size and shape of the forebrain varies among different species, although the general structure of the human brain is similar to that of other species (Clark & others, 2001). Many important structures are found in the forebrain region, but we'll begin by describing the most prominent—the cerebral cortex.



#### The Cerebral Cortex

The outer portion of the fore-brain, the **cerebral cortex**, is divided into two **cerebral hemispheres**. The word *cortex* means "bark," and much like the bark of a tree, the cerebral cortex is the outer covering of the forebrain. A thick bundle of axons, called the **corpus callosum**, connects the two cerebral hemispheres, as shown in **Figure 2.15**. The corpus callosum

FIGURE 2.15 The Cerebral Hemispheres and the Corpus Callosum The two hemispheres of the cerebral cortex can be clearly seen in this side-to-side cross-sectional view of the brain. The main communications link connecting the two cerebral hemispheres is the corpus callosum, a thick, broad bundle of some 300 million myelinated neuron axons.

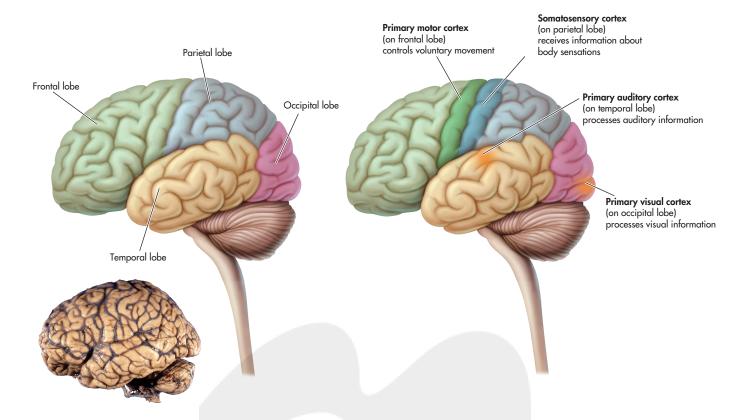


FIGURE 2.16 Lobes of the Cerebral Cortex Each hemisphere of the cerebral cortex can be divided into four regions, or lobes. Each lobe is associated with distinct functions. The association areas, also called the association cortex, make up most of the rest of the cerebral cortex.

Martin Rotker/Medical Images

serves as the primary communication link between the left and right cerebral hemispheres.

The cerebral cortex is only about a quarter of an inch thick. It is composed mainly of glial cells and neuron cell bodies and axons, giving it a grayish appearance—which is why the cerebral cortex is sometimes described as being composed of *gray matter*. Extending inward from the cerebral cortex are white myelinated axons that are sometimes referred to as *white matter*. These myelinated axons connect the cerebral cortex to other brain regions.

Numerous folds, grooves, and bulges characterize the human cerebral cortex. The purpose of these ridges and valleys is easy to illustrate. Imagine a flat, three-foot-by-three-foot piece of paper. You can compact the surface area of this piece of paper by scrunching it up into a wad. In much the same way, the grooves and bulges of the cerebral cortex allow about three square feet of surface area to be packed into the small space of the human skull.

Look again at Figure 2.13 on page 59. The drawing of the human brain is cut through the center to show how the cerebral cortex folds above and around the rest of the brain. In contrast to the numerous folds and wrinkles of the human cerebral cortex, notice the smooth appearance of the cortex in fish, amphibians, and birds in Figure 2.14. Mammals with large brains—such as cats, dogs, and nonhuman primates—also have wrinkles and folds in the cerebral cortex, but to a lesser extent than humans (Jarvis & others, 2005).

Each cerebral hemisphere can be roughly divided into four regions, or *lobes*: the *temporal, occipital, parietal,* and *frontal lobes* (see **Figure 2.16**). Each lobe is associated with distinct functions. Located near your temples, the **temporal lobe** contains the *primary auditory cortex,* which receives auditory information. At the very back of the brain is the **occipital lobe.** The occipital lobe includes the *primary visual cortex,* where visual information is received.

The **parietal lobe** is involved in processing bodily, or *somatosensory*, information, including touch, temperature, pressure, and information from receptors in the muscles and joints. A band of tissue on the parietal lobe, called the



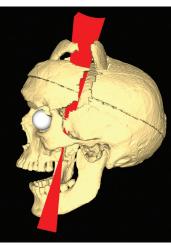


Image courtesy of John Darrell Van Horn, Ph.D., Institute of Neuroimaging and Informatics, University of Southern California. Mapping Connectivity Damage in the Case of Phineas Gage, PLoS One, May 2012, vol 7, issue 5.

Focus on the Frontal Lobes: Phineas Gage Early interest in the frontal lobes was sparked by the case of Phineas Gage, a railroad foreman. In 1848, a freak explosion shot a 13-pound, three-and-a-half-foot-long iron bar through his skull, piercing his brain. After the accident, the formerly conscientious, soft-spoken foreman was said to have become bad-tempered and irresponsible. After Gage's death in 1861, his physician proposed that Gage's personality changes were caused by damage to his frontal lobes (Harlow, 1869). More than a century later, neuroscientists studying Gage's skull confirmed that his left frontal lobe had been severely damaged (Damasio & others, 1994; Ratiu & Talos, 2004). A more recent model points to probable damage to white matter connections between Gage's frontal lobe and other brain regions associated with emotion and memory (van Horn & others, 2012). This disconnection may have contributed to Gage's personality changes after the accident. Interestingly, new research suggests that Gage went on to make a full recovery in the years after his accident (Kean, 2014; Macmillan, 2000; Macmillan & Lena, 2010).

somatosensory cortex, receives information from touch receptors in different parts of the body.

Each part of the body is represented on the somatosensory cortex, but this representation is not equally distributed (see Figure 2.17 on the next page). Instead, body parts are represented in proportion to their sensitivity to somatic sensations. For example, on the left side of Figure 2.17, you can see that your hands and face, which are very responsive to touch, have much greater representation on the somatosensory cortex than do the backs of your legs, which are far less sensitive to touch.

The **frontal lobe** is the largest lobe of the cerebral cortex, and damage to this area of the brain can affect many different functions. The frontal lobe is involved in planning, initiating, and executing voluntary movements. The movements of different body parts are represented in a band of tissue on the frontal lobe called the primary motor cortex. The degree of representation on the *primary motor cortex* for a particular body part reflects the diversity and precision of its potential movements, as shown on the right side of Figure 2.17. Thus, it's not surprising that almost one-third of the primary motor cortex is devoted to the hands and another third is devoted to facial muscles. The disproportionate representation of these two body areas on the primary motor cortex is reflected in the human capacity to produce an extremely wide range of hand movements and facial expressions.

The primary sensory and motor areas found on the different lobes represent just a small portion of the cerebral cortex. The remaining bulk of the cerebral cortex consists mostly of association areas, also called the association cortex. These areas are generally thought to be involved in processing and integrating sensory and motor information. For example, the prefrontal association cortex, situated in front of the primary motor cortex, is involved in the planning of voluntary movements. Another association area includes parts of the temporal, parietal, and occipital lobes. This association area is involved in the formation of perceptions and in the integration of perceptions and memories.

## The Limbic System

Beneath the cerebral cortex are several other important forebrain structures, which are components of the  $limbic\ system$ . The word  $limbic\ means\ "border,"$  and as you

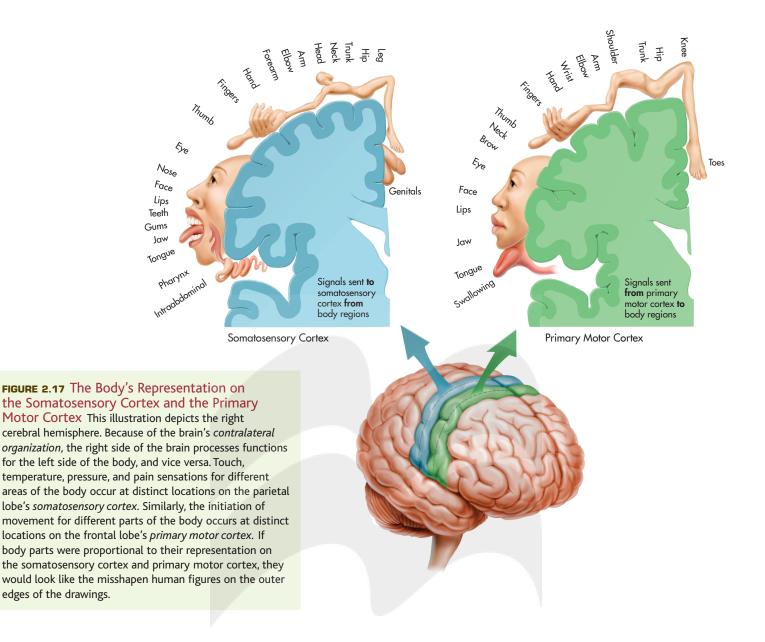
**temporal lobe** An area on each hemisphere of the cerebral cortex, near the temples, that is the primary receiving area for auditory information.

occipital lobe (ock-SIP-it-ull) An area at the back of each cerebral hemisphere that is the primary receiving area for visual information.

parietal lobe (puh-RYE-ut-ull) An area on each hemisphere of the cerebral cortex located above the temporal lobe that processes somatic sensations.

frontal lobe The largest lobe of each cerebral hemisphere; processes voluntary muscle movements and is involved in thinking, planning, and emotional control.

**limbic system** A group of forebrain structures that form a border around the brainstem and are involved in emotion, motivation, learning, and memory.



can see in Figure 2.18, the structures that make up the limbic system form a border of sorts around the brainstem. Limbic system structures form complex neural circuits that play critical roles in learning, memory, and emotional control.

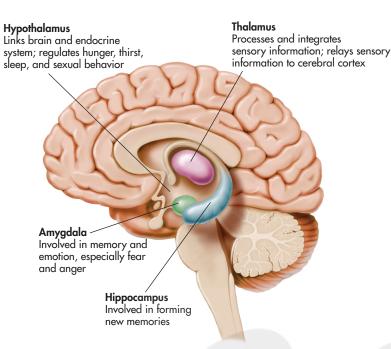
Next, we'll briefly consider some key limbic system structures and the roles they play in behavior.

The Hippocampus The hippocampus is a large structure embedded in the temporal lobe in each cerebral hemisphere (see Figure 2.18). The word *hippocampus* comes from a Latin word meaning "sea horse." If you have a vivid imagination, the hippocampus does look a bit like the curved tail of a sea horse. The hippocampus plays an important role in your ability to form new memories of events and information (Moscovitch & others, 2016). As noted earlier, neurogenesis takes place in the adult hippocampus. The possible role of new neurons in memory formation is an active area of neuroscience research (see Livneh & Mizrahi, 2012; Sakalem & others, 2017). In Chapter 6, we'll take a closer look at the role of the hippocampus and other brain structures in memory.

The Thalamus The word thalamus comes from a Greek word meaning "inner chamber." And indeed, the **thalamus** is a rounded mass of cell bodies located within each

**hippocampus** A curved forebrain structure that is part of the limbic system and is involved in learning and forming new memories.

**thalamus** (THAL-uh-muss) A forebrain structure that processes sensory information for all senses except smell, relaying that information to the cerebral cortex.



**FIGURE 2.18** Key Structures of the Forebrain and Limbic System In the cross-sectional view shown here, you can see the locations and functions of four important subcortical brain structures. In combination, these structures make up the *limbic system*, which regulates emotional control, learning, and memory.

cerebral hemisphere. The thalamus processes and distributes motor information and sensory information (except for smell) going to and from the cerebral cortex. Figure 2.19 depicts some of the neural pathways going from the thalamus to the different lobes of the cerebral cortex. However, the thalamus is more than just a sensory relay station. The thalamus is also thought to be involved in regulating levels of awareness, attention, motivation, and emotional aspects of sensations.

hypothalamus (hi-poe-THAL-uh-muss) A peanut-sized forebrain structure that is part of the limbic system and that regulates behaviors related to survival, such as eating, drinking, and sexual activity.

The Hypothalamus Hypo means "beneath" or "below." As its name implies, the hypothalamus is located below the thalamus. Although it is only about the size of a peanut, the hypothalamus contains more than 40 neural pathways. These neural pathways ascend to other forebrain areas and descend to the midbrain, hindbrain, and spinal cord. The hypothalamus is involved in so many different functions, it is sometimes referred to as "the brain within the brain."

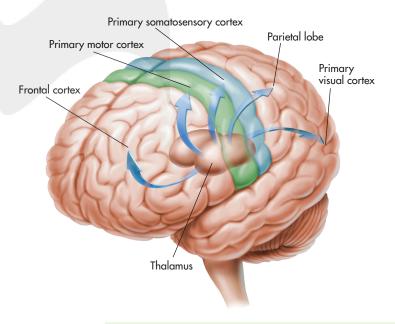
The hypothalamus regulates both divisions of the autonomic nervous system, increasing and decreasing such functions as heart rate and blood pressure. It also helps regulate a variety of behaviors related to survival, such as eating, drinking, frequency of sexual activity, fear, and aggression.

One area of the hypothalamus, called the *suprachiasmatic nucleus* (SCN), plays a key role in regulating daily sleep—wake cycles and other rhythms of the body. We'll take a closer look at the SCN in Chapter 4.

The hypothalamus exerts considerable control over the secretion of endocrine hormones by directly influencing the pituitary gland. The *pituitary gland* is situated just below the hypothalamus and is attached to it by a short stalk. The hypothalamus produces both neurotransmitters and hormones

that directly affect the pituitary gland. As we noted in the section on the endocrine system, the pituitary gland releases hormones that influence the activity of other glands.

**The Amygdala** The **amygdala** is an almond-shaped clump of neuron cell bodies at the base of the temporal lobe. The amygdala is involved in a variety



**FIGURE 2.19** The Thalamus Almost all sensory and motor information going to and from the cerebral cortex is processed through the thalamus. This figure depicts some of the neural pathways from different regions of the thalamus to specific lobes of the cerebral cortex.

Review the structures of the brain with **PsychSim6: Brain and Behavior**.

The Corpus Callosum In the drawing, the top of the brain has been cut away, exposing the thick fibers of the corpus callosum, which connect the left and right hemispheres.

amygdala (uh-MIG-dull-uh) An almondshaped cluster of neurons in the brain's temporal lobe, involved in memory and emotional responses, especially fear.

**cortical localization** The notion that different functions are located or localized in different areas of the brain; also called *localization* of function.

of emotional responses, including fear, anger, and disgust. Animal studies have shown that electrical stimulation of the amygdala can produce behaviors associated with fear or rage, while destruction of the amygdala reduces or disrupts such behaviors.

It's long been known that the amygdala is involved in the detection of threatening stimuli, but neuroscientists have discovered that the amygdala has a broader role. Brain imaging studies have shown that the amygdala responds to many different types of emotional stimuli, appealing as well as upsetting (Cunningham & Brosch, 2012). For example, hungry participants showed increased amygdala activation in response to pictures of food when they were hungry but not when they were satiated (Mohanty & others, 2008). Thus, some neuroscientists now believe that the amygdala aids in detecting and responding to environmental stimuli that are relevant to an organism's goals.

The amygdala is also involved in learning and forming memories, especially those with a strong emotional component (Phelps, 2006). In Chapters 6 and 8, we'll take a closer look at the amygdala's role in memory and emotion.

## Specialization in the Cerebral Hemispheres

#### KEY THEME

Although they have many functions in common, the two hemispheres of the cerebral cortex are specialized for different tasks.

#### **■ KEY QUESTIONS**

- How did Broca, Wernicke, and Sperry contribute to our knowledge of the brain?
- Why would the corpus callosum be surgically severed, and what effects would that produce?
- How do the functions of the right and left cerebral hemispheres differ?

If you hold a human brain in your hand, the two cerebral hemispheres would appear to be symmetrical. Although the left and right hemispheres are very similar in appearance, they are not identical. Anatomically, one hemisphere may be slightly larger than the other. There are also subtle differences in the sizes of particular structures, in the distribution of gray matter and white matter, and in the patterns of folds, bulges, and grooves that make up the surface of the cerebral cortex (Ocklenburg & Güntürkün, 2012).

What about differences in the functions of the two hemispheres? In many cases, the functioning of the left and right hemispheres is symmetrical, meaning that the same functions are located in roughly the same places on each hemisphere. Examples of such functional symmetry include the primary motor cortex and the somatosensory cortex, which we discussed in the previous section. With regard to other important processes, however, the left and right cerebral hemispheres do differ—each cerebral hemisphere is specialized for particular abilities.

As you'll see in this section, the first discoveries about the differing abilities of the two brain hemispheres were made more than a hundred years ago by two important pioneers in brain research, Pierre Paul Broca and Karl Wernicke.

## Language and the Left Hemisphere

#### THE EARLY WORK OF BROCA AND WERNICKE

*Phrenology* was a popular pseudoscience in the 1800s and early 1900s that "read" bumps on the skull to map character traits onto the brain. Although phrenology was wrong about the significance of bumps on the skull, its popularity did help trigger scientific speculation about *cortical localization* (Finger, 2010). **Cortical localization** refers to the idea that particular brain areas are associated with specific functions.



#### CRITICAL THINKING

### "His" and "Her" Brains?

Do men and women have fundamentally different brains? Some popular authors claim men's and women's brains are "hardwired" by hormones and genes to produce "separate realities" (Brizendine, 2006, 2010). According to this view, there are innate differences between the brains of males and females, differences that cause gender differences in behaviors, attitudes, personality traits, and skills (Fine, 2012, 2014). But what are these differences? Do they cause men and women to "think, feel, and behave differently," as some headlines and popular books claim?

Let's look at the scientific research.

Is it true that because their brains are wired differently, men and women think, feel, and behave differently?

MYTH **SCIENCE** 

A case in point is a recent study that used a form of diffusion MRI (see page 57) to compare the neural pathways, or connectomes, of over 900 chil-

dren and young adults. Madhura Ingalhalikar and her colleagues (2014) concluded that the scans of the adolescent and young adult participants showed "fundamental sex differences in the structural architecture in the human brain." On average, males had significantly more neural connections within the left and right hemispheres than females. And, females had significantly more neural connections between the left and right hemispheres than males.

The media jumped on the findings as evidence that sex differences were "hardwired" in the brain. Going well beyond the study's findings, print articles and online blogs claimed that the findings explained many supposed sex differences, such as why men were better at map-reading, physical coordination, and tasks requiring single-minded focus and why women were better at multitasking and were more socially competent (see O'Connor & Joffe, 2014). For the record, these behaviors were *not* measured in the participant pool.

But just how definitive were the study's results? First, while statistically significant, the differences identified in the study were still quite small (Cossins, 2015; Joel & Tarrasch, 2014). Second, the differences were *quantitative* rather than *qualitative*: that is, the differences were a matter of degree, not kind. Although the average number of connections differed, the general pattern of connections was the same in male and female participants (Fine, 2014).

And, critics noted that male brains are, on average, about 10% larger than female brains. Thus, the differences could have been associated with *brain size* rather than *brain sex*. A later study found that larger brains tend to have more interhemispheric connectivity than smaller brains, *regardless* of sex. In men's and women's brains that were the same size, there were no differences in the pattern of connections: the apparent sex effect disappeared (Hänggi & others, 2014).

Finally, the analysis did not take into account the participants' past experience, such as participation in sports or hobbies (Fine, 2014). Yet, as we've shown in this chapter, experience changes the brain.

#### **Thinking Critically About Brain Differences**

How should you interpret media sound bites about profound sex differences in the brain? Or claims that certain personality traits or behaviors are "hardwired in the brain"?

Sex Differences and the Brain Subtle gender differences in brain function and structure make headlines, often implying or stating outright that men and women "think differently."



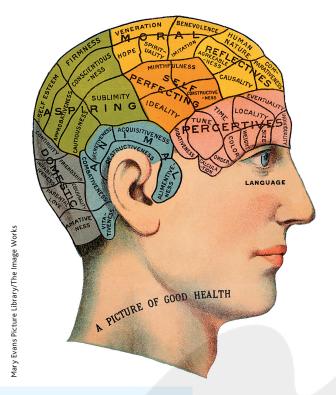
First, it's important to think critically about media claims. Unlike reporters, scientists are usually careful to qualify their conclusions and describe the limitations of their research. These limitations are rarely mentioned in media reports. For example, brain studies are typically based on small groups of participants, who may or may not be representative of the wider population of men and women. And, while findings of sex differences in brain structure or function tend to be widely reported in the media, findings of no difference go unreported. So, often, does the failure of studies to be replicated by other researchers (Eliot, 2011; Fine, 2013a, 2013b). In other words, the findings of individual research studies are rarely as earth-shattering as reported.

Second, most sex differences amount to minor variations in the size of a particular brain region or to statistical differences in the average level of activation of particular brain regions (Joel & others, 2015). Brain structures and functioning are essentially the *same* in men and women—including in the study highlighted above (Fine, 2014; Rippon & others, 2014). As you'll see in later chapters, when it comes to personality traits, abilities, and attitudes, *men and women are much more similar than they are different*.

Finally, it's important to remember that even differences that are biological in origin are not necessarily fixed, permanent, or inevitable (Fine, 2014; Hyde, 2014). Brain development and function are affected by biological influences, such as exposure to the sex hormones produced both before birth and throughout your life (Lombardo & others, 2012; McEwen & Milner, 2017). However, these biological factors themselves are strongly influenced by environmental factors, ranging from the food we eat to the stressful circumstances we experience. As we've emphasized throughout this chapter, both brain function and structure are highly responsive to environmental influences (Fine & others, 2013). Thus, sex differences in structures or function might well be the result of the different life experiences of men and women, rather than the cause (Rippon & others, 2014).

#### CRITICAL THINKING QUESTIONS

- Why are sweeping claims about fundamental sex differences in the human brain misleading?
- What is wrong with the statement that certain behaviors or personality traits are "hardwired" in the male or female brain?
- How might claims that sex differences are "hardwired" or innate affect attitudes or behavior?





Phrenology: The Bumpy Road to Scientific **Progress** Originated by Viennese physician Franz Joseph Gall in 1790, phrenology claimed that personality and character traits were reflected in the shape of the skull. Gall devised elaborate maps showing the location of the personality characteristics, or "faculties," that he believed were reflected in the shape of the head (left). In the early 1900s, many department stores and theater lobbies featured "psycographs" (right), helmets that measured the bumps on customers' heads and stamped out summaries of their personality traits (McCoy, 1996, 2000). Despite its pseudoscientific nature, phrenology helped advance the scientific study of the human mind and brain (Eghigian, 2011).

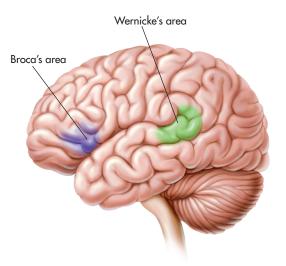
aphasia (uh-FAYZH-yuh) The partial or complete inability to articulate ideas or understand spoken or written language because of brain injury or damage.

**FIGURE 2.20** Broca's and Wernicke's Areas of the Cerebral Cortex Broca's area, located on the lower frontal lobe, is involved in the production of speech. Wernicke's area, found in the temporal lobe, is important in the comprehension of written or spoken language. Damage to either of these areas will produce different types of speech disturbances, or *aphasia*. In most people, both areas are found in the left hemisphere.

Physicians were also encountering brain-injured patients who experienced disruptions in speech and language, a condition called **aphasia**.

In the 1860s, speculation that some language functions were localized to the left frontal lobe was confirmed by French surgeon and neuroanatomist **Pierre Paul Broca**. Broca treated a series of patients who had great difficulty speaking but who could comprehend written or spoken language—a condition later called *Broca's aphasia*. Subsequent autopsies of these patients revealed a consistent finding—brain damage to an area on the *lower left frontal lobe*. Today, this area on the left hemisphere is referred to as *Broca's area*, and it is known to play a crucial role in speech production (**Figure 2.20**).

About a decade after Broca's discovery, a young German neurologist named **Karl Wernicke** discovered another area in the left hemisphere that, when dam-



aged, produced a different type of language disturbance. Unlike Broca's patients, Wernicke's patients had great difficulty understanding spoken or written communications, a condition now called Wernicke's aphasia. They could speak quickly and easily, but their speech made no sense. Autopsies of these patients' brains revealed consistent damage to an area on the left temporal lobe that today is called Wernicke's area (see Figure 2.20).

The discoveries of Broca and Wernicke provided the first compelling clinical evidence that language and speech functions are performed primarily by the left cerebral hemisphere. If similar brain damage occurs in the exact same locations on the *right* hemisphere, these severe disruptions in language and speech are usually *not* seen.

The notion that one hemisphere exerts more control over or is more involved in the processing of a particular psychological function is termed **lateralization of function**. Speech and language functions are *lateralized* on the left hemisphere. Generally, the left hemisphere exerts greater control over speech and language abilities in virtually all right-handed and the majority of left-handed people (Häberling & others, 2016). However, although damage to either Broca's area or Wernicke's area often produces aphasia, it's now known that speech and language functions are *not* localized to just these two areas. Rather, they are widely distributed throughout the brain (Tremblay & Dick, 2016).

At the beginning of this chapter, we described the symptoms experienced by your author Sandy's friend Asha in the weeks before and the months following her stroke. Asha, who is right-handed, had a stroke in her left temporal lobe. Asha experienced many symptoms of Wernicke's aphasia. Talking was difficult, not because Asha couldn't speak, but because she had to stop frequently to search for the right words. Asha was unable to name even simple objects, like the cup on her hospital dinner tray or her doctor's necktie. She recognized the objects but was unable to say what they were. She had great difficulty following a normal conversation and understanding speech, both in English and in her native language, Tulu.

Asha also discovered that she had lost the ability to read. She could see the words on the page, but they seemed to have no meaning. Asha recalls, "When I realized I couldn't read, I thought my life was over. I just lost it. I remember crying and telling the nurse, 'I have a doctorate and I can't read, write, or talk!"

When visiting Asha in the hospital, Sandy brought her a Christmas present: a portable music player with headphones and some albums of relaxing instrumental music. One album was a recording of Native American flute music called *Sky of Dreams*. The music was beautiful and rather unusual, with intricate melodies and unexpected, complex harmonies. Although it was very difficult for Asha to follow normal speech, listening to *Sky of Dreams* was an entirely different experience. As Asha explained,

I tried cranking up the music very high and it soothed me. I could sleep. At the time, the flute music seemed to be just perfectly timed with the way my brain was working. It was tuning out all the other noises so I could focus on just one thing and sleep. So I would play the music over and over again at a very high level. I did that for a long time because my mind was so active and jumbled that I couldn't think.

Asha's language functions were severely disrupted, yet she was able to listen to and appreciate instrumental music—even very complex music. Why? At the end of the next section, we'll offer a possible explanation for what seems to have been a disparity in Asha's cognitive abilities following her stroke.

## Cutting the Corpus Callosum THE SPLIT BRAIN

The most dramatic evidence illustrating the functions of the two cerebral hemispheres has come from a surgical procedure called the *split-brain operation*, used to reduce recurring seizures in severe cases of epilepsy (Wolman, 2012). The procedure involves surgically cutting the corpus callosum, the thick band of axons that connects the two hemispheres. Surprisingly, cutting the corpus callosum initially seemed to produce no noticeable effect on the patients, other than reducing their epileptic seizures. Their ability to engage in routine conversations and tasks seemed to be unaffected.

In the 1960s, psychologist and neuroscientist **Roger Sperry** (1982) and his colleagues recruited split-brain patients to try to begin to unravel the puzzle of the left



Left-Handed Orangutans Like humans, many animals also display a preference for one hand or paw (Ocklenburg & Güntürkün, 2012). Unlike humans, who are predominantly right-handed, animals tend to vary by species, population, and task (Hopkins & Cantalupo, 2005; Grant, 2014). For example, orangutans, like the one shown above, tend to be left-handed, but gorillas, chimpanzees, and bonobos tend to be right-handed (Hopkins & others, 2011; Prieur & others, 2016a, 2016b). Handedness is discussed in more detail in the Science Versus Pseudoscience box, "Brain Myths," on page 72.

**lateralization of function** The notion that specific psychological or cognitive functions are processed primarily on one side of the brain.

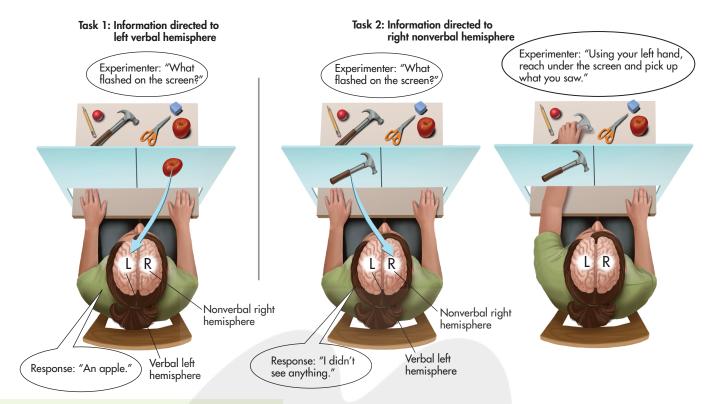


FIGURE 2.21 Testing a Split-Brain Person Objects are hidden behind a screen. The participant can reach beneath the screen to pick up objects, but can't see them. As a split-brain person focuses her attention on the middle of the screen, information is briefly flashed to either the left or right side of the midpoint. In Task 1, information is flashed to her right visual field, sending it to her left, verbal hemisphere. When asked about the information, she easily names it. In Task 2, information is directed to her left visual field, sending it to her right, nonverbal hemisphere. When asked about the information, she is unable to verbally reply with the correct answer. But when asked to use her left hand, which is controlled by the same right, nonverbal hemisphere that detected the flashed image, she is able to reach under the screen, feel the different objects, and pick up the correct one (Gazzaniga, 1983; Wolman, 2012).

Source: Research from Sperry (1982).

John Mazziotta et al./ Irology/Science Source and right hemispheres. Sperry and his colleagues used the apparatus shown in **Figure 2.21** to test the abilities of split-brain patients.

Because the two hemispheres were no longer connected by the corpus callosum, information projected to the *right* hemisphere was not perceived by the *left* hemisphere, and vice versa. If a split-brain subject was asked to verbally identify an image, she could do so only if the information was sent to her left, verbal hemisphere. If the information was sent to her right, nonverbal hemisphere, she would not be able to say what she had seen, and would in fact say that she had seen nothing at all. But the split-brain subject's right hemisphere still processed information and expressed itself *nonverbally*: The subject was able to pick up an object matching the image. Unable to share information, the hemispheres functioned independently.

Over the past decades, researchers have gained numerous insights about the brain's lateralization of functions by studying split-brain patients, using brain-imaging techniques with normal subjects, and employing other techniques (Gazzaniga, 2005; Hugdahl & Westerhausen, 2010). On the basis of this evidence, researchers have con-

cluded that—in most people—the left hemisphere is superior in language abilities, speech, reading, and writing (Haberling & others, 2016).

In contrast, the right hemisphere is more involved in nonverbal emotional expression and visual-spatial tasks (Corballis, 2010). Deciphering complex visual

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Hemispheres The red arrow at the top of each PET scan points to the front of the brain. The red and yellow colors indicate the areas of greatest brain activity. Listening to speech involves a greater degree of activation of the language areas of the left hemisphere. Listening to music involves more activation in righthemisphere areas. Notice, however, that there is some degree of activity in both hemispheres during these tasks.

Specialization in the Left and Right

cues, such as completing a puzzle or manipulating blocks to match a particular design, also relies on right-hemisphere processing (Gazzaniga, 1995, 2005). And the right hemisphere excels in recognizing faces and emotional facial cues, reading maps, copying designs, and drawing (Meng & others, 2012). Finally, the right

#### Specialized Abilities of the Two Hemispheres

General Function	Left-Hemisphere Dominance	Right-Hemisphere Dominance
Vision	Words Letters	Geometric patterns Faces Emotional expression
Hearing	Language sounds	Nonlanguage sounds Music
Memory	Verbal memory	Nonverbal memory
Language	Speech Grammar rules Reading Writing Arithmetic	Emotional tone of speech
Spatial ability and perception		Geometry Sense of direction Distance Mental rotation of shapes

Most people are left-hemisphere-dominant for speech and language tasks and right-hemisphere-dominant for visual and spatial tasks. Although the hemispheres display some specialized abilities, many functions are symmetrical and performed the same way on both hemispheres (Haberling & others, 2016).

hemisphere shows a higher degree of specialization for musical appreciation or responsiveness—but not necessarily for musical ability, which involves the use of the left hemisphere as well (Springer & Deutsch, 2001).

Table 2.2 summarizes the research findings for the different specialized abilities of the two hemispheres for right-handed people. As you look at the table, it's important to keep two points in mind. First, the differences between the left and right hemispheres are almost always relative differences, not absolute differences. In other words, both hemispheres of your brain are activated to some extent as you perform virtually any task (Toga & Thompson, 2003; Behrmann & Plaut, 2015). In the normal brain, the left and right hemispheres function in an integrated fashion, constantly exchanging information (Allen & others, 2007). Thus, Table 2.2 indicates the hemisphere that typically displays greater activation or exerts greater control over a particular function. Misconceptions about the roles played by the left and right hemispheres are common in the popular media, and even in education (Howard-Jones, 2014). The Science Versus Pseudoscience box on the next page, "Brain Myths," explores some of the most common misperceptions about the brain. Second, many functions of the cerebral hemispheres, such as those involving the primary sensory and motor areas, are symmetrical. They are located in the same place and are performed in the same way on both the left and the right hemispheres.

Given the basic findings on the laterality of different functions in the two hemispheres, can you speculate about why Asha was unable to read or follow a simple conversation but could easily concentrate on a complex piece of music? Why were her language abilities so disrupted, while her ability to focus on and appreciate music remained intact after her stroke?

A plausible explanation has to do with the location of the stroke's damage on Asha's left temporal lobe. Because language functions are usually localized on the left hemisphere, the stroke produced serious disruptions in Asha's language



#### THINK LIKE A SCIENTIST

Can you be classified as right-brained or left-brained? Go to LaunchPad: Resources to Think Like a Scientist about The Right Brain Versus the Left Brain.



## M

#### SCIENCE VERSUS PSEUDOSCIENCE

### **Brain Myths**

## Is it true that some people are "right-brained" and other people "left-brained"?

To investigate this question, researchers compared more than a thousand fMRI scans taken while participants rested. There was *no* evidence that participants preferentially relied on networks in the left or right hemisphere, as you would expect if some people were "left-brained" and others "right-brained" (Nielsen & others, 2013).

It certainly seems as if some people are more logical, analytical, or detail-oriented than others, especially in the way that they make decisions or tackle problems. But remember that the left and right hemispheres are highly interconnected in the normal, intact human brain. Unless the corpus callosum has been surgically sliced, all humans rely on the smooth, integrated functioning of both left and right hemispheres to speak, learn, and generally navigate everyday life. In fact, the more complex the task, the greater the likelihood that both hemispheres will be involved in performing it (Allen & others, 2007; Yoshizaki & others, 2007).

## What about left-handed people? Is it true that they are right-hemisphere-dominant?

Only about 10 to 13 percent of the population identify themselves as left-handed (Basso, 2007). Unlike right-handed people, who tend to use their right hands for virtually all tasks requiring dexterity, most left-handers actually show a pattern of "mixed" handedness. Strong left-handedness is extremely rare (Wolman, 2005).

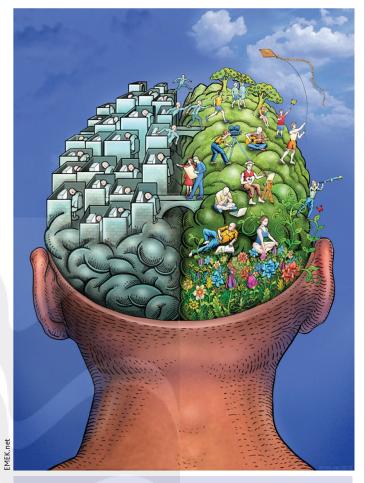
It's a myth that left-handers have a fundamentally different brain organization from right-handers (Haberling & others, 2016). About 75 percent of left-handers are left-hemisphere-dominant for language, just like right-handers. The remaining 25 percent are either right-hemisphere-dominant for language or bilateral, using both hemispheres for speech and language functions. Just for the record, about 5 percent of right-handed people are also either right-hemisphere or bilaterally specialized for language (Knecht & others, 2000; Ocklenburg & Güntürkün, 2012).

## Is the right brain responsible for creativity and intuition? Can you train your right brain?

Although the right hemisphere is specialized for holistic processing, there is no evidence that the right hemisphere is any more "intui-

#### MYTH SCIENCE

Is it true that the right brain is creative and intuitive, and the left brain is analytic and logical, but that left-brained people can educate their right brain? tive" or "creative" than the left hemisphere (Gazzaniga, 2005). In fact, a recent study found that a task requiring a *creative* solution involved greater left hemisphere activation than a task that required a *noncreative* 



**Left Brain, Right Brain?** As this image rather playfully suggests, many people see the two hemispheres as representing diametrically opposed ways of thinking and behaving: the left brain is cold, rational, and analytical; the right brain is emotional, artistic, and free-spirited. But how much truth is there to this myth?

solution (Aziz-Zadeh & others, 2013). There is also no evidence that any teacher, however skilled, could somehow selectively "educate" one side of your brain in isolation from the other (Goswami, 2006). While it is true that each hemisphere is specialized for different abilities, you rely on the integrated functioning of *both* hemispheres to accomplish most tasks. This is especially true for such cognitively demanding tasks as artistic creativity, musical performance, or finding innovative solutions to complex problems.

abilities. However, her *right* cerebral hemisphere sustained no detectable damage. Because one of the right hemisphere's abilities is the appreciation of musical sounds, Asha retained the ability to concentrate on and appreciate music.



Go to LaunchPad to test your understanding of The Brain with LearningCurve.

## **Closing Thoughts**

In our exploration of neuroscience and behavior, we've traveled from the activities of individual neurons to the complex interaction of the billions of neurons that make up the human nervous system, most notably the brain.

Although the nervous system is highly specialized, even simple behaviors involve the highly integrated interaction of trillions of synapses. Your ability to process new information and experiences, your memories of previous experiences, your sense of who you are and what you know, your actions and reactions—all depend upon the harmony of the nervous system.

The story of Asha's stroke illustrated what can happen when that harmony is disrupted. Asha survived her stroke, but many people who suffer strokes die or are left with severe impairments in their ability to function.

What happened to Asha? Fortunately, her story has a happy ending. Asha was luckier than many stroke victims—she was young, strong, and otherwise healthy. Asha's recovery was also aided by her high level of motivation and willingness to work hard. After being discharged from the hospital, Asha began months of intensive speech therapy. Her speech therapist assigned a great deal of homework that consisted of repeatedly pairing objects with words and words with objects. Asha was literally rewiring her brain by relearning the correct associations between words and their meanings.

With the help of her husband, Paul, and her mother, Nalini, who traveled from India to help coach her back to full recovery, Asha reached the goal she had set for herself. Eight months after her stroke, she returned to the classroom and her research lab.

Today, more than five years after her stroke, the average person would never know that Asha had sustained significant brain damage. Other than an occasional tendency to "block" on familiar words—especially when she's very tired—Asha seems to have made a complete recovery.

Thus, Asha's story illustrates a final theme—the brain's remarkable *plasticity*. Next, we take a closer look at how the brain responds to different types of environments. You will also learn how you can use research to enhance your own dendritic potential!



Asha's Recovery After leaving the hospital, Asha began retraining her brain with speech therapy. Day after day, Asha repeatedly paired words with objects or identified numbers, weekdays, or months. As Asha gradually made progress, her mother began taking her to stores. "She'd tell the clerk I was from India and that my English wasn't very good and ask them to please be patient with me. She basically forced me to talk to the sales clerks." Today, more than five years after the stroke, Asha has completely recovered and resumed teaching.

Courtesy Asha Hegde Niezgoda



#### **PSYCH FOR YOUR LIFE**

## Maximizing Your Brain's Potential

It was 1962 when a group of neuroscientists led by psychologist Mark Rosenzweig published the unexpected finding that the brains of rats raised in *enriched environments* were significantly different from the brains of rats raised in *impoverished environments*.

For lab rats, an *enriched environment* is spacious, houses several rats, and has assorted wheels, ladders, tunnels, and objects to explore. The environment is also regularly changed for further variety. Some enriched environments have been designed to mimic an animal's natural environment (see Heyman, 2003). In the *impoverished environment*, a solitary rat lives in a small, bare laboratory cage with only a water bottle and food tray to keep it company.

Decades of research have shown that enrichment increases the number and length of dendrites and dendritic

branches, increases the number of glial cells, and enlarges the size of neurons (Cohen, 2003). Enrichment produces more synaptic connections between brain neurons, while impoverishment decreases synaptic connections. With more synapses, the brain has a greater capacity to integrate and process information and to do so more quickly. In young rats, enrichment increases the number of synapses in the cortex by as much as 20 percent. But even the brains of extremely old rats respond to enriched environments. In fact, no matter what the age of the rats studied, environmental enrichment or impoverishment had a significant impact on brain structure (Kempermann & others, 1998).

Enrichment has also been shown to increase the rate of neurogenesis in many different species, from rodents to monkeys (Fan & others, 2007; Nithianantharajah & Hannan, 2006).



An Enriched Environment Primates in the wild, like this marmoset, live in complex, challenging, and ever-changing environments. At psychologist Elizabeth Gould's Princeton lab, marmosets are housed in large enclosures with natural vegetation and novel objects that are changed frequently. In one experiment, synaptic and dendritic connections increased dramatically in marmosets who lived in the enriched environment for just four weeks after being raised in standard laboratory cages (Kozorovitskiy & Gould, 2004).

Both the number and the survival time of new neurons increase in response to enrichment (Gould & Gross, 2002; van Praag & others, 2000). Interestingly, while enriched environments can increase neurogenesis, social isolation and a stressful environment *decrease* neurogenesis (Ming & Song, 2005).

Collectively, these changes result in increased processing and communication capacity in the brain. Behaviorally, enrichment has been shown to enhance performance on tasks designed to measure learning and memory, such as performance in different types of mazes (van Praag & others, 2000).

#### Who Moved My Exercise Wheel?

Neuroscientists have identified an additional factor that improves brain function, even in aging mammals: exercise (Hillman & others, 2008; Shors, 2014). In one study, just a month of daily exercise helped reverse cognitive declines associated with aging in previously sedentary, elderly mice (van Praag & others, 2005). The physically active elderly mice had a greatly increased rate of neurogenesis, and the new neurons functioned as well as new neurons generated in the brains of young mice.

#### From Animal Studies to Humans

Humans, too, benefit from aerobic exercise. Multiple studies have shown that physical and mental activity promotes brain health and results in increases in brain volume, even in

older adults (see Johansen-Berg & Duzel, 2016; Kleemayer & others, 2016.) Just six weeks of an exercise program increased hippocampal volume in young-to-middle-aged

MYTH SCIENCE

Is it true that the brain is essentially "hardwired" by adolescence?

adults, an increase that disappeared when exercise was discontinued (Thomas & others, 2016).

Neuroscientists have also amassed an impressive array of correlational evidence showing the human benefits from enriched, stimulating environments (Fischer, 2016). For example, several studies have compared symptoms of Alzheimer's disease in elderly individuals with different levels of education (Bennett & others, 2003). Autopsies showed that the more educated individuals had just as much damage to their brain cells as did the poorly educated individuals. However, because the better-educated people had more synaptic connections, their symptoms were much less severe than those experienced by the less-educated people (Melton, 2005).

The results of this study echo those from earlier research on intellectual enrichment: A mentally stimulating, intellectually challenging environment is associated with enhanced cognitive functioning. Just as physical activity strengthens the heart and muscles, mental activity strengthens the brain. Even in late adulthood, remaining mentally and physically active can help prevent or lessen mental decline (Greenwood & Parasuraman, 2012; Hertzog & others, 2009; Hillman & others, 2008).

#### **Pumping Neurons: Exercising Your Brain**

So, here's the critical question: Are you a mental athlete—or a cerebral couch potato? Whatever your age, there seems to be a simple prescription for keeping your brain fit. Along with regular physical activity, engaging in any kind of intellectually challenging pursuits will keep those dendrites



Keeping the Brain Young Musical training involves many different cognitive, sensory, and motor processes. Thus, it's not surprising that playing a musical instrument is associated with improved cognitive abilities as well as changes in brain structure and function (Zatorre, 2013). Could musical experience over the lifespan also be associated with better cognitive functioning in old age? Brenda Hanna-Pladdy and Alicia MacKay (2011) found that it was. In healthy adults aged 60 to 83, years of active musical participation was directly correlated with better cognitive functioning.

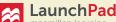
developing. Enrichment need not involve exotic or expensive pursuits. Novelty and complexity can be as close as your college campus or library. Here are just a few suggestions:

- Get regular aerobic exercise, even if it's no more than a brisk daily walk.
- Don't hide in your dorm room or apartment—seek out social interaction (except when it interferes with studying). Remember, the brain thrives on social stimulation.
- Learn to play a musical instrument or join a singing group.
- Try to learn a new language—a behavior that has been shown to increase brain volume (Mårtensson & others,
- 2012). The Internet offers a wealth of free language lessons if you can't take a class. For example, www .openculture.com/freelanguagelessons offers links to resources for learning 48 different languages, from Amharic and Arabic to Welsh and Yiddish.
- Read, and read widely. Buy magazines or check out library books in fields that are new to you.
- Try puzzles of all kinds—word, number, maze, or matching.

Better yet, take a few minutes and generate your own list of mind-expanding opportunities!

#### CHAPTER REVIEW

## Neuroscience and Behavior



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#### **KEY PEOPLE**

Pierre Paul Broca, p. 68

Roger Sperry, p. 70

Karl Wernicke, p. 68

system, p. 53

parasympathetic nervous

#### **KEY TERMS**

biological psychology, p. 40 neuroscience, p. 40 neuron, p. 40 sensory neuron, p. 40 motor neuron, p. 40 interneuron, p. 40 cell body, p. 41 dendrites, p. 42 axon, p. 42 glial cells, p. 42 myelin sheath, p. 42 action potential, p. 42 stimulus threshold, p. 43 resting potential, p. 43 synapse, p. 44 synaptic gap, p. 44 axon terminals, p. 45 synaptic vesicles, p. 45 neurotransmitters, p. 45 synaptic transmission, p. 45 reuptake, p. 45

acetylcholine, p. 46 dopamine, p. 47 serotonin, p. 47 norepinephrine, p. 47 glutamate, p. 47 GABA (gamma-aminobutyric acid), p. 47 endorphins, p. 47 agonist, p. 48 antagonist, p. 48 nervous system, p. 49 nerves, p. 49 central nervous system (CNS), p. 49 spinal reflexes, p. 49 peripheral nervous system, p. 51 somatic nervous system, p. 51 autonomic nervous system, p. 51 sympathetic nervous system, p. 52

endocrine system, p. 53 hormones, p. 53 pituitary gland, p. 54 oxytocin, p. 54 adrenal glands, p. 55 gonads, p. 55 positron emission tomography (PET) scan, p. 56 magnetic resonance imaging (MRI), p. 56 functional magnetic resonance imaging (fMRI), p. 56 diffusion MRI (dMRI), p. 56 functional plasticity, p. 58 structural plasticity, p. 58 neurogenesis, p. 58 brainstem, p. 59 hindbrain, p. 60 medulla, p. 60

cerebellum, p. 60 reticular formation, p. 60 midbrain, p. 60 substantia nigra, p. 60 forebrain, p. 61 cerebral cortex, p. 61 cerebral hemispheres, p. 61 corpus callosum, p. 61 temporal lobe, p. 62 occipital lobe, p. 62 parietal lobe, p. 62 frontal lobe, p. 63 limbic system, p. 63 hippocampus, p. 64 thalamus, p. 64 hypothalamus, p. 65 amygdala, p. 65 cortical localization, p. 66 aphasia, p. 68 lateralization of function, p. 69

pons, p. 60

### Neuroscience and Behavior

