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An Introduction to the Brain

**IN THE LINE OF FIRE**  It was November 9th, 2004, and U.S. Marine Brandon Burns was surrounded on all sides by gunfire. The enemy was everywhere, in the buildings, streets, and alleyways of Fallujah. “I was in the deepest part of the city [and] there was chaos,” remembers Brandon. At age 19, Brandon was on the front lines in the Iraq War, fighting in the battle of Fallujah.

“I was on top of the Humvee automatic grenade launcher shooting round after round,” Brandon remembers. Suddenly, there was darkness. A bullet from an enemy sniper impaled Brandon’s helmet, pierced his skull, and ricocheted through the back left side of his brain. Bleeding and unconscious, Brandon was rushed from Fallujah to Baghdad. Medics had to resuscitate him on five separate occasions during that ambulance ride. Brandon explains, “Five times I died.”

After arriving in Baghdad, Brandon was transferred to a hospital in Germany. Doctors concluded that some parts of his brain were no longer viable. “They removed part of my skull and dug out the injured part of my brain,” and now, Brandon says, “one third of my brain is gone.”
LEARNING OBJECTIVES

after reading and studying this chapter, you should be able to:

LO 1 Define neuroscience and explain its contributions to our understanding of behavior.
LO 2 Label the parts of a neuron and describe an action potential.
LO 3 Illustrate how neurons communicate with each other.
LO 4 Summarize various neurotransmitters and the roles they play in human behavior.
LO 5 Recognize the connections between the central and peripheral nervous systems.
LO 6 Describe the organization and function of the peripheral nervous system.
LO 7 Evaluate the role of the endocrine system and how it influences behavior.
LO 8 Describe the functions of the two brain hemispheres and how they communicate.
LO 9 Explain lateralization and how split-brain operations affect it.
LO 10 Identify areas in the brain responsible for language production and comprehension.
LO 11 Define neuroplasticity and recognize when it is evident in brains.
LO 12 Compare and contrast tools scientists use to study the brain.
LO 13 Identify the lobes of the cortex and explain their functions.
LO 14 Recognize the association areas and identify their functions.
LO 15 Distinguish the structures and functions of the limbic system.
LO 16 Distinguish the structures and functions of the brainstem and cerebellum.

Biology and Behavior: Studying the Last Frontier

Imagine that you lost a sizable chunk of your brain. How would it impact your life? Would you be the same person as before? Your brain houses your thoughts, emotions, and personality, and orchestrates your behavior. It files away all your memories and dark secrets, and is involved in your every move, from the beat of your heart to the blink of your eye.

However, the human brain is only one part of the most complex living entity known. The human nervous system is a communication network that conveys messages throughout your body, using electrical and chemical processes. The nervous system contains the brain, spinal cord, and other nerves and fibers, and includes some 100 billion (10^{11}) nerve cells. For a sense of what that number represents, consider that, in 2013, the population of the United States was approximately 314 million people; the number of nerve cells is approximately 333 times the number of people living in the United States. These cells are interlinked through some 100 quadrillion (10^{15}) connections (Tang, Nyengaard, De Groot, & Gundersen, 2001). This intricate, ever-adapting web of connections gives us the power to think and feel in ways that are different from—and vastly more complex than—the thinking and feeling capacities of other organisms.

LO 1 Define neuroscience and explain its contributions to our understanding of behavior.

Consider the many tasks your brain is juggling at this very moment. As you scan the words on this page, your brain helps control the tiny muscles moving your eyes back and forth as well as the larger muscles in your neck and torso that keep you sitting upright. Light-sensitive cells in the back of your eyes relay signals, using electricity and chemicals, to various brain regions that transform the black marks on
this page into words, sentences, and ideas for you to remember. And all the while, your brain is processing nonvisual sensory input such as sounds and smells, working with other nerve cells in your body to make sure your heart keeps pumping, your lungs keep breathing, and your glands and organs keep releasing hormones properly.

**NEUROSCIENCE** Brandon's injury resulted in a significant loss of his brain tissue. Remarkably, not only did he survive, but he can still talk about what occurred, think about the events, and feel emotions regarding what happened to him. How exactly does his brain orchestrate all these complex functions, especially after severe trauma? And how does a noninjured brain carry out these complicated processes? Scientists have developed a decent understanding of how individual brain cells communicate with each other, but they have yet to provide definitive answers to “big questions” involving the brain and other parts of the nervous system such as: How do we think? What is consciousness? Why must we sleep? This is why the brain may be regarded as the last frontier of medicine. **Neuroscience**, the study of the brain and nervous system, actually extends far beyond the borders of medicine and into disciplines as diverse as engineering, computer science, and our personal favorite—psychology. The subfield of psychology concerned with understanding how the brain and other biological systems influence human behavior is called **biological psychology**, which brings us to the goal of this chapter: to examine how biology influences our behavior.

**CONNECTIONS**

In Chapter 1, we presented the four major goals of psychology, which are to describe, explain, predict, and control behavior. These four goals guide psychologists' investigations of how biology influences behavior. As you read through this chapter, try to keep these goals in mind.

**Synonyms**

biological psychology, biopsychology, psychobiology, neuropsychology, physiological psychology, behavioral neuroscience
In the pages to come, we will discuss some exciting new research findings and technologies used in neuroscience, but first we must get down to the basics: an examination of the nervous system, and how its various components work together to create sensations, movement, thoughts, and emotions. Our chapter-long “learning tour” of the nervous system will begin in the microscopic world of nerve cells, or neurons. Neurons are specialized cells that communicate with each other through both electrical and chemical signals. They are the building blocks of the brain, spinal cord, and nerves.

**The Awakening**  Two weeks after the shooting, Brandon finally awoke from his coma. He could not move or feel the right side of his body, and he had lost the ability to use language. There were so many things he wanted to say to his family, but when he opened his mouth, the only sound that came out was “ugh.” Weeks went by before Brandon uttered his first word: “no.” That was all he could say for months, even when he was dying to say “yes.” During Brandon’s recovery, for example, his parents asked if he wanted some pizza, but all he could spit out was the word “no” (while nodding his head “yes”), even though he craved a hot, dripping slice like never before.

Apart from the paralysis to his right side and his difficulty with language, Brandon’s other abilities seemed fine. He could remember people, places, and objects, and he reported no trouble hearing, smelling, or tasting (The pizza tasted so good when he finally got it!). Although Brandon was not as outgoing and self-assured as before, he hadn’t changed much overall.

Why did the trauma to Brandon’s brain cause deficits in language, but not memory? Why was the right side of his body paralyzed, while the left side worked fine? Our discussion of the brain’s organization later in this chapter will clear up these mysteries for you. But first, let’s find out how neurons communicate.

### show what you know

1. Comprised of the brain, spinal cord, and other nerves, ________ is a communication network that conveys messages throughout the body, using electrical and chemical processes.
   a. consciousness  
   b. the human nervous system  
   c. a neuron  
   d. the skull

2. A researcher studying the impact of Brandon’s brain injury might work in the field of ____________, which includes the study of the brain and nervous system.

3. In the next section, you will learn much more about neurons, which are often referred to as the “building blocks” of the nervous system. What building blocks are you familiar with in other fields of study?

   ✔ CHECK YOUR ANSWERS IN APPENDIX C.

### Neurons and Neural Communication

In the next few pages, you will be introduced to some fairly tough biology concepts. Stay focused, do not give up, and reread the section if necessary. Communication among the cells in your nervous system underlies every behavior and mental process. In order to fully understand psychology, you need to understand the biology of the nervous system. So prepare to learn about something truly electrifying: the human neuron.
Cell body

Axon:
sends messages from cell body to terminal buds

Terminal buds:
transmit messages to other neurons

Nodes of Ranvier

Myelin sheath:
speeds communication

Dendrites:
receive messages

Just the Basics

**LO 2** Label the parts of a neuron and describe an action potential.

### THE STRUCTURE OF A TYPICAL NEURON
A typical neuron has three basic parts: a cell body, dendrites, and an axon (*FIGURE 2.1*). The **cell body** of a neuron contains the standard components found in most human cells: a nucleus containing DNA, protein-producing mechanisms, and other structures that nourish the cell. Extending from the cell body are many **dendrites** (den-drīts), which are tiny, branchlike fibers. Generally projecting in the opposite direction from the dendrites is a single **axon**, which is a long, skinny, tubelike extension of the cell body, with branches ending in **terminal buds**. Many axons are surrounded by a **myelin sheath** (mī-ə-lən shēth), a fatty substance that provides insulation. The axon is not entirely enclosed, but rather, covered in segments of myelin. The gaps between segments of the myelin are called **nodes of Ranvier**. The **synapse** (si-naps) is the tiny gap between a terminal bud of one axon and a neighboring dendrite of the next neuron (see photo on page 57). Just for perspective, the synaptic gap is only about 0.000127 millimeters ($1.27 \times 10^{-4}$) wide, whereas a single sheet of printer paper is 0.1 millimeter thick.

### HOLDING IT TOGETHER: GLIAL CELLS
The function of neurons is to transmit information up and down the body all day and night, and neurons need a little support and nurturing to get this tough job done. This is where the **glial cells** (glē-əl) come into play. In the human brain, glial cells outnumber neurons by approximately 50 to 1 (Yuhas & Jabr, 2012). They hold neurons together (*glia* means “glue” in Greek) and maintain the structure of the nervous system. For many years, scientists believed that glial cells simply kept things together, but we now know they do much more (Ndubaku & de Bellard, 2008).

Glial cells come to the rescue if the brain is injured. When Brandon was shot in the head, glial cells called **microglia** began multiplying and secreting substances to defend his brain from infection and inflammation (d’Avila et al., 2012; Streit, 2000).
Another class of glial cells called astrocytes began restoring the barrier between his brain and blood (Gruber, 2009). Astrocytes have been found to support communication between neurons as well (Araque & Navarrete, 2010). Another type of glial cells, Schwann cells, make the myelin that envelops axons.

Communication Within and Between

Neurons have properties that allow them to communicate with other cells. But what information do they convey? In essence, the message is simple: “I have been activated.” Neurons are activated in response to sensations, thoughts, and other neurons, and this forms the basis for all that we think, feel, and do.

**Processes Inside the Neuron**

A neuron is surrounded by and contains electrically charged solutions (Infographic 2.1). If the total charge in each of these solutions is different, a voltage will be generated between the outside and the inside of the cell. This voltage is determined by the electrical characteristics of particles called ions. (Some ions are negatively charged; others are positively charged.) The difference in the charges inside and outside of the neuron determines its polarity, the degree to which it is positive or negative overall. Two processes direct the flow of positive and negative ions into or out of the cell. Diffusion is the natural tendency of the ions to spread out or disperse, and electrostatic pressure causes similarly charged ions to spread apart and oppositely charged ions to move toward each other (like the behavior of magnets). The concentrations, inside and outside of the cell, of positively charged ions (sodium and potassium) and negatively charged ions (protein) determine the activity in most neurons. A neuron is encased in a membrane that is selectively permeable, allowing only some of the ions to pass in and out of its channels. The membrane is impermeable to positive sodium ions and negative protein ions (it does not allow these ions to enter or exit). Positive sodium ions move toward the membrane from the outside, and negative protein ions move toward the membrane from the inside; each moves closer to its side of the membrane wall (because the opposite charges are attracted to each other).

Inside the neuron, the concentration of potassium ions is about 30 times greater than that outside the membrane. Also inside the cell are negatively charged protein ions, which do not exist outside the cell. These protein ions are attracted to the excess positive charge outside and move toward the membrane, but they are too big to go through. Because the protein ions can’t get out, the inside of the neuron is negatively charged when the neuron is not active. The concentration of sodium ions inside the cell is much less than its concentration on the outside of the cell. As a result, the sodium ions on the outside are attracted to the cell wall. This is due not only to the force of diffusion, but also to the force of attraction that occurs between oppositely charged ions. An electrical potential is created by the differences in charge between the outside and the inside of the neuron, which is its resting potential.

**Resting Potential**

The resting potential represents the electrical potential of a cell “at rest,” the condition of a cell when it is not activated. The solutions on either side of the membrane wall come into equilibrium with a slightly more negative charge inside. In the resting state, the voltage inside the cell is about −70 millivolts (mV) compared to the voltage on the outside. (Think of a resting neuron like a battery, which holds a charge. For comparison, one double A battery has a 1,500 mV charge.) This resting potential is only one part of the story. Let’s look at what happens when a neuron stops “resting” and goes into “action.”

**Action Potential**

Although the positive sodium ions are being pulled toward the inside of the cell, they cannot move into the cell until the neuron is stimulated by neighboring cells. When this happens, a signal instructs the channels
Communication Within Neurons

Neural communication involves different processes within and between neurons. In this infographic, we follow the electrical action that conveys messages within the neuron, from one end to the other.

1. **THE NEURON AT REST**

   Before communication begins, the neuron is “at rest.” Closed channels in the cell membrane prevent some positive ions from entering the cell, and the inside of the cell is slightly more negative than the charge outside. At ~70 mV, the cell is at its resting potential.

2. **THE ACTION POTENTIAL**

   This graph shows the characteristic electrical trace of the action potential. When the neuron is stimulated, positive ions enter the cell, making the axon less negative (A). When the charge reaches threshold (~55 mV), an action potential is triggered. Positive ions flood the cell, quickly reversing the charge from negative to positive (B). Afterward, the cell is restored to resting potential (C).

3. **ACTION POTENTIAL TRAVELS LENGTH OF AXON**

   The action potential occurring in one axon segment causes a voltage change in the next, initiating an entirely new action potential there. This sequential action travels along the axon like a wave, carrying the message from axon hillock to terminal buds.
in the cell membrane to open up. The channels open, freeing the positive sodium ions to move into the cell, through the dendrites, to the cell body, and to finally reach the beginning of the axon, known as the axon hillock. The positive sodium ions cannot leave the cell, because the channels in the dendrites closed immediately after they entered.

The influx of the positive sodium ions at the axon hillock raises the internal cell voltage of the first segment of the axon from the resting voltage of $-70 \text{ mV}$ to the threshold potential of $-55 \text{ mV}$ relative to the outside. This change in voltage causes the sodium gates to open, and the positive sodium ions flood into the cell. The voltage inside that section of the axon rises rapidly, increasing from $-55 \text{ mV}$ to $+30 \text{ mV}$, after which the sodium gates immediately close. This produces a spike in the value of the voltage within the cell, as the charge inside the cell becomes more positive than that outside of the cell. This is the action potential, or the spike in electrical energy that passes through the axon of a neuron.

The potassium gates open, and the positive potassium ions, now repelled by the much more positively charged cell interior, flow out of the cell as the similarly charged ions repel each other. This segment of the neuron returns to the resting potential. However, because the proportion of sodium and potassium ions inside and outside the cell is not the same as before (the ions are no longer at equilibrium), a sodium/potassium pump within the cell membrane brings them back to their original values by pumping the excess positive sodium ions back outside the cell and the positive potassium ions back in. In this way, the solutions inside and outside this segment of the axon return to equilibrium.

**MOVING DOWN THE AXON** The firing of the first segment of the axon produces excess positive sodium ions on the inside of the cell, and these positive sodium ions diffuse to the next segment within the axon. This causes the voltage of the second segment of the axon to reach the threshold potential ($-55 \text{ mV}$), opening its sodium gates and causing a spike of voltage there ($+30 \text{ mV}$). Meanwhile, the first segment of the axon returns to its resting potential so that the electrical spike cannot go in that direction. This process repeats through each segment of the axon, like a row of dominos tumbling down. Every time a segment of the axon fires, the positive sodium ions flood in from the outside of the cell, while the prior segment returns to its resting potential, all along the length of the axon to its end. Each action potential takes about 1 millisecond to complete, and a typical neuron can fire several hundred times per second.

**EXCITATORY AND INHIBITORY SIGNALS** How do neighboring cells initially signal for the channels to open up to let the positive sodium ions move into the dendrites of a neuron? The message to fire begins at the dendrites. Chemical messages from surrounding neurons are sent to the cell body. If enough sending neurons signal the receiving neuron to pass along the message, their combined signal becomes excitatory and the neuron will fire. However, not all neighboring neurons send an excitatory signal. Some will send an inhibitory signal, instructing the neuron not to fire. For an excitatory signal to occur, there have to be more excitatory than inhibitory signals, and the difference between the two has to meet the threshold potential of $-55 \text{ mV}$. If “enough” positively charged ions enter the cell, the potential of the neuron increases and reaches the threshold, or trigger point, and the cell “fires.”

**ALL-OR-NONE** Action potentials are all-or-none: They either happen or they don’t. Their strength remains the same no matter what occurs. A neuron conveys the strength of a stimulus by firing more often and delivering its message to more
neurons. This is how we sense the difference between a quiet sound and a loud bang, for example. When we hear a loud bang: (1) The number of sensory neurons being fired is greater than the number that would have been fired for a quiet sound, and (2) each individual neuron fires more often than it would for a quiet sound. Thus, there is no such thing as a partial action potential, or a strong or weak action potential.

**MYELIN SHEATH** The firing of a neuron is facilitated by the myelin sheath, which insulates and protects the tiny spikes in electricity happening inside the axon. Because myelin is such a good insulator, it does not allow the exchange of ion fluid between the inside and the outside of the cell membrane. However, the axon is not covered with myelin at the nodes of Ranvier (you can see this in the photograph to the right). The exchange of ion fluid can only happen at the nodes of Ranvier, where there is no myelin. The action potential thus appears to “jump” from node to node, as opposed to traversing the entire axon in one continuous movement, speeding the transmission of the signal. The speed of the action potential in an unmyelinated axon is approximately 1.1 to 4.5 miles per hour (mph), and a myelinated axon has transmission speeds of approximately 157 to 268 mph (Susuki, 2010). Unmyelinated axons, or those damaged from multiple sclerosis or other diseases, have slower transmission speeds, because the signal must make its way down the entire length of the axon. The damaged myelination caused by multiple sclerosis can lead to many symptoms, including fatigue, trouble with vision, and cognitive disabilities (Su, Banker, Bourdette, & Forte, 2009).

**LO 3** Illustrate how neurons communicate with each other.

**COMMUNICATION BETWEEN** Neurons communicate with each other via chemicals called neurotransmitters. (Infographic 2.2 on page 59 demonstrates communication of neurotransmitters in detail.) An action potential moves down the axon, eventually reaching the branches of the terminal buds. The signal to release neurotransmitters is the voltage change from the action potential, which results in vesicles (small fluid-filled sacs) that contain neurotransmitters attaching to the membrane on the terminal bud. This allows the neurotransmitter to be released into the synaptic gap. The majority of these neurotransmitters drift across the synaptic gap and come into contact with receptor sites of the receiving neuron’s dendrites. Because there are a variety of neurotransmitters, a variety of receptor sites also exist. Just as it takes the right key to unlock a door, it is necessary for the right neurotransmitter to fit a corresponding receptor site to convey the message.

When the neurotransmitters latch onto the receptors of the dendrites of the receiving neuron, tiny gates in the receiving cell’s membrane fly open, ushering positively charged particles into the cell and thus restarting the cycle of the action potential (if the threshold is met). Keep in mind that the firing of one neuron contributes to the potential for neighboring neurons to fire as a result of its chemical message.

**REUPTAKE** When neurotransmitters are released into the synapse, many of them bind to receptors. Neurotransmitters that do not connect with receptor sites can be reabsorbed by the sending terminal bud in a process known as reuptake. Those that are not reabsorbed drift out of the synaptic gap, through diffusion. This is how the synaptic gap is cleared of neurotransmitters, in preparation for the next release of a new batch of chemical messengers.

**The Synapse**

The axon terminal of a sending neuron interacts with the dendrites of a receiving neuron by releasing chemical messengers (neurotransmitters) into the synapse. Once the neurotransmitters migrate across the gap and latch onto the dendrite’s receptor sites, the message has been conveyed. Jean-Claude Revy, ISM/Phototake
Major League Players: Neurotransmitters

As we have already mentioned, there are different types of neurotransmitters. Researchers have identified approximately 100 of them, with many more yet to be discovered. We already know that neurotransmitters secreted by one neuron under certain conditions can cause neighboring neurons to fire. Now let’s turn to how different neurotransmitters influence us in a variety of ways. The secretion of neurotransmitters can lead to a neuron firing, which can effect the regulation of mood, appetite, muscles, organs, arousal, and a variety of other outcomes. By examining what happens when neurotransmitters are not at their ideal levels, we can understand their effect at normal levels. We will describe only a handful of neurotransmitters, starting with the first neurotransmitter discovered, **acetylcholine**.

**Acetylcholine**

Acetylcholine is a neurotransmitter that relays messages from motor neurons (see page 62) to muscles, enabling movement. Any time you move some part of your body, whether dancing your fingers across a keypad or bouncing your head to one of your favorite songs, you have, in part, acetylcholine to thank for this. Too much acetylcholine leads to muscle spasms; too little causes paralysis. Acetylcholine is also known to be involved in memory. In particular, low levels of acetylcholine in the brain have been linked to Alzheimer’s disease (Kihara & Shimohama, 2004), which can lead to problems with memory, language, and thinking.

**Glutamate and GABA**

Much of the transmission of information involves two neurotransmitters: **glutamate** and **GABA** (short for gamma-aminobutyric acid). Glutamate is an excitatory neurotransmitter, so its main job is to kick neurons into action (make them fire), whereas GABA is inhibitory (it puts the brakes on firing). Glutamate plays a central role in learning and memory (Riedel, Platt, & Micheau, 2003); its overactivity may be associated with strokes (Castellanos et al., 2008); and its underactivity is theorized to be involved in some of the symptoms of schizophrenia (Gordon, 2010).

**Norepinephrine**

Norepinephrine has a variety of effects in the nervous system, but one of its most important functions is to help prepare the body for stressful situations. Think about how Brandon was surrounded by gunfire on every side while serving in Fallujah. Norepinephrine was working to enable Brandon’s nervous system to initiate action. In the brain, norepinephrine is involved in regulating arousal and sleep (Jones, 2003).

**Serotonin**

Serotonin is a neurotransmitter that plays a key role in controlling appetite, aggression, and mood, and also regulates sleep and breathing. Abnormally low serotonin activity is thought to drive depression. Many of the popular antidepressants called serotonin reuptake inhibitors (SSRIs), including Prozac and Zoloft, work to boost the effects of this “feel good” neurotransmitter (Chapter 14). Normally, neurotransmitters that do not connect with receptor sites can be reabsorbed by the sending terminal bud in the reuptake process. SSRIs work to prevent the reabsorption of serotonin back into the sending neuron. The longer the neurotransmitters (in this case, serotonin) are available in the gap, the more time they have to attach to a receptor.

**Dopamine**

The neurotransmitter **dopamine** is known to play a role in problems with drug use. Repeated use of drugs overstimulates and damages the functioning of the neurons in the brain’s reward circuit, theoretically making it more difficult to enjoy non-drug-related activities that would otherwise be rewarding. Dopamine also plays a key role in learning through reinforcement, attention, and regulating body movements. Deterioration of neurons that produce dopamine is linked to Parkinson’s disease.

Synonyms:

norepinephrine noradrenaline
Communication Between Neurons

Messages travel within a neuron using electrical currents. But communication between neurons depends on the movement of chemicals—neurotransmitters. Though they all work in the same way, there are many different types of neurotransmitters, each linked to unique effects on behavior. However, drugs and other substances, known as agonists and antagonists, can alter this process of communication between neurons by boosting or blocking normal neurotransmitter activity.

**NORMAL NEUROTRANSMISSION**

1. Action potential reaches terminal buds.
2. Action potential triggers vesicles to release neurotransmitters into synaptic gap.
3. Neurotransmitters bind to their matching receptor sites on receiving neuron’s dendrite, causing positively charged particles to enter cell. Action potential is created.
4. After binding, neurotransmitters are reabsorbed or diffuse out of synaptic gap.

**AGONIST**

Agonists boost normal neurotransmitter activity. Nicotine mimics acetylcholine and causes this same activation. More receptors are activated, and more messages are sent.

**ANTAGONIST**

Antagonists block normal neurotransmitter activity. Curare, the paralyzing poison used on blowgun darts, acts as an acetylcholine antagonist. It blocks acetylcholine receptors, preventing the neurotransmitter from activating them, so fewer messages are sent.

**INFOGRAPHIC 2.2**

Drugs and other substances can alter normal neurotransmission. Drugs and other substances can alter normal neurotransmission.
disease, an incurable disorder that causes trembling of the hands, arms, legs, and face, and difficulty with movement, coordination, and balance.

**ENDORPHINS** Endorphins are a group of naturally produced opioids (Chapter 4) that regulate the secretion of other neurotransmitters. The term endorphin is derived from the words “endogenous,” meaning it is created within, and “morphine.” With brisk exercise the production of endorphins is increased. This reduces the experience of pain and elevates mood. Endorphins are released in response to pain, thereby blocking pain receptor sites to prevent the pain message from being sent.

**AGONISTS AND ANTAGONISTS** Drugs and other substances influence behavior by interfering at the level of the synapse (Chapters 4 and 14). Certain substances can be used to act like neurotransmitters and others can be used to block normal neurotransmitter activity. Agonists are substances that increase the normal activity of the neurotransmitter (whether it normally sends an excitatory or inhibitory signal) and antagonists reduce the activity or block the release of the neurotransmitter (Infographic 2.2). For example, some substances, such as nicotine and muscarine (found in poisonous mushrooms), increase the secretion of acetylcholine, causing sweating, pupil constriction, nausea, and respiratory distress. These substances increase the normal activity of acetylcholine; thus, they are agonists. On the other hand, the popular anti-wrinkle treatment Botox is an antagonist because it blocks acetylcholine release, paralyzing the facial muscles so they can no longer wrinkle the overlying skin (Kim, Oh, & Paik, 2006).

**CAFFEINE AND NEUROTRANSMITTERS** Did you jump-start your day with coffee? Or perhaps you sipped a caffe latte, tea, or soda this morning? Caffeine works its magic, perking you up at the crack of dawn or jolting you from that mid-afternoon daze by manipulating the nervous system. One way caffeine works is by blocking the receptors for a neurotransmitter called adenosine. (Thus, caffeine’s primary role is as an antagonist.) When adenosine latches onto receptors, it slows down their activity (making them less likely to fire), and this tends to make you feel drowsy. Caffeine resembles adenosine enough that it can dock onto the same receptors (“posing” as adenosine), which makes fewer receptors available for adenosine. With caffeine occupying its receptors, adenosine can no longer exert its calming effect on the brain (Julien, Advokat, & Comaty, 2011). The result: More neurons fire and you feel full of energy. But note that continued use of caffeine can lead to anxiety, restlessness, and headaches if you reduce your consumption (Ozsungur, Brenner, & El-Sohemy, 2009; Chapter 4).

The effects of caffeine do not stop at the brain. As anyone who has enjoyed a double latte can testify, caffeine kicks the body into high gear by increasing activity in the branch of the nervous system serving the body (Corti et al., 2002). In the next section, we will examine the nervous system running through your arms, legs, fingers, toes—and everywhere else.

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**show what you know**

1. Many axons are surrounded by a ___________, which is a fatty substance that insulates the axon.
   - a. glial cells
   - b. dendrites
   - c. action potentials
   - d. sodium ions

2. When Brandon was injured, ___________ played an important role in his recovery by defending against infection and inflammation of the brain, as well as holding neurons together and maintaining the structure of the nervous system.
   - a. glial cells
   - b. dendrites
   - c. action potentials
   - d. sodium ions

3. ___________ are released into the ___________ when an action potential reaches the branches of the terminal buds.
   - a. Sodium ions; synaptic gap
   - b. Neurotransmitters; synaptic gap
   - c. Potassium ions; cell membrane
   - d. Neurotransmitters; sodium gates

4. Neural communication is very complicated. Draw a diagram depicting the process of neural communication, then explain it to yourself while looking at what you have drawn.

CHECK YOUR ANSWERS IN APPENDIX C.
The Supporting Systems

Like any complex system, the brain needs a supporting infrastructure to carry out its directives and relay essential information from the outside world. Running up and down your spine and branching throughout your body are neurons that provide the connections between brain and body. The **central nervous system (CNS)** is made up of the brain and spinal cord. The **peripheral nervous system (PNS)** includes all the neurons that are not in the central nervous system and is divided into two branches: the **somatic nervous system** and the **autonomic nervous system**. The peripheral nervous system provides the communication pathway between the central nervous system and the rest of the body. Thanks to your **spinal cord** and peripheral nervous system, you can flex your facial muscles into a smirk, feel a soft breeze, and flip through the pages of this book. **Figure 2.2** provides an overview of the entire nervous system.

The Spinal Cord and Simple Reflexes

Brandon suffered a devastating brain injury that temporarily immobilized half of his body. The paralysis would have affected his entire body if the bullet had pierced his **spinal cord**, the bundle of neurons that allows communication between the brain and the peripheral nervous system, connecting with the body’s muscles, glands, and organs.

**central nervous system (CNS)** A major component of the human nervous system that includes the brain and spinal cord.

**peripheral nervous system (PNS)** The part of the nervous system that connects the central nervous system to the rest of the body.

**spinal cord** The bundle of neurons that allows communication between the brain and the peripheral nervous system, connecting with the body’s muscles, glands, and organs.
Sensory neurons carry information from the environment to interneurons in the spinal cord. The brain then receives the message. Interneurons in the spinal cord activate motor neurons, which exit the spinal cord and excite muscles, initiating motion that pulls the hand away.

Heat activates sensory neurons. The spinal cord has two major responsibilities: (1) receiving information from the body and sending it to the brain; and (2) taking information from the brain and sending it throughout the body. If this pathway is blocked, commands from the brain cannot reach the muscles responsible for making you walk, dance, and wash dishes, and sensory information from the skin and elsewhere has no way of communicating crucial information to the brain, like “Ooh, that burner is hot,” or “Oh, this massage feels good.”

LO 5 Recognize the connections between the central and peripheral nervous systems.

How do the brain and spinal cord, which make up the central nervous system, communicate with the rest of the body through the peripheral nervous system? In essence, there are three types of neurons participating in this back-and-forth communication. Sensory neurons receive information about the environment from the sensory systems and convey this information to the brain for processing. Motor neurons carry information from the central nervous system to produce movement in various parts of the body, such as muscles and glands. Motor neurons provide a mechanism for performing activities determined or commanded by the spinal cord and brain. Interneurons, which reside exclusively in the brain and spinal cord, act as bridges connecting sensory and motor neurons. By assembling and processing sensory input from multiple neurons, interneurons facilitate the nervous system’s most complex operations, from solving tough problems to forming life-long memories. They are also involved in a relatively simple operation, the reflex.

THE REFLEX ARC Some activities don’t involve the interneurons in the brain (at least at the start). Consider the withdrawal reaction to painful stimuli (Figure 2.3). If you accidentally touch a hot pan, you activate a pathway of communication that goes from your sensory neurons through interneurons in your spinal cord and right back out through motor neurons, without initially involving the brain. In the following example, you can see how the pain reflex includes a number of steps: (1) Your hand touches the hot pan, activating sensory receptors, which cause the sensory neurons to carry a signal from your hand to the spinal cord. (2) In the spinal cord, the signal from
the sensory neurons is received by interneurons. (3) The interneurons quickly activate motor neurons and instruct them to respond. (4) The motor neurons then instruct your muscles to contract, causing your hand to withdraw quickly. A sensory neuron has a rendezvous with an interneuron, which then commands a motor neuron in the spinal cord to react—no brain required. We refer to this process, in which a stimulus causes an involuntary response, as a reflex arc.

Eventually, your brain does process the event; otherwise, you would have no clue it ever happened. However, you become consciously aware of your reaction after it has occurred (my hand just pulled back; that pan was hot!). Although many sensory and motor neurons are involved in this reaction, it happens very quickly, hopefully in time to reduce damage or injury in cases when the reflex arc involves pain. Think about touching a flame or something sharp. You want to be able to respond, without waiting for information to get to the brain or for the brain to send a message to the motor neurons instructing the muscles to react.

Test your knowledge of the reflex arc using Brandon as an example. As you recall, Brandon’s brain injury led to paralysis on the right side of his body. What do you think would happen if a doctor tapped on his right knee—would he experience a reflex?

What Lies Beyond: The Peripheral Nervous System

It is now time to look more specifically at how the peripheral nervous system is organized and how it allows for communication between the central nervous system and the rest of the body.

LO 6 Describe the organization and function of the peripheral nervous system.

The peripheral nervous system includes all the neurons that are not in the central nervous system. These neurons are bundled together and act like electrical cables carrying signals from place to place. The collections of neurons are called nerves. Nerves are the primary mechanism for communication of information by the peripheral nervous system, supplying the central nervous system with information about the body’s environment—both the exterior (for example, sights, sounds, and tastes) and the interior (for example, heart rate, blood pressure, and temperature). The central nervous system, in turn, makes sense of all this information and then responds by dispatching orders to the muscles, glands, and other tissues through the nerves of the peripheral nervous system. Information flows from the peripheral nervous system (via sensory nerves) into the central nervous system, and then new information is sent back out through the peripheral nervous system (via motor nerves). The PNS has two functional branches: the somatic nervous system and the autonomic nervous system.

THE SOMATIC NERVOUS SYSTEM

The somatic nervous system includes sensory nerves and motor nerves. (Somatic means “related to the body.”) The sensory nerves gather information from sensory receptors, sending it to the central nervous system. The motor nerves receive information from the central nervous system and send this information to the muscles, instructing them to initiate voluntary muscle activity (which results in movement). The somatic nervous system controls the skeletal muscles that give rise to voluntary movements, like using your arms and legs. It also receives sensory information from the skin and other tissues, providing the brain with constant feedback about temperature, pressure, pain, and other stimuli.

The supporting systems
The autonomic nervous system has two divisions, the sympathetic and parasympathetic nervous systems. In a stressful situation, the sympathetic nervous system initiates the "fight-or-flight" response. The parasympathetic nervous system calms the body when the stressful situation has passed.

The sympathetic nervous system initiates what is often referred to as the "fight-or-flight" response, which is how the body prepares to deal with a crisis. When faced with a stressful situation, the sympathetic nervous system prepares the body for action, by increasing heart rate and respiration, slowing digestion and other vital bodily functions. Earlier, we mentioned that caffeine makes you feel physically energized. This is because it activates the fight-or-flight system (Corti et al., 2002).

The parasympathetic nervous system, on the other hand, oversees the "rest-and-digest" process, which basically works to bring the body back to a noncrisis mode. The parasympathetic nervous system takes over when the crisis has ended by reversing the activity of these processes (for example, lowering heart rate and respiration, increasing digestion and other maintenance activities). The two systems work together,...
balancing the activities of these primarily involuntary processes. Sometimes they even work toward a common goal. For example, parasympathetic stimulation increases blood flow to the penis to create an erection, but it is the sympathetic system that causes ejaculation (Goldstein, 2000). Working together, these two systems allow us to fight if we need to, flee when necessary, and calm down when danger has passed.

The fight-or-flight response would certainly come in handy if fleeing predators was part of your day-to-day life (as it may have been for our primitive ancestors), but you probably are not chased by wild animals very often. You may, however, notice your heart racing and your breathing rate increase during other types of anxiety-producing situations—going on a first date, taking a test, or speaking in front of an audience. You have your sympathetic nervous system to thank for these effects (Chapter 12).

**TEND AND BEFRIEND** Fighting and running like mad are not the only ways we respond to stress. Many women have an inclination to “tend and befriend” in response to a threat, or direct energy toward nurturing offspring and forging social bonds (Taylor et al., 2000). The tend-and-befriend response is also evident in men, especially in high-pressure situations. In one small study, men placed in a stressful situation were more likely to show increased trust of others; those others, in turn, were more likely to feel that these men were trustworthy. The trusting men were also more willing to share resources than were those who were not subjected to stress (von Dawans, Fischbacher, Kirschbaum, Fehr, & Heinrichs, 2012). Brandon likely experienced this increase of trust while serving in Iraq with his fellow soldiers.

Women are generally more likely to “tend and befriend,” but are there other gender disparities related to the nervous system? Many of us believe males and females are “hardwired” differently or socially conditioned to develop certain tendencies. Let’s take a look at some of the evidence.

**THINK again**

It is a well-known fact that the numbers of women employed in certain fields, such as science, math, engineering, and technology, continue to be low (Blickenstaff, 2005; **Figure 2.5** on page 66). Does society encourage boys to pursue science and technology interests while pushing girls into the social sciences and humanities? There is no denying that social and cultural factors influence female achievement in math and science. Studies suggest, for example, that gender stereotypes, which are commonly held beliefs about the nature of men and women, can influence performance in math and science. When exposed to statements such as “women possess poor math ability” just before taking a test, some women will actually perform at a lower level (Josephs, Newman, Brown, & Beer, 2003; Chapter 15).

But there might also be something biological at play. Research shows that male and female brains are far more alike than they are different, but some intriguing differences exist, both in terms of anatomy and function. An fMRI study by Goldstein and colleagues (2001) found that certain regions of the limbic cortex and the frontal lobes were larger in women, while areas of the parietal cortex, the amygdala, and hypothalamus were larger in men. How these differences translate into behavior is not totally clear, but we know, for example, these regions are involved in spatial reasoning, memory, and emotion (Cahill, 2012). It appears that both **nature and nurture** are responsible for the gender imbalance in math and the sciences. While women are statistically underrepresented in math and science, their presence in these fields has grown dramatically over the past 50 years, a clear sign of positive change. For more on gender differences, see Chapter 10.  

**CONNECTIONS**

In Chapter 1, we presented the nature-nurture issue and its importance in the field of psychology. Here, we can see this issue in relation to the gender imbalance in math and science. Researchers continue to evaluate the relative influence of nature and nurture in the development of academic and career goals.
The Endocrine System and Its Slowpoke Messengers

Imagine that you are 19-year-old Brandon Burns fighting in the battle of Fallujah. How would it feel to be immersed in one of the bloodiest battles of the Iraq War? The sound of gunfire rings through the air. Bullets zip past your helmet. People are dying around you. Your life could end at any moment. Unless you have been in a similar situation, it would be difficult to fathom how it feels. But one thing seems certain: You would feel extremely stressed.

When faced with imminent danger, the sympathetic nervous system responds almost instantaneously. Activity in the brain triggers the release of neurotransmitters that cause increases in heart rate, breathing rate, and metabolism—changes that will come in handy if you need to defend yourself or flee the situation. But the nervous system does not act alone. The endocrine system is also hard at work, releasing stress hormones, such as cortisol, which prompt similar physiological changes.

The endocrine system (en-da-krən) is a communication system that uses glands, rather than neurons, to convey messages (FIGURE 2.6). These messages are delivered by hormones, chemicals released into the bloodstream that can cause aggression and mood swings, as well as influence growth, alertness, cognition, and appetite. Like neurotransmitters, hormones are chemical messengers that can influence many processes and behaviors. In fact, some chemicals, such as norepinephrine, can act as both neurotransmitters and hormones depending on where they are released. Neurotransmitters are unloaded into the synapse, whereas hormones are secreted into the bloodstream by glands stationed around the body. These glands collectively belong to the endocrine system.

Following an action potential, neurotransmitters are released into the synaptic gap and their effects can be almost instant. Hormones usually make long voyages to faraway targets by way of the bloodstream, creating a relatively delayed but usually longer-lasting impact. A neural impulse can travel over 250 mph, which means signals arrive at their destinations within fractions of a second, much faster than messages sent via hormones, which take minutes (if not longer) to arrive where they are going. Although not as fast as neurotransmitters, the messages sent via hormones are more widely spread because they are disseminated through the bloodstream.

If the endocrine system had a chief executive officer, it would be the pituitary gland, a gland about the size of a pencil eraser located in the center of the brain, just
under the hypothalamus (a structure of the brain we will return to later). Controlled by the hypothalamus, the pituitary gland influences all the other glands, as well as promoting growth through the secretion of hormones. The thyroid gland regulates the rate of metabolism by secreting thyroxin, and the adrenal glands (a-drē-nal) are involved in responses to stress as well as the regulation of salt balance.

Other endocrine glands and organs directed by the pituitary include the pineal gland, which secretes melatonin (controls sleep-wake cycles); the pancreas, which secretes insulin (regulates blood sugar); and the ovaries and testes, whose secretion of sex hormones may be one reason that men and women are different. Together, these glands and organs influence a variety of processes and behaviors: (1) growth and sex characteristics, (2) regulation of some of the basic body processes, and (3) responses to emergencies. Just as our behaviors are influenced by neurotransmitters we can’t see and action potentials we can’t feel, the hormones secreted by the endocrine system are also hard at work behind the scenes.

Now that we have discovered how information moves through the body via electrical and chemical signals, let’s turn our attention toward the part of the nervous system that integrates this activity, creating a unified and meaningful experience. Let’s explore the brain.

**show what you know**

1. __________ carry information from the central nervous system to activate various parts of the body, such as muscles and glands.
   a. Interneurons
e. Sensory neurons
   b. Dendrites
   d. Motor neurons

2. When a stimulus causes an involuntary response, we refer to it as a reflex arc; the simple communication pathway goes from a sensory neuron through interneurons in the __________ and back out through motor neurons.
   a. Brain
   b. Spinal cord
e. Axon hillock
   d. Nodes of Ranvier

3. The __________ gland, located in the center of the brain, just under the hypothalamus, is in charge of the endocrine system.

4. When confronted with a potentially threatening situation, the sympathetic nervous system sometimes prepares for “fight or flight” and/or “tend and befriend.” How would you explain these two very different responses using the evolutionary perspective?
As Brandon Burns began his long journey to recovery, a 17-year-old girl in Bristol, Pennsylvania, was enjoying a particularly successful senior year of high school. Christina Santhouse was an honor roll student for the fourth year in a row, and she had been named captain of the varsity bowling team. But these accomplishments did not come so easily. It took Christina twice as much time as classmates to do homework assignments and projects because her brain needed extra time to process information. She had to invent a new bowling technique to use in games because the left side of her body was partially paralyzed, and she was constantly aware of being “different” from the other kids at school. Christina wasn’t simply different from her classmates, however. She was extraordinary because she managed to do everything her classmates did (and more) with nearly half of her brain missing.

Christina's remarkable story began when she was 7 years old. She was a vibrant, healthy child who loved soccer and playing outside with her friends. Barring an occasional ear infection, she basically never got sick—that is, until the day she suffered her first seizure. It was the summer of 1995 and Christina's family was vacationing on the Jersey Shore. While playing in a swimming pool with her cousins, Christina hopped onto the deck to chase a ball. At that moment, she noticed that something wasn't quite right. She looked down and saw her left ankle twitching uncontrollably. Her life was about to change dramatically.

Christina continued to experience tremors in her ankle. As the days and weeks wore on, those tremors moved up her left side and eventually spread throughout her body. In time, she was having seizures every 3 to 5 minutes. Christina was evaluated by various doctors, who suspected she had Rasmussen's encephalitis, a rare disease that causes severe swelling in one side of the brain, impairing movement and thinking and causing seizures that come as often as every few minutes (National Institute of Neurological Disorders and Stroke, 2011). As one doctor put it, “The disease eats away at your brain like a Pac-Man.”

Christina and her mother decided to seek treatment at The Johns Hopkins Hospital in Baltimore, the premiere center for children with seizure disorders. They met with Dr. John Freeman, a pediatric neurologist and an expert in hemispherectomy, a surgery to remove nearly half of the brain. A rare and last-resort operation, the hemispherectomy is only performed on patients suffering from severe seizures that can't be controlled in other ways. After examining Christina, Dr. Freeman made the same diagnosis of her condition—Rasmussen's encephalitis—and indicated that the seizures would get worse, and they would get worse fast. He recommended a hemispherectomy and told Christina (and her mother) to let him know when she had reached her limit with the seizures. Then they would go ahead with the operation.

Why did Dr. Freeman recommend this drastic surgery to remove nearly half of Christina's brain? And what side of the brain did he suggest removing? Before addressing these important questions, we need to develop a general sense of the brain's geography.

**The Hemispheres**

**THE GIRL WITH HALF A BRAIN**  As Brandon Burns began his long journey to recovery, a 17-year-old girl in Bristol, Pennsylvania, was enjoying a particularly successful senior year of high school. Christina Santhouse was an honor roll student for the fourth year in a row, and she had been named captain of the varsity bowling team. But these accomplishments did not come so easily. It took Christina twice as much time as classmates to do homework assignments and projects because her brain needed extra time to process information. She had to invent a new bowling technique to use in games because the left side of her body was partially paralyzed, and she was constantly aware of being “different” from the other kids at school. Christina wasn't simply different from her classmates, however. She was extraordinary because she managed to do everything her classmates did (and more) with nearly half of her brain missing.

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**Right Brain, Left Brain: The Two Hemispheres**

**LO 8** Describe the functions of the two brain hemispheres and how they communicate.

If you look at a photo or an illustration of the brain, you will see a walnut-shaped wrinkled structure—this is the cerebrum (Latin for “brain”), the largest and most conspicuous part of the brain. The cerebrum includes virtually all parts of the brain except the brainstem structures, which you will learn about later. Like a pecan or walnut,
The cerebrum looks like a walnut with its two wrinkled halves. Regions of the left and right hemispheres specialize in different activities, but the two sides of the brain are constantly communicating and collaborating.

Pre-Op
Christina is wheeled into the operating room for her 14-hour hemispherectomy. She had a seizure in the elevator on the way to the surgery. William Johnson

Within 2 months, Christina’s seizures were occurring every 3 minutes, hundreds of times a day. She was unable to play soccer or go outside during school recess, and she sat on a beanbag chair in class so she wouldn’t hurt herself when overcome with a seizure. “I couldn’t do anything anymore,” Christina says. “I wasn’t enjoying my life.” In February 1996 the doctors at Johns Hopkins removed the right hemisphere of Christina’s brain. The operation lasted some 14 hours.

When Christina emerged from the marathon surgery, her head was pounding with pain. “I remember screaming and asking for medicine,” she recalls. The migraines persisted for months but eventually tapered off, and ultimately the surgery served its purpose: Christina no longer experienced debilitating seizures.

Removing nearly half of a brain may sound barbaric, but hemispherectomies have proven to be effective for eliminating and reducing seizures. In a study of the 111 children who had hemispherectomies at Johns Hopkins between 1975 and 2001, 65% no longer suffered seizures at all, and 21% experienced infrequent, “nonhandicapping” seizures. The remaining 14% still had seizures described as “troublesome” (Kossoff et al., 2003).

Hemispherectomies are exceptionally rare, used only when seizures occur many times a day, cannot be tempered with drugs, and stem from problems in one hemisphere (Choi, 2007, May 24). A less extreme, last-resort surgery for drug-resistant seizures is the split-brain operation, which essentially disconnects the right and left hemispheres. Normally, the two hemispheres are linked by a bundle of nerve fibers known as the corpus callosum (kōr-pəs, ka-lō-səm). Through the corpus callosum, the left and right sides of the brain communicate and work together to process information. But this same band of nerve fibers can also serve as a passageway for the electrical storms responsible for seizures. With the split-brain operation, the corpus callosum is severed so that these storms can no longer pass freely between the hemispheres (Wolman, 2012, March 15).

In addition to helping many patients with severe, drug-resistant epilepsy (Abou-Khalil, 2010), the consequences of split-brain operations have provided researchers with an excellent opportunity to explore the specialization of the hemispheres. Before we start to look at...
FIGURE 2.7
The Split-Brain Experiment
The image to the right shows a top view of the corpus callosum, the bundle of neurons linking the right and left hemispheres. When the corpus callosum is severed, we can easily see functional differences between the two sides of the brain. Studies of people who have undergone this procedure are known as “split-brain” experiments. An example of this type of experiment is shown here. Terence H. Williams, Nedzad Gluhbegovic/Wolters Kluwer

this research, you need to understand how visual information is processed. Each eye receives visual sensations, but that information is sent to the opposite hemisphere, and shared between the hemispheres via the corpus callosum (Chapter 3). Specifically, visual information seen by the right eye is processed in the left hemisphere, and visual information seen by the left eye is processed in the right hemisphere.

Equipped with this knowledge, American neuropsychologist Roger Sperry (1913–1994) and his student Michael Gazzaniga (1939–) conducted groundbreaking research on epilepsy patients who had undergone split-brain operations to alleviate their seizures. (This research ultimately led to Sperry’s 1981 Nobel Prize in Physiology or Medicine.) Not only did Sperry and Gazzaniga’s “split-brain” participants experience fewer seizures, they had surprisingly normal cognitive abilities and showed no obvious changes in “temperament, personality, or general intelligence” as a result of their surgeries (Gazzaniga, 1967, p. 24). But under certain circumstances, the researchers observed, they behaved as though they had two separate brains (Gazzaniga, 1967, 1998; FIGURE 2.7). Because the hemispheres were disconnected, the researchers could study each hemisphere separately to explore its own unique capabilities (or “specializations”).

I see an apple.
I don’t see anything.
The subject can touch the correct object even if he can’t say what has been projected in his left visual field. The subject uses his left hand, which is controlled by the right hemisphere, where the visual information has been processed.
Imagine that the researchers flashed an image (let’s say an apple) on the right side of a screen, ensuring that it would be processed by the brain’s left hemisphere. The split-brain participant could articulate what she had seen (“I saw an apple”). If, however, the apple appeared on the left side of the screen (processed by the right hemisphere), she would claim she saw nothing. But when asked to identify the image in a nonverbal way (pointing or touching with her left hand), she could do this without a problem (Gazzaniga, 1967, 1998). These findings are extremely useful in understanding the capabilities of the left and right hemispheres.

**LATERALIZATION** The split-brain experiments offered an elegant demonstration of **lateralization**, the tendency for the left and right hemispheres to excel in certain activities. When images are flashed in the right visual field, the information is sent to the left side of the brain, which excels in language processing. This explains why the split-brain participants were able to articulate the image they had seen on the right side of the screen. Images appearing in the left visual field are sent to the right side of the brain, which is generally not responsible for processing language but instead excels at visual spatial tasks. This is why the participants were tongue tied when asked to report what they had seen on the left side of the screen. They could, however, reach out and point to it. What hand do you think they used? The image was flashed in the left visual field and the sensory information was sent to the right hemisphere, which is unable to put into words what was seen. The left hand, which is controlled by the right hemisphere, pointed to the object (Gazzaniga, 1998; Gazzaniga, Bogen, & Sperry, 1965). The bottom line: The left hemisphere plays a crucial role in language processing and the right hemisphere plays a crucial role in managing visual spatial tasks.

This is only a generalization, however. While there are clear differences in the way the hemispheres process information (and the speed at which they do it), they can also process the same types of information. In a split-brain patient, communication between the hemispheres is limited. This is *not* the case for someone with an intact corpus callosum. Regardless of the type of information coming in or being processed, our hemispheres are constantly integrating and sharing information (Lilienfeld, Lynn, Ruscio, & Beyerstein, 2011). Next time you hear someone claim that some people are more “left-brained” or “right-brained,” ask him to identify the research that backs up such a claim. Similarly, beware of catchy sales pitches for products designed to increase your “logical and analytical” left-brain thinking or to help you tap into the “creative” side of your right brain. This way of thinking is oversimplified.

Keep this in mind while reading the upcoming sections on specialization in the left and right sides of the brain. The two hemispheres may each have certain areas of expertise, but they work as a team to create your experience of the world.

**Language and the Left**

Armed with this new knowledge of the split-brain experiments, let’s return our focus to Brandon. Brandon’s injury occurred on the left side of his brain, devastating his ability to use language. Before the battle of Fallujah, he had breezed through western novels at breakneck speeds. After his injury, even the simplest sentence baffled him. Words on a page looked like nothing more than black lines and curls. Brandon remembers, “It was like a puzzle that I couldn’t figure out.”

**HANDEDNESS AND LANGUAGE DOMINANCE** Brandon’s difficulties with language are fairly typical for someone with a brain injury to the left hemisphere, because regions on the left side of the brain tend to predominate in language. This is not true for everyone, however. In a study examining handedness and language
dominance, researchers administered a test to participants to determine degree of handedness (righty or lefty) and used brain scan technology to determine their predominant side for language processing. They found that around 27% of strongly left-handed participants and 4% of strongly right-handed participants had language dominance in the right hemisphere (Knecht et al., 2000). What does this mean? The left hemisphere controls language in most but not all people, and it doesn’t necessarily correspond to right- or left-handedness.

**LO 10** Identify areas in the brain responsible for language production and comprehension.

**BROCA’S AREA** Evidence for the “language on the left” trend appeared as early as 1861, when a French surgeon by the name of Pierre Paul Broca (1824–1880) encountered two patients who had, for all practical purposes, lost the ability to talk. One of the patients could only say the word “tan,” and the other had an oral vocabulary of only five words. When Broca later performed autopsies on the men, he found that both had sustained damage to the same area on the side of the left frontal lobe (right around the temple; *FIGURE 2.8*). Over the years, Broca identified several other speech-impaired patients with damage to the same area, a region now called **Broca’s area** (brō-kəz) (Greenblatt, Dagi, & Epstein, 1997), which is involved in speech production.

**WERNICKE’S AREA** Around the same time Broca was doing his research, a German doctor named Karl Wernicke (1848–1905) pinpointed a different place in the left hemisphere that seemed to control speech comprehension. Wernicke noticed that patients suffering damage to a small tract of tissue in the left temporal lobe, now called **Wernicke’s area** (ver-nə-kəz), struggled to make sense of what others were saying. Wernicke’s area is the brain’s headquarters for language comprehension.

Broca’s and Wernicke’s work, along with other early findings, highlighted the left hemisphere’s critical role in language. Scientists initially suspected that Broca’s area was responsible for speech creation and Wernicke’s area for comprehension, but it is now clear the use of language is far more complicated. These areas may perform additional functions, such as processing music and interpreting hand gestures (Koelsch et al., 2002; Xu, Gannon, Emmorey, Smith, & Braun, 2009), and they cooperate with multiple brain regions to allow us to produce and understand language. Furthermore, some speech processing appears to occur in the right hemisphere.

**FIGURE 2.8**

**Language Areas of the Brain**

For most people, the left hemisphere controls language. Broca’s area plays a critical role in language production, and Wernicke’s area language comprehension.

**Broca’s area** (brō-kəz) An area of the cortex that is critical for speech production.

**Wernicke’s area** (ver-nə-kəz) A region of the left cortex that plays a pivotal role in language comprehension.

**neuroplasticity** The brain’s ability to heal, grow new connections, and reorganize in order to adapt to the environment.

**The Role of the Right**

Research involving two split-brain patients suggests the right hemisphere is more proficient than the left in some visual tasks (Corballis, 2003), such as determining whether two objects are identical as opposed to mirror images of one another (Funnell, Corballis, & Gazzaniga, 1999), or judging if lines are oriented in the same direction (Corballis, Funnell, & Gazzaniga, 2002). Other findings suggest the right hemisphere is crucial for understanding abstract and humorous use of language (Coulson & Van Petten, 2007); somewhat better than the left for following conversations that change topic (Dapretto, Lee, & Caplan, 2005); and important for our ability to recognize faces (Kanwisher, McDermott, & Chun, 1997).
Brain Games
Christina’s dramatic recovery was facilitated by physical, occupational, vision, and speech therapy. “The more therapy,” says Christina, “the better chance of recovery.” William Johnson

The Amazing Brain
When Christina was wheeled out of surgery, her mother approached, grabbed hold of her right hand, and asked her to squeeze. Christina squeezed, demonstrating that she could understand and respond to language. Remember, she still had her left hemisphere.

Christina may not have lost her language abilities, but losing the right hemisphere did come at a cost. We know that Christina suffers partial paralysis on the left side of her body; this makes sense, because the right hemisphere controls movement and sensation on the left. We also know that it took Christina extra time to do her schoolwork. But if you ask Christina whether she has significant difficulty with any of the “right-brain” tasks described above, her answer will be no.

Christina’s recovery has been nothing short of astonishing. After the surgery, she went back to school and outperformed many of her classmates. In addition to making the honor roll and leading the bowling team, she managed to get her driver's license (even though some of her doctors said she never would), graduate from high school, and go to college. These accomplishments are the result of Christina’s steadfast determination, but also a testament to the brain’s amazing ability to heal and regenerate.

Neuroplasticity
LO 11 Define neuroplasticity and recognize when it is evident in brains.

The brain undergoes constant alteration in response to experiences and is capable of some degree of physical adaptation and repair. Its ability to heal, grow new connections, and make do with what is available is a characteristic we refer to as neuroplasticity. New connections are constantly forming between neurons, and unused ones are fading away. Vast networks of neurons have the ability to reorganize in order to adapt to the environment and an organism’s ever-changing needs, a quality particularly evident in the young. Even after brain injuries, younger children have better outcomes than do adults; their brains show more plasticity (Johnston, 2009).

In one study, researchers removed the eyes of newborn opossums and found that brain tissues normally destined to become visual processing centers took a
different developmental path. What was particularly striking was that the brain areas that were normally dedicated to vision became involved in processing other sensory information, such as touch. This is a clear example of neuroplasticity in action.

You Asked, Christina Answers
http://qrs.ly/jo3ipcn
What kind of therapy did you have and for how long?

CONNECTIONS
In Chapter 1, we described the guidelines psychologists use to ensure the ethical treatment of humans and animals in their studies. In the study described here, the researchers were required to get approval from an ethics board to conduct their study. The board determined the proposed research required the surgery on the baby opossums and that they would be treated humanely.
Cure All?
Because stem cells can differentiate into any type of cell in the body, they have great therapeutic potential. The cells pictured here are derived from a human embryo, but stem cells also reside in various adult tissues such as the brain and bone marrow. Professor Miodrag Stojkovic/Science Source

Baby Beethoven
For millions of Chinese children, learning to play an instrument like the violin or piano begins early. Children with musical training outperform their untrained peers on tests of IQ and language skills. Is this because music lessons make children smarter, or because smart children are more likely to take them? Researchers are still trying to get to the bottom of this conundrum. Lou Linwei/Sinopix

neurogenesis The generation of new neurons in the brain.
stem cells Cells responsible for producing new neurons.
phrenology An early approach to explaining the functions of the brain by trying to link the physical structure of the skull with a variety of characteristics, such as intelligence.

The Plastic Brains of Our Children
Some 40 million children in China are learning to play the piano. Special piano kindergartens have sprung up across that country, their 4- and 5-year-old pupils studying scales and chords on top of traditional subjects. After school, these children may devote another 2 to 3 hours to piano practice (Lebrecht, 2010, February 1; Trelawny, 2008, June 5). The reason many Chinese parents push the piano so hard? Learning an instrument, they believe, will help their children thrive in school and life (Trelawny, 2008, June 5).

Meanwhile on the other side of the Pacific, American parents are playing classical music to their unborn fetuses and showing “Baby Mozart” DVDs to their developmental turn. Instead, they became areas that specialize in processing other types of sensory stimuli, such as sounds and touch (Karlen, Kahn, & Krubitzer, 2006). The same appears to happen in humans. Brain scans reveal that when visually impaired individuals learn to read Braille early in life, a region of the brain that normally specializes in handling visual information becomes activated, suggesting it is used instead for processing touch sensations (Burton, 2003; Liu et al., 2007).

Remarkably, this plasticity is evident even with the loss of an entire hemisphere. Researchers report that the younger the patient is when she has a hemispherectomy, the better her chances are for recovery. In fact, even with the loss of an entire left hemisphere (the primary location for language processing), speech is less severely impacted (though some impact is inevitable) in young patients. The younger the person undergoing the procedure, the less disability is evident in speech (Choi, 2008).

STEM CELLS Scientists once thought that people were born with all the neurons they would ever have. Brain cells might die, but no new ones would crop up to replace them. Thanks to research beginning in the 1990s, that dismal notion has been turned on its head. In the last few decades, studies with animals and humans have shown that some areas of the brain are constantly generating new neurons, a process known as neurogenesis, which might be tied to learning and creating new memories (Eriksson et al., 1998; Gould, Beylin, Tanapat, Reeves, & Shors, 1999; Reynolds & Weiss, 1992).

The cells responsible for churning out these new neurons are known as stem cells, and they are quite a hot topic in biomedical research. Scientists hope to harness these little cell factories to repair tissue that has been damaged or destroyed. Imagine that you could use stem cells to bring back all the neurons that Brandon lost from his injury or replace those that Christina lost to surgery. Cultivating new brain tissue is just one potential application of stem cell science. These cellular cures might also be used to alleviate the symptoms of Parkinson’s disease, or replenish neurons of the spine, enabling people with spinal cord injuries to regain movement. Both have already been accomplished in mice (Keirstead et al., 2005; Wernig et al., 2008). Although embryonic stem cells can be used for such purposes, some stem cells can be found in tissues of the adult body, such as the brain and bone marrow. Earlier we explained how neuroplasticity is more evident in young people. So what can we do to promote positive brain changes in our children? Some people think that early exposure to music is a critical factor, but is there evidence to support this belief?
babies and toddlers. Many of these moms and dads have been led to believe that early exposure to classical music promotes brain development, and they will do whatever it takes to give their kids a leg up on their peers (Hirsh-Pasek, Golinkoff, & Eyer, 2003).

Some evidence suggests that learning an instrument may indeed have cognitive benefits. Studies show that people with musical training generally score higher on language, auditory, and overall IQ tests than those without such training (Schellenberg, 2011; Schellenberg & Winner, 2011). But such research is correlational; the link between the variables is not necessarily causal. Even with a strong correlation or link between playing a musical instrument and increased cognitive abilities, we cannot be sure that one of these variables causes changes in the other. The only way to determine a cause-and-effect link is to conduct a study using the experimental method. As for playing Mozart to babies, there is no solid data demonstrating that merely listening to music enhances intelligence (Hirsh-Pasek et al., 2003). Enjoying the dynamic melodies of Mozart stimulates the brain and may improve mood, which can provide temporary cognitive benefits, but the same could be said for a host of other activities (Schellenberg, 2011).

From Bumps to Brain Scans: We’ve Come a Long Way

Both Brandon and Christina underwent many brain scans before and after their surgeries, which allowed doctors to get a detailed look inside their heads without lifting a scalpel. But had Brandon and Christina lived in a different era, brain scans would not have been an option.

Before there were technologies to study the brain, people could only speculate about what was going on beneath the skull of a living person. One theory was that bumps on a person’s skull could reveal characteristics about him. Judging the topography of a person’s head was a core part of phrenology, the now discredited brain “science” that achieved enormous popularity at the beginning of the 19th century through its founder Franz Joseph Gall (1757–1828). But flaws in the theory behind phrenology were recognized early on. Another early (but more scientific) way of studying the brain was through ablation, a technique used by physiologist Pierre Flourens (1794–1867) to determine the functions of different brain regions.
(Pearce, 2009). This technique involved destroying parts of the brain of living animals and then determining whether some functioning was lost following this surgery. These days, scientists no longer try to interpret what’s going on inside living brains by running fingers over people’s heads. There are now technologies that allow us to sift through the brain’s constant buzz of activity, behold its three-dimensional structure, and identify interesting hot spots (see Table 2.1). Nevertheless, one of Gall and Flourens’ major contributions was the idea that there might be areas of the brain that have particular functions. In other words, there are locations in the brain that are responsible for specific brain activities: there is a localization of function.

<table>
<thead>
<tr>
<th>Tools for Studying the Brain</th>
<th>Function</th>
<th>Use</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electroencephalogram (EEG)</td>
<td>Detects electrical energy in the brain and displays information that can be interpreted.</td>
<td>Monitors and studies brain processes, diagnoses brain conditions, and sheds light on the way substances affect brain function.</td>
<td>Records activity happening on the surface of the brain.</td>
</tr>
<tr>
<td>Computerized Axial Tomography (CAT scan or CT scan)</td>
<td>X-rays create many cross-sectional images of the brain (or body); similar to bread slices, you can examine the pieces individually.</td>
<td>Spots tumors and brain damage and presents the brain’s structural features.</td>
<td>Exposes people to radiation, potentially increasing cancer risk (National Cancer Institute, 2010).</td>
</tr>
<tr>
<td>Positron Emission Tomography (PET)</td>
<td>Uses radioactive glucose; scanner sensitive to radioactivity, detects active areas of the brain, which have absorbed the most sugar.</td>
<td>Captures the brain in a variety of activities (e.g., dreaming, hallucinating, or appreciating the scent of a rose).</td>
<td>From injection to scan, PET scans are time-consuming. This procedure can be expensive, and it exposes people to radiation.</td>
</tr>
<tr>
<td>Magnetic Resonance Imaging (MRI)</td>
<td>Using radio frequency waves, the MRI produces cross-sectional images (slices) of the brain; detects tumors, bleeding, infections, and the size and shape of various brain structures.</td>
<td>Provides information on the anatomy of the brain.</td>
<td>MRIs produce more detailed images than CTs, but are more time-consuming and expensive.</td>
</tr>
<tr>
<td>Functional Magnetic Resonance Imaging (fMRI)</td>
<td>Captures changes in brain activity.</td>
<td>Reveals patterns of blood flow in a particular area of the brain, providing a good indicator of how much oxygen is being used as a result of activity.</td>
<td>Indirectly measures neural activity via blood flow; not necessarily identifying the precise location of cognitive processes.</td>
</tr>
</tbody>
</table>

Technologies to study the brain are continuing to evolve. Summarized here are the most commonly used technologies. 


SOCIAL MEDIA and psychology

Facebook in the Brain

One of the main themes of this chapter is specialization, the idea that certain areas of the brain tend to become active during certain tasks. When we say “tasks,” we mean just about any activity you can imagine, from riding a bicycle to managing friend networks on Facebook.
The average number of Facebook “friends” is 245, but the friend tally varies significantly from one person to the next, ranging from zero to 5,000, the maximum allowed by Facebook (Ball, 2010, May 28; Tsukayama, 2012, February 3). What does a Facebook friend number reveal about a person—job networking skills, offline popularity, time wasted at work? According to one preliminary study, friend volume may reflect something about the brain of the user.

Using MRI technology, researchers studied the brain structures of a sample of Facebook users. What they discovered was a correlation between the number of Facebook friends and the density of gray matter (the primary tissue of the cerebral cortex) in areas of the brain important for social interaction. One of those regions, the superior temporal sulcus, is thought to be important for detecting socially meaningful movements such as hand gestures and eye shifts. Another, known as the entorhinal cortex, appears to play a key role in matching faces to names, a critical skill for Facebookers (Kanai, Bahrami, Roylance, & Rees, 2012). As anyone with a few hundred friends can testify, keeping track of all those names and faces can be challenging.

We should point out that this study is merely correlational. It does not reveal whether the number of friends causes changes in brain structure, or whether the characteristics of brain structures determine the number of friends. Perhaps some other variable is responsible for both. This single study needs replication, but it has generated intriguing questions for researchers to tackle in the future.

LO 12 Compare and contrast tools scientists use to study the brain.

In the past, most of what scientists learned about the brain came from probing the skulls of cadavers and observing the behavior of people suffering from brain damage. But the last century, and particularly the last few decades, has witnessed an explosion of brain research technologies. Such technological advances have made it possible to observe the brain as it makes decisions, sleeps, and even tells lies (Dang-Vu et al., 2008; Hampton & O’Doherty, 2007; Kozel et al., 2009). See Table 2.1 for information on the different types of technologies, their function, uses, and limitations (also see Infographic 2.3 on the next page). With the technology available today, we can even track the activities of strings of neurons.

Electric Surprise

Stimulating brain cells may be trickier than we thought.

Scientists and doctors have long used electricity to both study and treat the brain. But a report in the August 27, 2009, issue of Neuron indicates that the brain’s response to electricity is exceptionally complex. Using a new type of optical imaging, Harvard Medical School researchers observed neurons as they were stimulated by an electrode. Instead of activating a small sphere of surrounding neurons as expected, the electrodes caused sparse strings of neurons to fire across the brain. The finding suggests that brain surgeons and the designers of neural prosthetics have a much smaller margin of error than previously thought—shifting an electrode even slightly could activate an entirely different set of neurons. Melinda Wenner. Reproduced with permission. Copyright © 2010 Scientific American, a division of Nature America, Inc. All rights reserved.
Ways to Study the Living Brain

For hundreds of years, scientists interested in the brain were limited to surgical techniques, often on cadavers. Imaging and recording technologies now allow us to investigate the living brain by assessing structure, function, or both. CAT and MRI techniques provide static pictures of brain structures, while functional imaging and recording techniques allow us to see the relationship between brain activity and specific mental functions. Functional techniques can also be used to diagnose injuries and diseases earlier than techniques that look at structure.

New technologies are continually being developed, allowing us to study the brain in ways we couldn’t imagine just a few years ago.

**Looking at Brain STRUCTURE**

**COMPUTERIZED AXIAL TOMOGRAPHY**
Using X-rays, a scanner creates multiple cross-sectional images of the brain. Here, we see the brain from the top at the level of the ventricles, which form the butterfly-shaped dark spaces in the center.

**MAGNETIC RESONANCE IMAGING**
An MRI machine’s powerful magnets create a magnetic field that passes through the brain. A computer analyzes the electromagnetic response, creating cross-sectional images similar to those produced by CAT, but with superior detail.

**Watching Brain FUNCTION**

**EEG**
Electrodes placed on the scalp record electrical activity from the cortical area directly below. When the recorded traces are lined up, as in the computer readout seen here, we can see the scope of functional responses across the lobes.

**PET**
A radioactively labeled substance called a tracer is injected into the bloodstream and tracked while the subject performs a task. A computer then creates 3-D images showing degrees of brain activity. Areas with the most activity appear in red.

**fMRI**
The flow of oxygen-rich blood increases to areas of the brain that are active during a task. fMRI uses powerful magnets to track changes in blood-oxygen levels. Like PET, this produces measurements of activity throughout the brain.

**What’s Next? Making Connections**
The intricate pathways of myelinated axons in the brain can’t be seen in the imaging techniques above. But new technologies like diffusion spectrum imaging (DSI), which tracks the diffusion of water molecules through brain tissue, are being used to map neural connections. The resulting images show a complex information superhighway, with different colors indicating directions of travel.
show what you know

1. The brain is constantly undergoing alterations in response to experiences and is capable of a certain degree of physical adaptation and repair. This ability is known as:
   a. neuroplasticity  
   b. phrenology  
   c. ablation  
   d. lateralization

2. ___________ are responsible for creating new neurons.

3. Scientists hope that in the future they will be able to discover how we can use stem cells to help people like Brandon and Christina. The goal would be for doctors to induce the process of ___________ to restore the lost brain tissue.
   a. ablation  
   b. agonists  
   c. neurogenesis  
   d. lateralization

4. You have been asked to set up an experiment to determine if playing classical music to infants leads to improved cognitive abilities. What would your independent and dependent variables be? How would your experimental and control groups be treated differently?

The Cortex: A Peek Beneath the Skull

Imagine you were one of the surgeons performing Christina’s hemispherectomy. What exactly would you see when you peeled away the scalp and cut an opening into the skull? Before seeing the brain, you would come upon a layer of three thin membranes, the meninges, which envelop and protect the brain and spinal cord. Perhaps you have heard of meningitis, a potentially life-threatening condition in which the meninges become inflamed as a result of an infection. The meninges are bathed in a clear watery substance called cerebrospinal fluid, which offers additional cushioning and helps in the transport of nutrients and waste in and out of the brain and the spinal cord. Once you peeled back the meninges, you would behold the pink cerebrum.

CEREBRAL CORTEX As Christina’s surgeon, your main task would be to remove part of the cerebrum’s outermost cellular layer, the cerebral cortex. The cerebral cortex processes information and is the layer of cells surrounding nearly all the brain’s structures. You’ll remember from our earlier presentation that the cerebrum looks like a wrinkled walnut. This is because the cortex is scrunched up and folded onto itself to fit inside a small space (the skull).

LO 13 Identify the lobes of the cortex and explain their functions.

THE LOBES OF THE BRAIN The cortex overlaying each hemisphere is separated into different sections, or lobes (INFOGRAPHIC 2.4 on p. 81). The major function of the frontal lobes is to organize information among the other lobes of the brain. The frontal lobes are also responsible for higher-level cognitive functions, such as thinking, perception, and impulse control. The parietal lobes receive and process sensory information such as touch, pressure, temperature, and spatial orientation. Visual information goes to the occipital lobes for processing, and hearing and language comprehension are largely handled by the temporal lobes. We’ll have more to say about the lobes shortly.

LO 14 Recognize the association areas and identify their functions.

THE ASSOCIATION AREAS In addition to these broad functions of the brain lobes, there are specific functions associated with particular areas of the lobes. Some areas in the lobes are home to networks of neurons that specialize in certain activities. The motor areas direct movement, the sensory areas receive and analyze sensory stimuli, and the association areas integrate information from all over the brain. The association areas are located in all four lobes of the brain; however, they are much harder to pinpoint than are the motor and sensory areas. The association areas allow us to learn (just as you’re doing now), have abstract thoughts (for example, 2 + 2 = 4), and carry out complex behaviors like texting and tweeting. The language-processing hubs we learned about earlier, Broca’s area and Wernicke’s area, are association areas that integrate information from all over the brain, allowing us to learn, think in abstract terms, and carry out other intellectual tasks.
that play a role in the production and comprehension of speech. In humans, the vast majority of the cortical surface is dedicated to the association areas.

The Lobes: Up Close and Personal

Prior to her hemispherectomy, Christina was extroverted, easygoing, and full of energy. “I had absolutely no worries,” she says, recalling her pre-Rasmussen’s days. After her operation, Christina became more introverted and passive. She felt more emotionally unsettled. “You go into surgery one person,” she says, “and you come out another.”

The transformation of Christina’s personality may be a result of many factors, including the stress of dealing with a serious disease, undergoing a major surgery, and readjusting to life with disabilities. But it could also have something to do with the fact that she lost a considerable amount of brain tissue, including her right frontal lobe. Networks of neurons in the frontal lobes are involved in processing emotions, making plans, controlling impulses, and carrying out a vast array of mental tasks that each person does in a unique way (Williams, Suchy, & Kraybill, 2010). The frontal lobes play a key role in the development of personality (Stuss & Alexander, 2000). A striking illustration of this phenomenon involves an unlucky railroad foreman, Phineas Gage.

PHINEAS GAGE AND THE FRONTAL LOBES  The year was 1848, and Phineas Gage was working on the railroad. An accidental explosion sent a 3-foot iron tamping rod clear through his frontal lobes (Infographic 2.4). The rod, about as thick as a broom handle, drove straight into Gage’s left cheek, through his brain, and out the top of his skull (Macmillan, 2000). What’s peculiar about Gage’s mishap (besides the fact that he was walking and talking just hours later) is the extreme transformation it caused. Before the accident, Gage was a well-balanced, diligent worker whom his supervisors referred to as their “most efficient and capable foreman” (Harlow, 1848, as cited in Neylan, 1999, p. 280). After the accident, he was unreliable, unpleasant, and downright vulgar. His character was so altered that people acquainted with him before and after the accident claimed he was “no longer Gage” (Harlow, 1848, as cited in Neylan, 1999, p. 280). As he could not continue working as a foreman, Gage eventually began to travel to the larger towns of New England, “exhibiting himself and the tamping iron” (Macmillan, 2000, p. 55).

Modern scientists have revisited Gage’s case, using measurements from his fractured skull and brain imaging data to estimate exactly where the damage occurred. Their studies suggest that the metal rod caused destruction in both the left and right frontal lobes (Damasio, Grabowski, Frank, Galaburda, & Damasio, 1994). The only good thing about Gage’s horrible accident, it seems, is that it illuminated the importance of the frontal lobes in defining personality characteristics.

CANINES AND THE MOTOR CORTEX  Toward the rear of the frontal lobes is a strip of the brain known as the motor cortex, which works with other areas to plan and execute voluntary movements (Infographic 2.4). Persuasive evidence pointing to this region’s involvement in muscle movement came initially from a study of dogs by Gustav Fritsch (1838–1927) and Edvard Hitzig (1838–1907). Working from a makeshift lab, the two doctors discovered they could make the animals move by electrically stimulating their brains (Gross, 2007). A mild shock to the right side of the cortex might cause a twitch in the left forepaw or the left side of the face, whereas stimulating the left would spur movement on the right (Finger, 2001).

ALBERT EINSTEIN AND THE PARIETAL LOBES  Directly behind the frontal lobes on the crown of your head are the parietal lobes (Infographic 2.4). The parietal lobes help orient the body in space, are involved in tactile processing (for example, interpreting sensations related to touch, such as pain and pressure), and may play
Getting Into the Brain

Finding Personality in the Brain
In 1848 an accidental blast drove a 3-foot iron bar through the head of railroad worker Phineas Gage. He survived, but his personality was disastrously affected. Previously reliable and agreeable, post-injury Gage was prone to angry outbursts and became unable to hold down a job.

Using measurements from his fractured skull, modern scientists have been able to connect Gage’s personality changes to frontal lobe damage. Cases like this have helped psychologists understand the role of different structures in the brain.

Getting TO the Brain
In order to study the brain, we must get to it first. Peel away the scalp and cut away the bony skull, and you will find still more layers of protection. Three thin membranes—the meninges—provide a barrier to both physical injury and infection. Bypass them, and the outermost layer of the brain, the cortex, is revealed.

Lobes of the Brain
This drawing shows the left hemisphere of the brain. Each hemisphere is divided into lobes, which are known for the major functions found there.

Specialized Areas of the Brain
Unlike the lobes, which are associated with many functions, some areas of the brain have one specialized function.
This research study compared one man’s brain to a control group of 35 men. In Chapter 1, we discussed the importance of having a large enough sample size to give us reliable findings, which might be a consideration here. Also, we discussed the potential problems with using case studies for making generalizations to the population, and in the current study, the use of Einstein as a single participant to compare to the control group could be considered a type of case study.

Superbrain
A recently rediscovered photo of Einstein’s brain shows what researchers have referred to as his “extraordinary prefrontal cortex” (Falk, Lepore, & Noe, 2012, p. 1). The irregularities in Einstein’s parietal lobes may explain some of his spectacular mathematical and visuospatial abilities (Witelson, Kigar, & Harvey, 1999; Falk et al., 2012). Could it be that Einstein’s mathematical activities caused changes to his parietal lobes? Harvey Collection. Otis Historical Archives, National Museum of Health and Medicine

FIGURE 2.9
The Motor and Somatosensory Cortex
This drawing shows how the motor and somatosensory cortex correspond to the various regions of the body. Parts of the body that are shown larger, such as the face and hands, indicate areas of greater motor control or sensitivity. The size of each body part reflects the amount of cortex allocated to it.

somatosensory cortex A band of tissue running parallel to the motor cortex that receives and integrates sensory information from all over the body.
The parietal lobes are home to the somatosensory cortex, a strip of the brain running parallel to the motor cortex that receives and integrates sensory information from all over the body, for example, pain and temperature. Penfield, the neurosurgeon who created the homunculus for the primary motor cortex, mapped the somatosensory cortex in the same way (Penfield & Boldrey, 1937; Figure 2.9). As you might expect, the most sensitive areas of the body like the face and tongue are oversized on the homunculus, whereas areas less sensitive to stimulation, such as the forearm and the calf, are smaller.

THE TEMPORAL LOBES AND THE AUDITORY CORTEX  
Behind the parietal lobes, on the sides of your head, are the temporal lobes, which process auditory stimuli, recognize visual objects, especially faces, and play a key role in language comprehension and memory (Hickok & Poeppel, 2000; Infographic 2.4 on page 81). The temporal lobes are home to the auditory cortex, which receives information from the ears and allows us to “hear” sounds. In particular, researchers have supported the notion, based on studies of primate vocalizations, that the ability to recognize language has evolved over time and is processed within the temporal lobes (Scott, Blank, Rosen, & Wise, 2000; Squire, Stark, & Clark, 2004).

THE OCCIPITAL LOBES AND THE PRIMARY VISUAL CORTEX  
Visual information is initially processed in the occipital lobes, in the lower back of the head (Infographic 2.4). If you have ever suffered a severe blow to the rear of your head, you may remember “seeing stars,” probably because activity in the occipital lobes was disrupted (hopefully only for a few seconds). It is here, where the optic nerve connects to the primary visual cortex, that our visual information is received and interpreted, and where we process information (for example, about color, shape, and motion). (See Chapter 3 on sensation and perception for a full discussion.) Even for a person with healthy eyes, if this area were damaged, severe visual impairment could occur. At the same time, the individual would still be able to “see” vivid mental images (Bridge, Harrold, Holmes, Stokes, & Kennard, 2012).

The cortex is the outermost section of the brain. It is also the part that is “newest,” or most recently evolved compared to the “older” structures closer to the core. We know this because researchers have compared the brains of humans with other primates. Those structures we share with our primate relatives are considered more primitive, or less evolved.

Now that we have surveyed the brain’s outer terrain, identifying some of the hotspots for language and other higher cognitive functions, let’s dig deeper and examine some of its older structures.

show what you know

1. The major function of the ________ is to organize information among the other lobes of the brain.
   a. parietal lobes
   b. frontal lobes
   c. corpus callosum
   d. temporal lobes

2. The ________ integrate information from all over the brain, allowing us to learn, have abstract thoughts, and carry out complex behaviors.

3. This section introduces the lobes of the cortex and their associated functions. Create a way to remember the lobes and their specific functions using a rhyme or another memorization technique you know.

4. Phineas Gage suffered a horrific accident in the mid-1800s, when an explosion sent a metal rod through his brain and out the top of his skull. Which of the following caused the sudden change in his personality following the accident?
   a. damage to his occipital lobes
   b. damage to his temporal lobes
   c. damage to his frontal lobes
   d. damage to his somatosensory cortex

CHECK YOUR ANSWERS IN APPENDIX C.
Digging Below the Cortex
Drama Central: The Limbic System

LO 15  Distinguish the structures and functions of the limbic system.

Buried beneath the cortex is the **limbic system**, a group of interconnected structures that play an important role in our experiences of emotion, motivation, and memory. It also fuels our most basic drives, such as hunger, sex, and aggression. The limbic system includes the hippocampus, amygdala, thalamus, and hypothalamus (FIGURE 2.10).

**FIGURE 2.10**
The Limbic System
The limbic system fuels basic drives and processes emotions and memories. Stockbyte/Getty Images

**HIPPOCAMPUS** The largest structure in the limbic system is the hippocampus, a pair of seahorse-shaped structures. The **hippocampus** is primarily responsible for processing and forming new memories from experiences, but is not where memories are permanently stored (Eichenbaum, 2004). Given its key role in memory, it may come as no surprise that the hippocampus is one of the brain areas affected by Alzheimer’s disease (Henneman et al., 2009; Wang et al., 2003). On the brighter side of things, the hippocampus is also one of the few places in the brain known to give birth to new neurons throughout life (Eriksson et al., 1998).

**AMYGDALA** Another structure of the limbic system is the **amygdala** (ə-mig-də-lə), which processes basic emotions like fear and aggression and the memories associated with them (Kalin, Shelton, & Davidson, 2004; Kluver & Bucy, 1939; LeDoux, 2000). Having spent many months in a war zone, Brandon encountered more than his fair share of fear-provoking near-death experiences. On one occasion, he was riding at nearly 60 mph in a Humvee that spun out of control and almost flipped over. "My heart was beating faster than ever before," Brandon recalls. In dangerous situations like this, activity in the nervous system increases drastically, including in the amygdala, triggering an emotional reaction (for example, terror) and orchestrating a whole-body response to the threat (racing heart, sweaty palms, and the like).
THALAMUS  Seated at the center of the limbic system is the thalamus (th-a-lə-məs), whose job is to process and relay sensory information to the appropriate parts of the cortex (visual information to the visual cortex, and so on). The great majority of the data picked up by all the sensory systems, except olfaction (sense of smell), pass through the thalamus before moving on to the cortex for processing (Kay & Sherman, 2007). You might think of the thalamus as an air traffic control tower guiding incoming aircraft; when pilots communicate with the tower, the controllers direct the route to take or the runway to use.

HYPOTHALAMUS  Just below the thalamus is the hypothalamus (hi-pō-tha-lə-məs; hypo means “under” in Greek), which keeps the body’s systems in a steady state, making sure functions like blood pressure, body temperature, and fluid/electrolyte balance remain within a healthy range. The hypothalamus is also involved in regulating sleep–wake cycles (Saper, Scammell, & Lu, 2005), sexual arousal (Laan & Janssen, 2007), and appetite (Ahima & Antwi, 2008). For example, neurons from the digestive system send signals to the hypothalamus (such as “stomach is empty”), which then sends signals to higher regions of the brain (such as “it’s time to eat”). But deciding what and when to eat does not always come down to being hungry or full. Other brain areas are involved in eating decisions and can override the hypothalamus, driving you to polish off the French fries or scarf down that chocolate bar even when you are not that hungry.

Deeper Yet: The Brainstem and Cerebellum

The brain is made up of structures responsible for processes as complex as being able to rebuild a car’s engine to selecting the right classes for a degree program. Yet delving deeper in the brain, we find structures that control more primitive functions.

LO 16 Distinguish the structures and functions of the brainstem and cerebellum.

The brain’s ancient core consists of a stalklike trio of structures called the brainstem (FIGURE 2.11 on page 86). The brainstem extends from the spinal cord to the forebrain, which is the largest part of the brain and includes the cerebral cortex and the limbic system. Located at the top of the brain stem is the midbrain, and although there is some disagreement about which brain structures belong to the midbrain, most agree it plays a role in levels of arousal. The midbrain is also home to neurons that help generate movement patterns in response to sensory input (Stein, Stanford, & Rowland, 2009). An example would be flinching when someone shouts, “Look out!”

RETICULAR FORMATION  Part of the reticular formation is located in the midbrain. The reticular formation is an intricate web of neurons that is responsible for levels of arousal—whether you are awake, dozing off, or somewhere in between. It is also involved in your ability to attend selectively to important incoming information by sifting through sensory data on its way to the cortex, picking out what’s relevant and ignoring the rest. Imagine how overwhelmed you would feel by all the sights, sounds, tastes, smells, and physical sensations in your environment if you didn’t have a reticular formation to help you discriminate between the important (the sound of a honking car horn) and trivial (the sound of a dog barking in the distance) information.

The hindbrain includes areas of the brain responsible for fundamental life-sustaining processes. The pons, which helps regulate sleep–wake cycles and coordinates movement between the right and left sides of the body, is an important structure of the hindbrain. The pons sits atop the medulla (ma-dū-lə), a structure that oversees some

**Synonyms**

- reticular formation
- reticular activating system

**limbic system** A horseshoe-shaped collection of structures that regulates emotions and basic drives like hunger, and aids in the creation of memories.

**hippocampus** A pair of seahorse-shaped structures located in the limbic system; primarily responsible for creating new memories.

**amygdala** (a-mig-da-lə) A pair of almond-shaped structures in the limbic system that processes basic emotions, such as fear and aggression, as well as associated memories.

**thalamus** (th-a-lə-məs) A structure in the limbic system that processes and relays sensory information to the appropriate areas of the cortex.

**hypothalamus** (hi-pō-tha-lə-məs) A small structure located below the thalamus that maintains a constant internal environment within a healthy range; helps regulate sleep–wake cycles, sexual behavior, and appetite.

**forebrain** Largest part of the brain; includes the cerebral cortex and the limbic system.

**midbrain** The part of the brain stem involved in levels of arousal; responsible for generating movement patterns in response to sensory input.

**reticular formation** A network of neurons running through the midbrain that controls levels of arousal and quickly analyzes sensory information on its way to the cortex.

**hindbrain** Includes areas of the brain responsible for fundamental life-sustaining processes.

**pons** A hindbrain structure that helps regulate sleep–wake cycles and coordinate movement between the right and left sides of the body.

**medulla** (ma-dū-lə) A structure that oversees vital functions, including breathing, digestion, and heart rate.
of the body's most vital functions, including breathing and heart rate maintenance (Broadbelt, Paterson, Rivera, Trachtenberg, & Kinney, 2010).

**Cerebellum** Behind the brainstem, just above the nape of the neck, sits the orange-sized **cerebellum** (ser-e-bell-um). (Latin for “little brain,” the cerebellum looks like a mini-version of the whole brain.) Centuries ago, scientists found that removing parts of the cerebellum from animals caused them to stagger, fall, and act clumsy. Although the cerebellum is best known for its importance in muscle coordination and balance, scientists are beginning to understand just how much this “little brain” influences higher cognitive processes in the “big brain,” such as abstract reasoning and language production (Fine, Ionita, & Lohr, 2002). People with damaged cerebellums struggle with certain fine distinctions, such as telling the difference between words that sound somewhat alike (for example, “pause” versus “paws”) or for producing emotional reactions that are appropriate to a given situation (Bower & Parsons, 2003).

### Wrapping It Up

We’ve come a long way in our journey. Let’s step back and summarize what we have learned. The body has two main systems of communication: the fast-acting nervous system and the slower endocrine system. Commanding and coordinating the activity of the nervous system is the brain, whose various regions excel in performing certain tasks. While it may be tempting to view the brain as a collection of parts doing various jobs independent of each other, the reality is that most everything the brain does is the result of many components working in sync. Violins alone won’t make a symphony; you need the flutes, trumpets, and all the instruments in the orchestra to create a unified sound. If one violin in the orchestra breaks, there are other violinists to play the same part, compensating for the loss. Likewise, the brain houses many networks of neurons that have the ability to carry out the same job. When one stops working, another can take over (Doidge, 2007).

This allows us to dispel an urban myth: we do use more than 10% of our brains! In fact, people use 100% of their brains, but they don’t always use them effectively, efficiently, or wisely. Brandon Burns and Christina Santhouse have made the most of their brains, and they are living rich and meaningful lives because of it.

### show what you know

1. The ____________ represents a group of interconnected structures that process emotions, memories, and basic drives.
   - a. left hemisphere
   - b. limbic system
   - c. corpus callosum
   - d. superior temporal sulcus

2. The specific part of the brain that processes basic emotions, such as fear and aggression and the memories associated with them, is the ____________.

3. How might the specific structures of the limbic system, the brainstem, and the cerebellum come into play if you were out on a first date?

4. The primary role of the thalamus is to ____________:
   - a. relay sensory information.
   - b. keep the body’s systems in a steady state.
   - c. generate movement patterns in response to sensory input.
   - d. regulate sleep–wake cycles.

CHECK YOUR ANSWERS IN APPENDIX C.
WHERE ARE THEY NOW? 

You may be wondering what became of Brandon Burns and Christina Santhouse. Three years after returning from Iraq, Brandon married a young woman named Laura who has witnessed the dramatic unfolding of his recovery. When Laura first met Brandon, he had a lot of trouble communicating his thoughts. His sentences were choppy; he often omitted words and spoke in a flat and emotionless tone. “His speech was very delayed, very slow,” Laura recalls. Over the years, however, Brandon’s vocabulary has expanded considerably, and he can now express himself with greater feeling and fluidity. “He is able to use more humor and emotion when he’s speaking,” Laura says. This young veteran, who was once unable to talk, read, or write, can now articulate his thoughts in lengthy, complex sentences; read a book; and write for his Web site.

These days, Brandon is quite a busy fellow. Much of his time is spent at home in Bartlett, Tennessee, caring for his sons, 4-year-old Porter and 2-year-old Morgan, and his newborn daughter MacCrea Iona. He also works in a church ministry providing much-needed help to people in the inner city of Memphis, and he has traveled to numerous countries, including Haiti, Kenya, and Honduras, to assist pastors in developing new strategies for reaching out to their communities.

As for Christina, she continues to reach for the stars—and grab them. After studying speech–language pathology at Misericordia University in Dallas, Pennsylvania for 5 years (and making the dean’s list nearly every semester), Christina graduated with both a bachelor’s and master’s degree. Those years in academia were not smooth sailing. When Christina first embarked upon her major, she remembers the department chairman telling her that she wouldn’t be able to handle the rigors of the program. According to Christina, on graduation day, that same chairman presented her with the department’s Outstanding Achievement Award. “This is the man who said I would never be able to make it, that I should try a new major,” Christina says. “People often don’t expect too much from people with disabilities.”

Today, Christina works as a full-time speech–language pathologist in Pennsylvania’s public school system. She spends her days helping elementary schoolchildren overcome their difficulties with stuttering, articulation, and other speech problems. She is also a member of the local school district’s Brain STEPS team, which supports students who are transitioning back into school following brain injuries. “Hopefully, I have opened some doors for other people with disabilities,” Christina offers. “There were never doors open for me; I’ve had to bang them down.”

Brandon and Christina provide breathtaking illustrations of neuroplasticity—the brain’s ability to heal, grow new connections, and make do with what is available. And although neuroplasticity played a role in these two people’s recoveries, we would be remiss not to recognize the vast number of medical professionals, such as neuropsychologists, physical therapists, occupational therapists, speech pathologists, nurses, and doctors, who assisted them in their rehabilitation. The recoveries of Brandon and Christina bear testimony to the awesome tenacity of the human spirit.
Define neuroscience and explain its contributions to our understanding of behavior. (p. 50)

Neuroscience is the study of the nervous system and the brain, extending into a variety of disciplines and research areas. Our understanding of behavior is further explored in biological psychology, a subfield of psychology focusing on how the brain and other biological systems influence behavior. Neuroscience helps us explore physiological explanations for mental processes, searching for connections between behavior and the human nervous system, particularly the brain.

Label the parts of a neuron and describe an action potential. (p. 53)

A typical neuron has three basic parts: a cell body, dendrites, and an axon. The dendrites receive messages from other neurons, and the branches at the end of the axon send messages to neighboring neurons. The messages are in the form of electrical and chemical activity. When a neuron fires, the action potential moves down the axon. Action potentials are all-or-none, meaning they either fire or do not fire.

Illustrate how neurons communicate with each other. (p. 57)

Neurons communicate with each other via chemicals called neurotransmitters. An action potential moves down the axon and reaches the branches of the terminal buds, where the command to release neurotransmitters is conveyed. The neurotransmitters are released into the synapse. Most of these neurotransmitters drift across the gap and come into contact with receptor sites of the receiving neuron’s dendrites.

Summarize various neurotransmitters and the role they play in human behavior. (p. 58)

Neurotransmitters are chemical messengers that neurons use to communicate. There are many types of neurotransmitters, each with its own type of receptor site, including: acetylcholine, glutamate, GABA, norepinephrine, serotonin, dopamine, and endorphins. Neurotransmitters can influence mood, cognition, and many other processes and behaviors.

Recognize the connections between the central and peripheral nervous systems. (p. 62)

The brain and spinal cord make up the central nervous system (CNS), which communicates with the rest of the body through the peripheral nervous system (PNS). There are three types of neurons participating in this back-and-forth communication: Motor neurons carry information from the CNS to various parts of the body such as muscles and glands; sensory neurons relay data from the sensory systems (for example, eyes and ears) to the CNS for processing; and interneurons, which reside exclusively in the CNS and act as bridges connecting sensory and motor neurons. Interneurons mediate the nervous system’s most complex operations. They assemble and process sensory input from multiple neurons and, in addition, connect what is happening now to our memory of experiences in the past. They also give rise to our thoughts and feelings, and direct our behaviors.

Describe the organization and function of the peripheral nervous system. (p. 63)

The peripheral nervous system is divided into two branches: the somatic nervous system and the autonomic nervous system. The somatic nervous system controls the skeletal muscles, and the autonomic nervous system regulates involuntary processes within the body. The autonomic nervous system is made up of the sympathetic nervous system and the parasympathetic nervous system. The sympathetic nervous system initiates the fight-or-flight response. The parasympathetic nervous system is responsible for the rest-and-digest process.

Evaluate the role of the endocrine system and how it influences behavior. (p. 66)

The endocrine system is a communication system that uses glands to convey messages and is closely connected with the nervous system. Its messages are conveyed by hormones, chemicals released into the bloodstream that can cause aggression and mood swings, as well as influence growth and alertness.

Describe the functions of the two brain hemispheres and how they communicate. (p. 68)

The cerebrum includes virtually all parts of the brain except for the primitive brainstem structures. It is divided
into two hemispheres: the right cerebral hemisphere and the left cerebral hemisphere. The left hemisphere controls most of the movement and sensation on the right side of the body. The right hemisphere controls most of the movement and sensation on the left side of the body. Language is processed primarily in the left hemisphere. Running between the two hemispheres is the corpus callosum, a band of fibers that connects the activities of the two hemispheres, allowing for communication between them.

LO 9 Explain lateralization and how split-brain operations affect it. (p. 69)
Each hemisphere excels in certain activities, which is known as lateralization. The left hemisphere excels in language and the right hemisphere excels in visual spatial tasks. Under certain experimental conditions, split-brain operation participants act as if they have two separate brains, each hemisphere exhibiting its own specialization.

LO 10 Identify areas in the brain responsible for language production and comprehension. (p. 72)
There are several areas in the brain that together are responsible for speech. Broca’s area is primarily responsible for speech production, and Wernicke’s area is primarily responsible for language comprehension.

LO 11 Define neuroplasticity and recognize when it is evident in brains. (p. 73)
Neuroplasticity refers to the ability of the brain to form new connections between neurons and adapt to changing circumstances, including structural changes in the brain. Vast networks of neurons have the ability to reorganize in order to adapt to the environment and an organism’s ever-changing needs—a quality that is particularly evident in the young.

LO 12 Compare and contrast tools scientists use to study the brain. (p. 76)
There are a variety of technologies used to study the brain. The EEG detects electrical impulses in the brain. The CT uses X-rays to create many cross-sectional images of the brain. The MRI uses pulses of radio frequency waves to produce more detailed cross-sectional images than does a CT scan; however, both study the structure of the brain. The PET uses radioactivity to track glucose consumption to construct a map of the brain. The fMRI also captures changes in activity in the brain. However, instead of tracking glucose consumption, it reveals patterns of blood flow in a particular area of the brain, which is a good indicator of how much oxygen is being used as a result of activity in that particular area.

LO 13 Identify the lobes of the cortex and explain their functions. (p. 79)
The outermost layer of the cerebrum is the cerebral cortex. The cortex is separated into different sections called lobes. The major function of the frontal lobes is to organize information among the other lobes of the brain. The frontal lobes are also responsible for higher-level cognitive functions, such as thinking and personality characteristics. The parietal lobes receive and process sensory information such as touch, pressure, temperature, and spatial orientation. Visual information goes to the occipital lobes, where it is processed. The temporal lobes are primarily responsible for hearing and language comprehension.

LO 14 Recognize the association areas and identify their functions. (p. 79)
The lobes include networks of neurons that specialize in certain activities: motor areas, sensory areas, and association areas. The motor areas direct movement, the sensory areas receive and analyze sensory stimuli, and the association areas integrate information from all over the brain, allowing us to learn, have abstract thoughts, and carry out complex behaviors.

LO 15 Distinguish the structures and functions of the limbic system. (p. 84)
The limbic system is a group of interconnected structures that play an important role in our experiences of emotion and our memories. The limbic system includes the hippocampus, amygdala, thalamus, and hypothalamus. In addition to processing emotions and memories, the limbic system fuels the most basic drives, such as hunger, sex, and aggression.

LO 16 Distinguish the structures and functions of the brainstem and cerebellum. (p. 85)
The brain’s ancient core consists of a stalklike trio of structures called the brainstem, extending from the spinal cord to the forebrain, which is the largest part of the brain and includes the cerebral cortex and the limbic system. Located at the top of the brainstem is the midbrain, and although there is some disagreement about which brain structures belong to the midbrain, most agree it plays a role in levels of arousal. The hindbrain includes areas of the brain responsible for fundamental life-sustaining processes.
key terms

action potential, p. 56
adrenal glands, p. 67
all-or-none, p. 56
amygdala, p. 84
association areas, p. 79
autonomic nervous system, p. 64
axon, p. 53
biological psychology, p. 51
Broca’s area, p. 72
cell body, p. 53
central nervous system (CNS), p. 61
cerebellum, p. 86
cerebral cortex, p. 79
cerebrum, p. 68
corpus callosum, p. 69
dendrites, p. 53
endocrine system, p. 66
forebrain, p. 85
frontal lobes, p. 79
glial cells, p. 53
hindbrain, p. 85
hippocampus, p. 84
hormones, p. 66
hypothalamus, p. 85
interneurons, p. 62
lateralization, p. 71
limbic system, p. 84
medulla, p. 85
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motor cortex, p. 81
motor neurons, p. 62
myelin sheath, p. 53
nerves, p. 63
neurogenesis, p. 74
neurons, p. 52
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neuroscience, p. 51
neurotransmitters, p. 56
occipital lobes, p. 79
parasympathetic nervous system, p. 64
parietal lobes, p. 79
peripheral nervous system (PNS), p. 61
phrenology, p. 75
pituitary gland, p. 66
pons, p. 85
receptor sites, p. 57
reflex arc, p. 63
resting potential, p. 54
reticular formation, p. 85
reuptake, p. 57
sensory neurons, p. 62
somatic nervous system, p. 63
somatosensory cortex, p. 82
spinal cord, p. 61
split-brain operation, p. 69
stem cells, p. 74
sympathetic nervous system, p. 64
synapse, p. 53
temporal lobes, p. 79
thalamus, p. 85	hyroid gland, p. 67
Wernicke’s area, p. 72

TEST PREP  are you ready?

1. __________ are the specialized cells found in the nervous system that are the building blocks of the central nervous system and the peripheral nervous system.
   a. Neurotransmitters  c. Neurons
   b. The hemispheres  d. Hormones

2. When positive ions at the axon hillock raise the internal cell voltage of the first segment of the axon from its resting voltage to its threshold potential, the neuron becomes activated. This spike in electrical energy causes __________ to occur.
   a. an action potential  c. a reflex arc
   b. reuptake  d. lateralization

3. A colleague of yours tells you that she has been diagnosed with multiple sclerosis. Luckily, the disease was diagnosed early and she is getting state-of-the-art treatment. So far, it does not appear that she has experienced problems with the __________ covering the axons in her nervous system.
   a. myelin sheath  c. glutamate
   b. reticular formation  d. neurotransmitters

4. Match the neurotransmitter with its primary role(s).
   ______ acetylcholine
   ______ 2. glutamate
   ______ 3. endorphins
   ______ 4. serotonin
   a. reduces experience of pain
   b. learning, memory
   c. enables movement
   d. mood, aggression, appetite

5. A neuroscientist studying the brain and the spinal cord would describe her general area of interest as the:
   a. central nervous system.
   b. peripheral nervous system.
   c. autonomic nervous system.
   d. neurons.

6. A serious diving accident can result in damage to the __________, which is responsible for receiving information from the body and sending it to the brain, and for sending information from the brain throughout the body.
   a. corpus callosum  c. reflex arc
   b. spinal cord  d. somatic nervous system

7. While sitting at your desk, you hear the tone signaling an incoming e-mail. That sound is received by your auditory system and information is sent via sensory neurons to your brain. Here, we can see how the __________ provides a communication link between the central nervous system and the rest of the body.
   a. endocrine system  c. corpus callosum
   b. cerebrum  d. peripheral nervous system

8. After facing a frightening situation in a war zone, Brandon’s parasympathetic nervous system is in charge of the:
   b. “fight-or-flight” response.
   c. “tend-and-befriend” process.
   d. “rest-and-digest” process.

9. Lately, your friend has been prone to mood swings and aggressive behavior. The doctor has pinpointed a problem in his __________, which is a communication system that uses __________ to convey messages via hormones.
   a. endocrine system; action potentials
   b. endocrine system; glands
   c. central nervous system; glands
   d. central nervous system; peripheral nervous system
10. Which of the following statements is correct regarding the function of the right hemisphere in comparison to the left hemisphere?
   a. The right hemisphere is less competent handling visual tasks.
   b. The right hemisphere is more competent handling visual tasks.
   c. The left hemisphere is more competent judging if lines are oriented similarly.
   d. The right hemisphere is more competent with speech production.

11. Although Gall’s phrenology has been discredited as a true brain “science,” Gall’s major contribution to the field of psychology is the idea that:
   a. locations in the brain are responsible for certain activities.
   b. the left hemisphere is responsible for activity on the right side of the body.
   c. the left hemisphere is responsible for language production.
   d. stem cells can be used to repair tissue that has been damaged.

12. Broca’s area is involved in speech production, and ____________ is critical for language comprehension.
   a. the corpus callosum
   b. the right hemisphere
   c. the parietal lobe
   d. Wernicke’s area

13. Match the structures with their principle functions:
   ____. 1. association area
   ____. 2. temporal lobes
   ____  3. meninges
   ____  4. occipital lobes
   ____  5. parietal lobes
   a. three thin membranes protect brain
   b. integrates information from all over brain
   c. hearing and language comprehension
   d. receives sensory information, such as touch
   e. processes visual information

14. The limbic system is a group of interconnected structures in the brain. Match the structures below with their principle functions:
   _____ 1. amygdala
   _____ 2. hippocampus
   _____ 3. hypothalamus
   _____ 4. thalamus
   a. responsible for making new memories
   b. processes basic emotions
   c. relays sensory information
   d. keeps body systems in steady state

15. The ____________ is located in the midbrain and is responsible for levels of arousal and your ability to selectively attend to important stimuli.
   a. cerebellum
   b. thalamus
   c. hippocampus
   d. reticular formation

16. Describe the differences between the agonists and antagonists and develop an analogy to help you remember these differences.

17. The “knee-jerk” reaction that occurs when a doctor taps your knee with a rubber hammer provides a good example of a reflex arc. Describe this involuntary reaction and then draw your own diagram to show the reflex arc associated with it.

18. Describe two major differences between neurotransmitters and hormones and how they influence behavior.

19. The research conducted by Sperry and Gazzaniga examined the effects of surgeries that severed the corpus callosum. Describe what these split-brain experiments tell us about the lateralization of the hemispheres of the brain and how they communicate.

20. We described a handful of tools scientists use to study the brain. Compare their functions and weaknesses.

   ✔ CHECK YOUR ANSWERS IN APPENDIX C.

Get personalized practice by logging into LaunchPad at http://www.worthpublishers.com/launchpad/Licht to take the LearningCurve adaptive quizzes for Chapter 2.