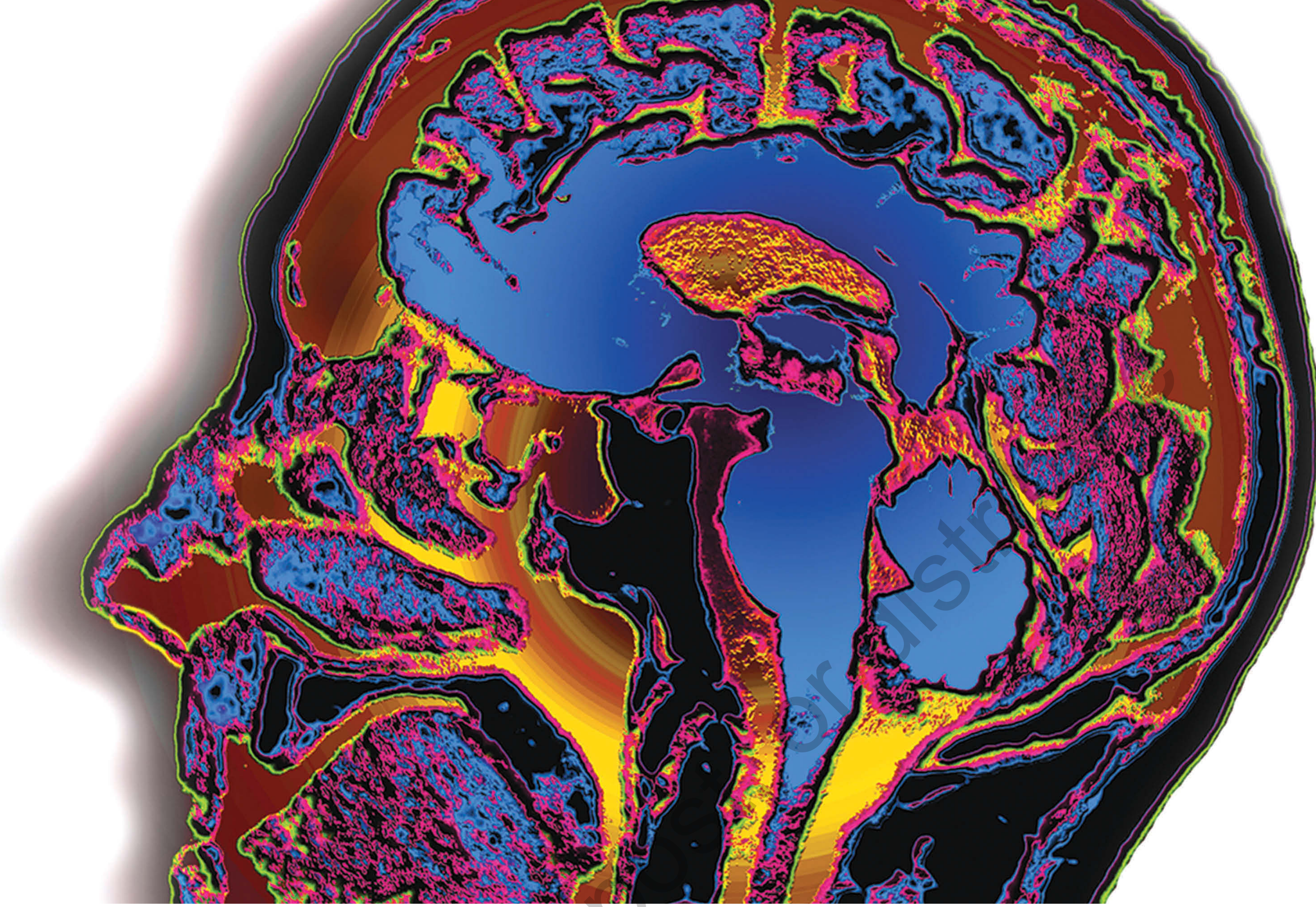

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3

BIOLOGICAL PROCESSES

LEARNING OBJECTIVES

3.1 Identify and describe the three major types of neurons—their structure and function—and explain how the steps of neural transmission solve the problem of connecting world and brain.

3.2 Identify the two major parts of the nervous system and discuss how specialized structures in the brain initiate and control the components of behavior and mind.

3.3 Explain the major functions of the endocrine system, especially the need for long-term and extended communication, and contrast this communication system with neural transmission.

3.4 Assess how psychologists determine which features of our body and mind are adaptations—that is, products of natural selection—and the role that genetics plays in the process.

3.5 For each of the major sections of the chapter, summarize how biological processes solve critical problems of behavior and mind.

CHAPTER OUTLINE

Located within the confines of a protective layer of bone floats a 3- to 4-pound mass of tissue called the brain. Fueled by simple blood sugar and amino acids, the brain's billions of cells are engaged in a continuous dance of activity. The rhythms and movements of this dance are not well understood, but a "whole" is created that is collectively greater than the sum of the individual parts. From chaotic patterns of cellular activity arise the complexities of human behavior, thought, emotion, and creativity.

Psychologists assume that virtually all our actions arise from the activity of this brain—not just mundane things like breathing, maintaining a beating heart, and walking, but our intimate thoughts and feelings as well. Every time you think, act, or feel, biological activity in your brain plays a critical, if not primary, role. Disorders of the mind, such as schizophrenia and clinical depression, are products of the brain as well. This chapter introduces you to the field of **neuroscience**, which studies the connection between the brain and behavior.

THE PROBLEMS TO BE SOLVED: WHAT ARE BIOLOGICAL SYSTEMS FOR?

Our discussion of biological processes revolves around four central questions:

1. How do we communicate internally?
2. How do we initiate and control behavior?
3. How do we regulate growth and other internal functions?
4. How do we adapt and transmit the genetic code?

Each question represents a critical problem that must be solved by the systems in our bodies. Not surprisingly, each plays a critical role in explaining psychological phenomena as well. As you'll soon see, we've evolved a set of sophisticated tools to meet these needs.

Communicating Internally: Connecting World and Brain

Our actions are often adaptive because we're able to monitor the environment continuously and produce quick and appropriate responses. If a dog suddenly runs in front of your car, you quickly hit the brake, saving the animal. These nearly instantaneous world-to-behavior links are possible because of a sophisticated communication network linking the outside world to the brain. Information from the environment is translated into the language of the nervous system and relayed to appropriate processing sites throughout the body.

Initiating Behavior: A Division of Labor

The nervous system may handle the complicated task of receiving and communicating information, but information by itself does not translate into hand movements, quick reactions, or artistic creativity. Somehow the body must assign meaning to the information it receives and coordinate the appropriate responses. As you'll see, there are specific structures in the brain that initiate and coordinate our thoughts, actions, and emotions.

Regulating Growth and Internal Functions: Extended Communication

The systems in the body also have widespread and long-term internal communication needs. To resolve these needs, structures in the body control the release of chemicals into the bloodstream that serve important regulatory functions, influencing growth and development, sexual behavior, the desire to eat or drink, and even emotional expression.

Adapting and Transmitting the Genetic Code

The genetic code you inherited from your parents has been shaped by the forces of natural selection. It determines much of who you are and what you have the potential to become. Molecules carrying the genetic code influence more than eye color, height, and hair color. Intelligence, personality, and even susceptibility to mental disorders can be influenced significantly by genetic information. We'll review the basic principles of genetics and discuss how nature and nurture interact to guide and constrain behavior.

COMMUNICATING INTERNALLY: CONNECTING WORLD AND BRAIN

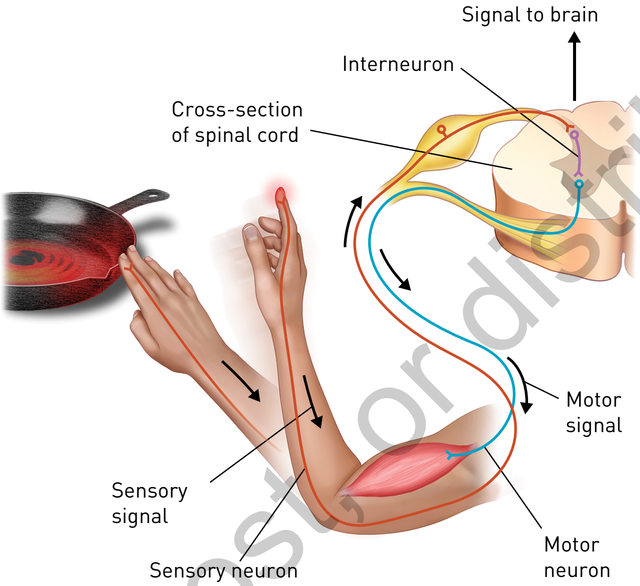
Strike a match and hold it an inch or so away from the tip of your index finger. Now move it a bit closer. Closer. Closer still. Let the flame approach and momentarily touch the flesh of your finger. On second thought, skip this experiment. You already know the outcome. Flame approaches flesh, and you withdraw your finger quickly, automatically, and efficiently. Let's consider the nervous system mechanisms that produce this kind of reaction, because it represents one of the simplest kinds of world-to-brain communications. The main components of the nervous system are individual cells, called **neurons**, that receive, transmit, and integrate information. The language used by the neurons to communicate is *electrochemical*—that is, it's part electrical and part chemical. There are three major types of neurons:

1. **Sensory neurons** make the initial contact with the environment and are responsible for carrying the message inward toward the spinal cord and brain. The heat of the flame excites receptor regions in the sensory neurons in your fingertip, which then pass the message along to the spinal cord.
2. **Interneurons**, the most plentiful type of neuron, make no direct contact with the world, but they convey information from one internal processing site to another. Interneurons in the spinal cord receive the message from the sensory neurons, then pass it on to the motor neurons.

3. **Motor neurons** carry the messages and commands away from the central nervous system to the muscles and glands that produce responses. In the match example in Figure 3.1, the motor neurons contact the muscles of the finger, which leads to a quick and efficient finger withdrawal.

FIGURE 3.1 ■ A Simple Reflex Pathway

The information that a hot pan has touched flesh travels through a sensory neuron to the spinal cord, which directs it to an interneuron, which sends it on to a motor neuron. The motor neuron then alerts the finger muscles, which quickly withdraw from the heat. The original information is also passed upward to the brain, which registers pain.



Carolina Hrejsa/Body Scientific Intl.

The nervous system also contains **glial cells**, which perform support functions such as removing waste, filling in empty space, and helping neurons to communicate efficiently. Neuroscientists used to believe that glial cells vastly outnumbered neurons in the nervous system (perhaps by as much as 10:1), but the true ratio of glial cells to neurons is probably closer to 1:1 (von Bartheld et al., 2016). Glial cells help speed up neural transmission by acting as insulation for the neuron. They form a coating called the **myelin sheath** that protects the cell, much like the rubber or plastic coating around an electrical wire protects it from environmental threats and leakage. Glial cells are thought to play a role in a wide variety of brain processes, including learning and memory (De Pitta et al., 2016) and even the control of body weight (García-Cáceres et al., 2019). The reason is that glial cells seem to be capable of modulating neuron activity in selective areas of the brain. Glial cells are also of interest because they play an important role in brain dysfunction, including brain cancer, Parkinson's disease, multiple sclerosis, and possibly even psychological disorders such as schizophrenia and bipolar disorder.

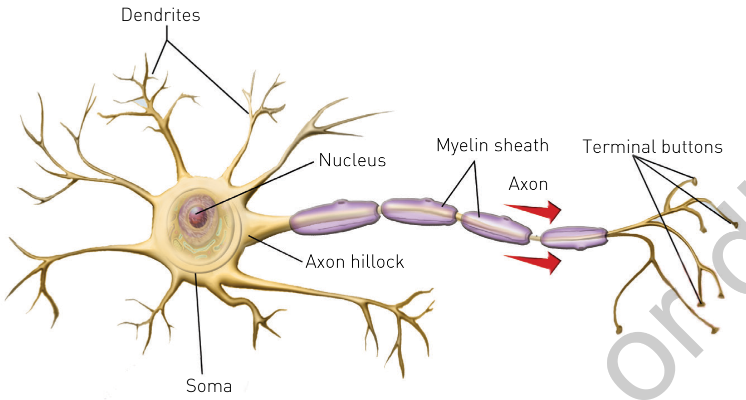
So far, the brain hasn't figured into our discussion of fingers and flames. The message is passed upward to the brain, through the activity of more interneurons, and you consciously experience the heat of the flame in the brain. But in situations requiring a quick response, as in the case of a flame touching your finger, the nervous system can produce a collection of largely automatic reactions. These reactions, called **reflexes**, are controlled primarily by spinal cord pathways. A reflex requires no input from the brain. Cut the spinal cord, blocking communication between most of the body and the brain, and you won't feel the pain or react with a facial grimace, but your finger will still twitch. Reflex pathways allow the body to respond quickly to environmental events in a simple and direct way. People don't think or feel with their spinal cords, but reflex pathways are an important part of our ability to adapt successfully to the world.

The Anatomy of Neurons

As shown in Figure 3.2, neurons have four major structural parts: *dendrites*, a *soma*, an *axon*, and *terminal buttons*. For a communication system to work properly, it must have a way to receive information, a way to process received messages, and a means for generating an appropriate response. The four components of the neuron play these roles in the communication chain.

FIGURE 3.2 ■ The Components of a Neuron

The dendrites are the primary information receivers, the soma is the cell body, and the axon transmits the cell's messages. The myelin sheath that surrounds the axon helps speed up neuron transmission. Terminal buttons at the end of the axon contain the chemicals that carry messages to the next neuron.



The **dendrites**, which look like tree branches extending outward from the main body of the cell, are the primary information receivers. A sensory neuron passes information about a burning flame along to an interneuron by interacting with the interneuron's dendrites. A particular neuron may have thousands of these dendritic branches, enabling the cell to receive input from many different sources. Once received, the message is processed in the **soma**, the main body of the cell. The soma is also the cell's metabolic center, and it is where genetic material is stored. The **axon** is the cell's transmitter. When a neuron transmits a message, it sends an electrical pulse called the *action potential* down its axon toward other neurons. Near its end the axon branches out to contact other cells. At the tip of each branch are tiny swellings called **terminal buttons**. Chemicals released by these buttons pass the message on to the next neuron.

Neurons don't touch. The **synapse** is a small gap between cells, typically between the terminal buttons of one neuron and the dendrite or cell body of another. The chemicals released by the terminal buttons flow into this gap. The synapse and the chemicals released into it are critical factors in the body's communication network, as you'll see next.

Solving the Transmission Problem: The Electrochemical Message

Neurons may differ in size and shape, but the direction of information flow is predictable and consistent:

Dendrites → Soma → Axon → Terminal buttons

Information arrives at the dendrites from multiple sources—many thousands of contacts might be made—and is passed along to the soma. Here all the received messages sum together; if the combined message strength exceeds a threshold, an action potential will be generated. The action potential travels down the axon toward the terminal buttons, where it causes the release of chemicals into the synapse. These chemicals move the message from the end of the axon to the dendrites of the next neuron, starting the process all over again. That's the general sequence of information flow: Messages travel electrically from one point to another within a neuron, but the message is transmitted chemically between neurons. Now let's consider each of these processes in more detail.

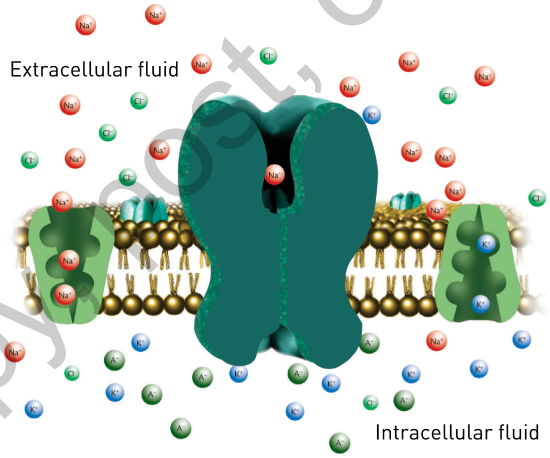
The Resting Potential

Neurons possess electrical properties even when they aren't receiving or transmitting messages. Specifically, a tiny electrical charge, called the **resting potential**, exists between the inside and the outside of the cell. This resting potential is created by the presence of electrically charged atoms and molecules, called *ions*, that are distributed unevenly between the inside and the outside of the cell. The main ions in neural transmission are positively charged *sodium* and *potassium* ions and negatively charged *chloride* ions. Normally, ions will distribute themselves evenly in an environment through a process called diffusion. However, the neuron's cell wall, or membrane, only allows certain ions to pass in and out through special ion channels.

As shown in Figure 3.3, when the neuron is resting, the sodium and chloride ions are concentrated outside of the cell, and the potassium ions are largely contained inside. These unequal concentrations are maintained, in part, by a sodium–potassium pump that actively moves the ions into and out of the cell. If you measured the electrical potential of the neuron, you would find that the fluid inside the cell is slightly negative with respect to the outside (between –60 and –70 millivolts). Most of the negative charge comes from large protein molecules inside the cell, which are too big to pass through the ion channels.

FIGURE 3.3 ■ The Resting Potential

Neurons possess electrical properties even when they are neither receiving nor transmitting messages. The resting potential, a tiny negative electrical charge across the inside and outside of a resting cell, is created by an uneven distribution of ions across the cell membrane.



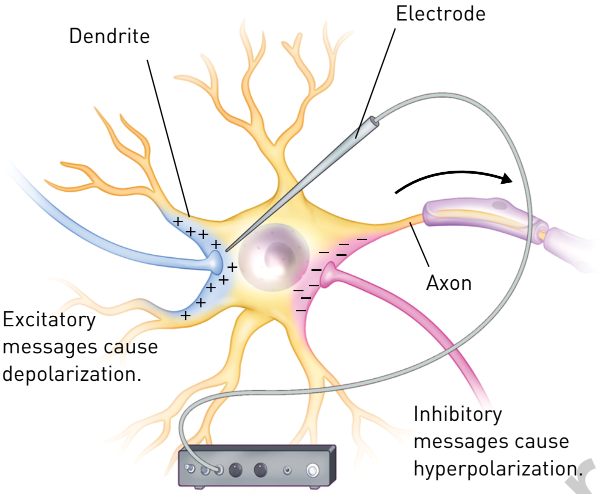
Generating an Action Potential

For a neuron to generate an **action potential**—that is, fire its own message—the electrical potential inside the cell needs to change. This change happens because of contact from other neurons. Two types of messages can be passed from one neuron to the next, excitatory messages and inhibitory messages. If the message is excitatory, the ion channels in the cell membrane open, and sodium ions flow into the cell. This process is called *depolarization*, and it moves the electrical potential of the cell from negative toward zero. When the message is inhibitory, the opposite happens: The cell membrane either pushes more positive ions out of the cell or allows negative ions to move in. The result is *hyperpolarization*: The electrical potential of the cell becomes more negative.

Remember, each neuron in the nervous system is in contact with many other neurons. As a result, small changes in potential occur in many input regions of the neuron as messages are received (see Figure 3.4). Near the point where the axon leaves the cell body, in a special trigger zone called the *axon hillock*, all of the excitatory and inhibitory potentials combine. If enough excitatory messages have been received—that is, if the net electrical potential inside the cell has become sufficiently less negative—the cell will "fire," and an action potential will be generated.

FIGURE 3.4 ■ Summing Excitatory and Inhibitory Messages

Each neuron is in contact with many other neurons. Some contacts initiate excitatory messages, or depolarization, and others initiate inhibitory messages, or hyperpolarization. A neuron generates its own action potential only if the summed messages produce sufficient depolarization (the negative potential moves closer to zero).



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The firing of an action potential is an *all-or-none* process. It fires either completely or not at all. Once the firing threshold is reached, meaning there has been a sufficient change in the electrical potential around the axon hillock, the action potential begins and travels completely down the axon toward the terminal buttons. The process is somewhat like flushing a toilet. Once sufficient pressure is delivered to the handle, the toilet flushes, and it doesn't matter how hard you yank on the handle. The same is true for an action potential—increasing the intensity of the original message does not increase the intensity of the nerve impulse. There simply has to be enough of a potential change to get the message started.

The speed of the message, however, can depend on the axon's size and shape. In general, the thicker the axon, the faster the message will travel. The speed of an action potential varies among neurons in a range from about 2 to 200 miles per hour (which is still significantly slower than the speed of electricity through a wire or printed circuit). Another factor that increases the speed of transmission is the myelin sheath. Myelin provides insulation for the axon, similar to the plastic around copper wiring. At regular points there are gaps in the insulation, called *nodes of Ranvier*, that permit the action potential to jump down the axon rather than traveling from point to point. This method of transmission from node to node is called *saltatory conduction*; it comes from the Latin *saltare*, which means "to jump." The myelin sheath speeds transmission, and it also protects the message from interference by other neural signals.

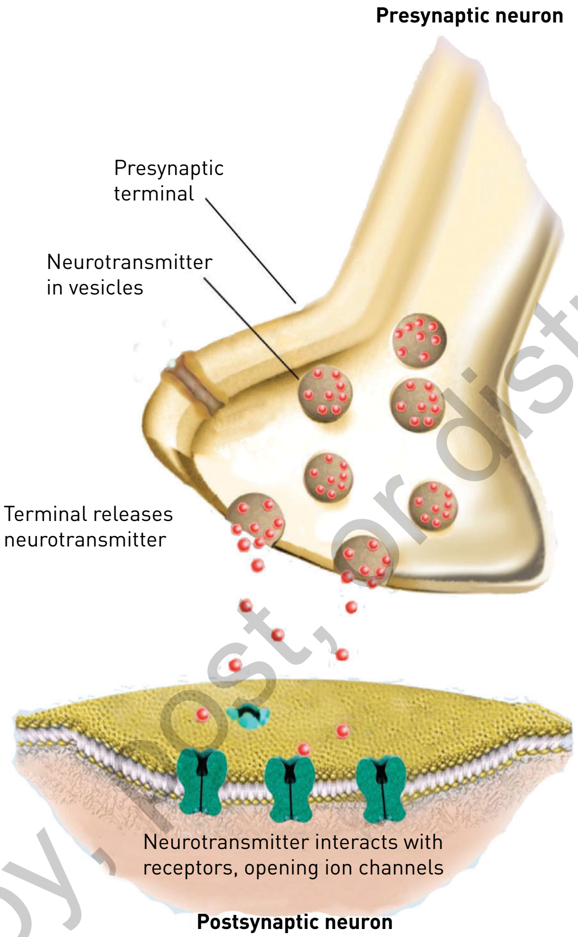
Neurotransmitters: The Chemical Messengers

When the action potential reaches the end of the axon, it triggers the release of chemical messengers from small sacs, or vesicles, in the terminal buttons (see Figure 3.5). These chemical molecules, called **neurotransmitters**, spill out into the synapse and interact chemically with the cell membrane of the next neuron (called the postsynaptic membrane). Depending on the characteristics of this membrane, the neurotransmitter will transfer either an excitatory or an inhibitory message.

The released neurotransmitter acts as a kind of key in search of the appropriate lock. It flows quickly across the synapse and activates receptor molecules contained in the postsynaptic membrane. When the message is excitatory, the neurotransmitter causes channels in the cell wall to open, allowing positive sodium ions to flow into the receiving cell. When the message is inhibitory, negative chloride ions can enter the cell, and positive potassium ions are allowed to leave. It is important to note, though, that

FIGURE 3.5 ■ Releasing the Chemical Messengers

When the action potential reaches the end of the axon, chemical messengers, or neurotransmitters, are released into the synapse, where they interact with the postsynaptic membrane of the next neuron, opening or closing its ion channels.



neurotransmitters, by themselves, are neither excitatory nor inhibitory. It is really the nature of the receptor molecule that determines whether a particular neurotransmitter will produce an excitatory or inhibitory effect; the same neurotransmitter can produce quite different effects at different sites in the nervous system.

We don't know how many different neurotransmitters exist in our brain, but some important ones have been identified and are well studied. The most common neurotransmitter in the brain is **glutamate**. Glutamate is an excitatory neurotransmitter, and it's involved in many aspects of brain functioning, including memory. The neurotransmitter **acetylcholine** acts as the primary transmitter between motor neurons and muscles in the body. When released into the synapse between motor neurons and muscle cells, acetylcholine creates excitatory messages that lead to muscle contraction. Any voluntary motor movement, like lifting your arm or walking, involves acetylcholine. The neurotransmitter **dopamine**, which can produce either excitatory or inhibitory effects, is also involved in motor movements. Dopamine helps to dampen and stabilize communications in the brain and elsewhere. Inhibitory effects of this type keep the brain on an even keel and allow us to produce smooth voluntary muscle movements, sleep without physically acting out our dreams, and maintain posture. If neurotransmitters had only excitatory effects, there would be an endless chain of communication, producing a blooming, buzzing ball of confusion in the brain.

Dopamine is of special interest to psychologists because it's thought to play a role in reward and pleasure but also schizophrenia, a serious psychological disorder that disrupts thought processes and produces delusions and hallucinations. When patients with schizophrenia take drugs that inhibit the action of dopamine, their hallucinations and delusions are often reduced or even eliminated. It's been suggested that an inability to regulate dopamine successfully in the brain is partly responsible for this debilitating disorder (e.g., Maia & Frank, 2017). Further support linking dopamine and schizophrenia comes from the study of Parkinson's disease, a movement disorder that results from the underproduction of dopamine. Parkinson's patients are sometimes given the drug L-dopa, which increases the levels of dopamine in the brain, to reduce the tremors and other movement problems caused by the disease. For some patients, however, one of the side effects of L-dopa is a mimicking of the thought disorders characteristic of schizophrenia (Schmack et al., 2018).

Neurotransmitters in the brain control our thoughts and actions—that much is clear—but the mechanisms are not well understood. We know, for example, that people with Alzheimer's disease have suffered destruction of cells that play a role in producing acetylcholine (Kandimalla & Reddy, 2017). Because memory loss is a common problem for Alzheimer's patients, a close connection is believed to exist between acetylcholine and certain kinds of memory functioning. **Serotonin** affects sleep, dreaming, and general arousal and may be involved in a host of psychological disorders including depression, obsessive–compulsive disorder, and autism spectrum disorder (C. L. Muller et al., 2016). Many medications used to treat depression, such as Prozac (fluoxetine), act by modulating the effectiveness of serotonin. Similarly, researchers have suspected for some time that a neurotransmitter called **gamma-aminobutyric acid (GABA)** plays an important role in the regulation of anxiety. Many medications for anxiety (e.g., tranquilizers such as Valium) regulate GABA in the brain.

Researchers are trying to understand the neural pathways involved in these effects and disorders. However, much of our knowledge remains correlational at this point—we know that as the levels of particular neurotransmitters vary in the body, so too do the symptoms of disorders. This is useful information for treatment, but it doesn't establish a true cause-and-effect link between neurotransmitters and psychological characteristics. For example, current medications for schizophrenia target dopamine receptors in the brain, and can be quite effective in reducing symptoms of the disorder, but these medications affect other neurotransmitter receptor systems as well. Hence, it can be difficult to determine exactly what is responsible for any improvement (Howes et al., 2015). For a summary of neurotransmitters and their effects, see Concept Review 3.1.

CONCEPT REVIEW 3.1
NEUROTRANSMITTERS AND THEIR EFFECTS

Neurotransmitter	Nature of Effect*	What It Is Involved In
Glutamate	Excitatory	Most common neurotransmitter in the brain. Probably involved in a host of mental processes, including learning and memory.
Dopamine	Mixed	Involved in reward/pleasure systems; helps ensure smooth motor function. Plays a role in both schizophrenia and Parkinson's disease.
Acetylcholine	Excitatory	Communication between motor neurons and muscles in the body, leading to muscle contraction. May also play a role in Alzheimer's disease.
Serotonin	Inhibitory	Involved in sleep, mood, appetite, and general arousal. Thought to play a role in some psychological disorders, including depression.
GABA	Inhibitory	The regulation of anxiety; tranquilizing drugs act on GABA to decrease anxiety.

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* *Note:* A neurotransmitter, on its own, can be either excitatory or inhibitory; the nature of its action depends on specific characteristics of the receiving cell's membrane.

Drugs and the Brain

Because the transmission of messages between neurons is chemical, if you consume a drug—by swallowing, smoking, snorting, or another method of ingestion—it can significantly affect the communication networks in your brain. Drugs called *agonists* enhance or mimic the action of neurotransmitters. For example, the nicotine in cigarette smoke can act like the neurotransmitter acetylcholine. Nicotine stimulates the body, such as by increasing heart rate, because it produces excitatory messages in much the same way as acetylcholine. Cocaine is an agonist for dopamine—it allows dopamine to linger longer in the synapse, increasing its effectiveness.

The caffeine in coffee interferes with drowsiness by interacting with the chemical messenger systems in the brain.

iStockPhoto/Halfpoint

Other drugs act as *antagonists*, which means that they block the action of neurotransmitters. As mentioned earlier, many of the drugs used to treat schizophrenia are antagonists for dopamine—they bind to receptors and block the effect of dopamine release. The lethal drug curare, which is sometimes used on the tips of hunting arrows and blow darts in South America, is antagonistic to acetylcholine. Curare blocks the receptor systems involved in muscle movements, including those muscles that move the diaphragm during breathing. The result is paralysis and likely death from suffocation. Botox, which is commonly used cosmetically to treat facial wrinkles, is an antagonist as well—it also blocks the release of acetylcholine, which, in turn, prevents muscle contractions and allows bothersome wrinkles to relax and soften. Of course, in its more lethal form—the deadly illness botulism—the antagonistic effects are more widespread, disrupting the ability to breathe and swallow.

In the early 1970s, membrane receptor systems were discovered in the brain that react directly to morphine, a painkilling and highly addictive drug derived from the opium plant (Pert & Snyder, 1973; S. H. Snyder, 2017). Of course, we aren't born with morphine in our brains. It turns out we have receptor systems that are sensitive to morphine because the brain produces its own morphine-like substances called **endorphins**. Endorphins serve as natural painkillers in the body. Systems in the brain release endorphins under conditions of stress or exertion to reduce pain and possibly to provide pleasurable reinforcement (Pert, 2002). As you may already know, endorphins have been linked to the so-called runner's high. It's well established, in fact, that prolonged exercise can indeed lead to endorphin release. Some have even suggested that people can become "addicted" to exercise and experience withdrawal-like symptoms if regular exercise is discontinued. As this point, though, the connection between runner's high, endorphins, and exercise addiction remains controversial (see Szabo et al., 2019). Moreover, it's important not to confuse the runner's high with the mind-altering effects of opioid medications. As you know, there is a serious opioid crisis in the United States and elsewhere. We'll return to the study of drugs, particularly their effects on conscious awareness, in Chapter 6.

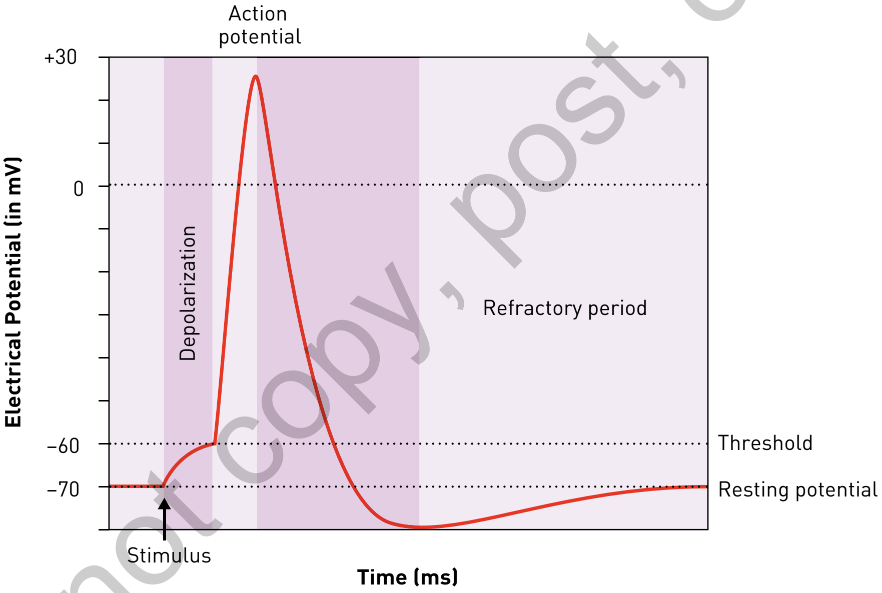
The Communication Network

To unravel the complex relationship between the brain and mental processes, we must understand how neurons work together. A vast communication network exists within the brain, involving the operation of thousands of neurons. The way in which these cells interact is critically important. Behaviors, thoughts, feelings, ideas—they don't arise from the activation of single neurons; instead, it is the *pattern of activation* produced by groups of neurons operating together that produces conscious experience and complex behaviors. As a result, we need to be mindful of the specific ways in which neurons are connected and the means through which those connections can be modified by experience.

Information is partly communicated in the nervous system by the *firing rate* of a neuron, which means the number of action potentials it generates per unit of time. The stronger the incoming message, the more rapidly the receiving neuron tends to fire. These firing rates, however, are subject to some natural limitations. For instance, a **refractory period** usually follows the generation of an action potential; during this period, additional action potentials cannot be generated (see Figure 3.6). Even with the refractory period, though, neurons are still able to fire off a relatively steady stream of messages in response to environmental input. Many neurons even appear to have spontaneous firing rates, which means they generate a steady stream of action potentials with little or no apparent input from the environment. A continuously active cell is adaptive because more information can be coded by increasing or decreasing a firing rate than by simply turning a neuron on or off.

FIGURE 3.6 ■ The Action Potential and Its Refractory Period

A refractory period usually follows the generation of an action potential; during this period, additional action potentials cannot be generated.



Carolina Hrejsa/Body Scientific Intl.

Because the brain contains billions of neurons, it's impractical to try to map out individual neural connections. So how can we ever hope to discover how everything works together to produce behavior? One solution is to study nonhuman organisms, whose circuits of neurons are less complex and more easily mapped. Another option is to try to simulate activity of the mind—such as simple learning and memory processes—by creating artificial networks of neurons on computers.

At this point, no one has come close to achieving anything resembling an artificial brain, but simple computerized networks have been developed that show brainlike properties. For example, computerized neural networks can recognize objects when given incomplete information and can perform reasonably well if artificially damaged. If a subset of input units is turned off, perhaps mimicking damage to the brain, activation of the remaining units can still be sufficient to produce the correct output response. This is an adaptive characteristic of both neural circuits in the brain and neural networks. Each can sustain damage and still produce correct responses.

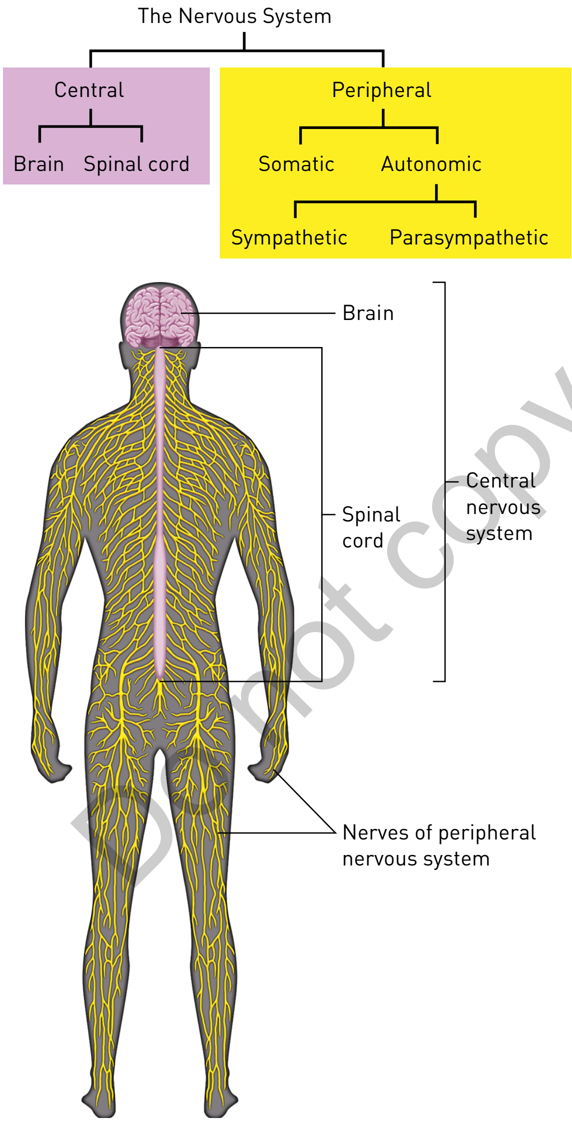
KNOWLEDGE CHECK 3.1

Now test your knowledge about neurons and how they communicate. Select your answers from the following list of terms: *dendrites, soma, axon, terminal buttons, action potential, neurotransmitters, refractory period*. (You will find the answers in the Appendix.)

1. The main body of the cell, where excitatory and inhibitory messages combine: ________
2. The long tail-like part of a neuron that serves as the cell's main transmitter device: ________
3. The all-or-none electrical signal that travels to the end of the axon, causing the release of chemical messengers: ________
4. The branchlike fibers that extend outward from a neuron and receive information from other neurons: ________
5. Acetylcholine, serotonin, GABA, and dopamine are all examples of ________

FIGURE 3.7 ■ The Nervous System

The central nervous system contains the brain and the spinal cord, and the peripheral nervous system is made up of the nerves outside the brain and spinal cord.



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INITIATING BEHAVIOR: A DIVISION OF LABOR

The nervous system has a lot of tough problems to solve. Besides generating behavior and mental processes such as thinking and feeling, the brain must maintain a beating heart, control breathing, and signal the body that it's time to eat. If your body is deprived of food or water, or if its constant internal temperature gets out of whack, you must be motivated to find food, water, or the appropriate shelter. Even the simplest of everyday activities—producing spoken language, walking, perceiving a complex visual scene—require a great deal of coordination among the muscles and sensory organs of the body. To accomplish these different functions, the nervous system divides its labor.

The Central and Peripheral Nervous Systems

The nervous system is divided into two major parts, the **central nervous system** and the **peripheral nervous system**. The central nervous system consists of the brain and spinal cord and acts as the central executive of the body. Decisions are made here, and messages are then communicated to the rest of the body via bundles of axons called **nerves**. The nerves outside the brain and spinal cord form the peripheral nervous system.

It is through the peripheral nervous system that muscles are moved, internal organs are regulated, and sensory input is directed toward the brain. As you can see in Figure 3.7, the peripheral nervous system can be divided further into the somatic and autonomic systems. Information travels to the brain and spinal cord through *afferent* (sensory) nerve pathways; *efferent* (motor) nerve pathways carry central nervous system messages outward to the muscles and glands. The **somatic system** consists of the nerves that transmit sensory information toward the brain, as well as the nerves that connect to the skeletal muscles to initiate movement. Without the somatic system, information about the environment could not reach the brain, nor could we begin a movement of any kind. The **autonomic system** controls the more automatic needs of the body, such as heart rate, digestion, blood pressure, and the activity of internal glands.

These two systems work together to make certain that information about the world is communicated to the brain for interpretation, that movements are carried out, and that the life-sustaining activity of the body is continued.

One critical function of the autonomic system, besides performing the automatic "housekeeping" activities that keep the body alive, is to help us handle and recover from emergency situations. When we're faced with an emergency, such as a sudden attack, our bodies typically produce a fight-or-flight response. The *sympathetic division* of the autonomic system triggers the release of chemicals, creating a state of readiness (e.g., by increasing heart rate, blood pressure, and breathing rate). After the emergency has passed, the *parasympathetic division* calms the body down by slowing heart rate and lowering blood pressure. Parasympathetic activity also helps increase the body's supply of stored energy, which may be diminished in response to the emergency. We'll be discussing the fight-or-flight response in more detail later in the chapter.

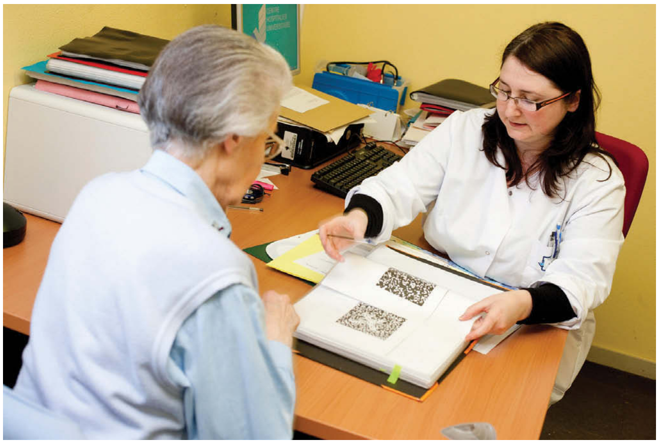
Determining Brain Function

Now let's consider the techniques that researchers use to determine how various parts of the brain work. The anatomical features of the nervous system as a whole—the various nerve tracts and so on—can be studied through dissection of the body (after death, of course!). But the dissection of brain tissue, which contains billions of neurons, tells only a limited story. To determine the architecture of the brain, researchers need a broader set of tools. We'll briefly consider three popular techniques: (1) the study of brain damage, (2) activating the brain, and (3) monitoring the brain in action.

Brain Damage

One of the oldest methods for determining brain function is to study people with brain damage. A patient arrives with an injury—perhaps a blow to the right side of the head—and complains of a specific problem, such as trouble moving the left side of the body. In this way, a link is established between a brain area and its function. As early as the 19th century, it was known that damage to the left side of the brain can create movement problems on the right side of the body as well as specific speech difficulties. Destruction of Wernicke's area results in a patient who cannot easily understand spoken language (Wernicke, 1874); damage to Broca's area produces a patient who can understand but not easily produce spoken language (Broca, 1861). Cases such as these suggest that psychological functions are controlled by specific areas of the brain.

Neuroscientists have made many significant advances by studying brain injury. For example, brain-damaged patients have taught us about how knowledge is organized and represented in the brain (Mahon & Caramazza, 2009). Damage to one part of the brain can affect a person's ability to name tools but not fruit; damage to another area might affect the ability to recognize a face. Neuroscientist V. S. Ramachandran (2011) provides a fascinating account in his book *The Tell-Tale Brain*. We meet Jason who is unable to talk, walk, or recognize people—he follows people with his eyes but otherwise exists in a zombie-like state. When his father visits Jason, Jason is incapable of interaction. But if his father calls him on the phone from another room, Jason suddenly becomes fully conscious and carries on a natural conversation. As Ramachandran notes, "It is as if there are two Jasons trapped inside one body: the one connected to vision, who is alert but not conscious, and the one connected to hearing who is alert *and* conscious" (p. 7).



Neuroscientists have made significant progress in the understanding of brain function by studying people with brain damage.

Phanie / Alamy Stock Photo

Case studies of brain damage are useful, but they do have limitations. For one thing, researchers have no control over when and where the injury occurs. In addition, most instances of brain damage, either from an accident or from a tumor or a stroke, produce widespread damage. It's difficult to know exactly which portion of the damaged brain is responsible for the behavioral or psychological problem.

As we saw in Chapter 2, case studies can be rich sources of information, but the researcher typically lacks important controls. Researchers have taken advantage of the fact that brain tissue contains no pain receptors to explore the effects of brain damage in nonhuman animals. It's possible to destroy, or *lesion*, particular regions of an animal's brain by administering an electric current, injecting chemicals, or cutting tissue. Even here it is difficult to pinpoint the damage exactly (because everything in the brain is interconnected), but lesion studies in animals have frequently led to significant advances in our understanding of the brain (Pinel, 1999).

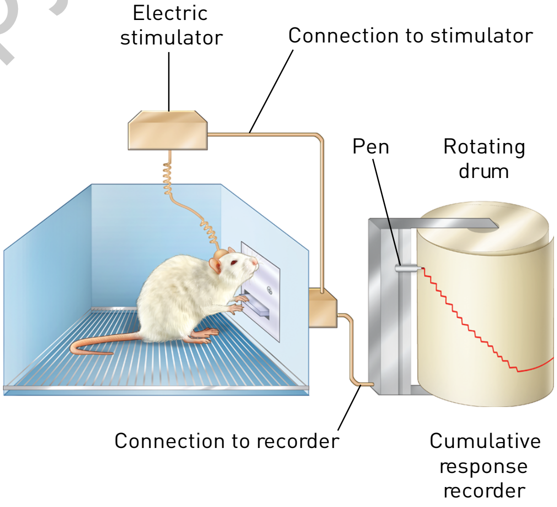
Activating the Brain

It's also possible to activate the brain directly by capitalizing on the electrochemical nature of the communication network. Essentially, messages can be created where none would have normally occurred. Chemicals can be injected that excite the neurons in an area of the brain. Researchers can also insert small wire electrodes into brain tissue, allowing an area's cells to be stimulated electrically. The researcher initiates a message externally, then observes behavior.

Electrical stimulation techniques have been used primarily with animals. Electrodes can be implanted in such a way as to allow an animal to move freely about in its environment (see Figure 3.8). A small pulse of current can then be delivered to various brain regions. Studies have shown that electrical brain stimulation can cause animals to suddenly start eating, drinking, engaging in sexual behavior, or preparing for an attack. Researchers have also discovered that stimulation of some brain regions can act as a powerful reward, leading the animals to engage repeatedly in whatever behavior led to the stimulation (Leon & Gallistel, 1998; Olds, 1958). For example, if rats are taught that pressing a metal bar leads to electrical stimulation of a reward area, they will press the bar thousands of times in an hour. It is tempting to conclude that these regions act as "pleasure centers," at least for rats, but such a conclusion is unwarranted. Electrical stimulation can have widespread effects and may, for instance, lead to changes in the levels or effectiveness of neurotransmitters in the brain. We just don't know. Moreover, it's widely agreed that pleasure in the human brain involves an array of brain regions rather than a single location (Berridge & Kringelbach, 2015).

FIGURE 3.8 ■ Electrical Stimulation

When the rat presses a bar, a small pulse of electric current is delivered to its brain. Stimulation of certain brain areas appears to be quite rewarding to the rat because it presses the bar very rapidly.

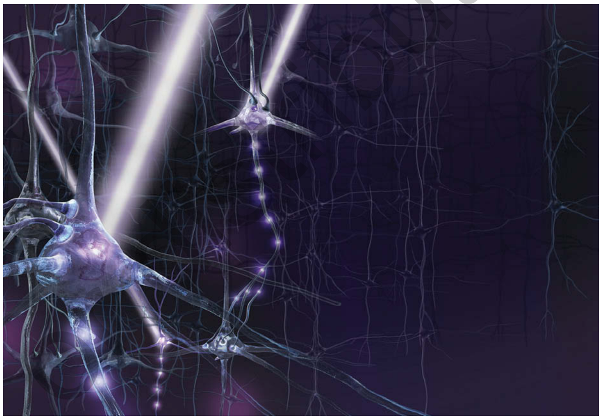


Carolina Hrejsa/Body Scientific Intl.

Under some circumstances, it's possible to stimulate cells in the human brain and note the effects. During certain kinds of brain surgery (such as surgery to reduce the seizures produced by epilepsy), the patient is kept awake while the brain is stimulated with an electrode. Because there are no pain receptors in the brain, the patient typically receives only a local anesthetic prior to the surgery (along with some drugs for relaxation). Keeping the patient awake is necessary because the surgeon can stimulate an abnormal area, prior to removal, to make sure that vital capabilities such as speech or movement will not be affected. Electrical stimulation under these conditions has caused patients to produce involuntary movement, hear buzzing noises, and in some rare instances even experience what they report to be memories (Penfield & Perot, 1963).

In humans, it is also possible to stimulate brain activity through the application of localized magnetic fields. In **transcranial magnetic stimulation (TMS)**, special coils are used to generate magnetic fields that, in turn, direct electrical current to targeted areas in the brain. This stimulation can be used to selectively activate or disrupt performance on an ongoing task. Although safe and reversible, TMS is often used by scientists to create "virtual lesions" in the brain that are diagnostic about brain function. For example, in one recent study, TMS was used to induce "blindsight," an interesting phenomenon in which people report no conscious awareness of seeing a stimulus (e.g., a line of a particular orientation) but can correctly answer questions about it (Koenig & Ro, 2019). TMS is currently used to study a variety of brain functions, including visual perception and memory (Sheu et al., 2019).

Finally, although it is not available for human use, neuroscientists are also experimenting with a technique called **optogenetics** that uses light to activate and control neurons that have been genetically engineered to respond to light. This technique has enabled researchers to investigate how neurons respond when animals learn and remember and then to track those neurons over time. It has even been possible to reinstate prior memories in mice by reactivating those neurons with light delivered through fiber optics into the brain (e.g., Lacagnina et al., 2019). This is an exciting new technique that may have applications at some point to brain disorders such as Alzheimer's disease.



Optogenetics uses light to activate and control neurons that have been genetically engineered to respond to light.

Henning Dalhoff / Science Source

Monitoring the Brain

Other techniques monitor the brain directly and are more easily used to study the human brain. An **electroencephalograph (EEG)** is a device that simply monitors the gross electrical activity of the brain. Recording electrodes attached to the scalp measure global changes in the electrical potentials of thousands of brain cells in the form of line tracings, or brain waves. The EEG is useful not only as a research tool but also for diagnostic purposes. Brain disorders, including psychological disorders, can sometimes be detected through abnormalities in brain waves (Yadollahpour et al., 2017).

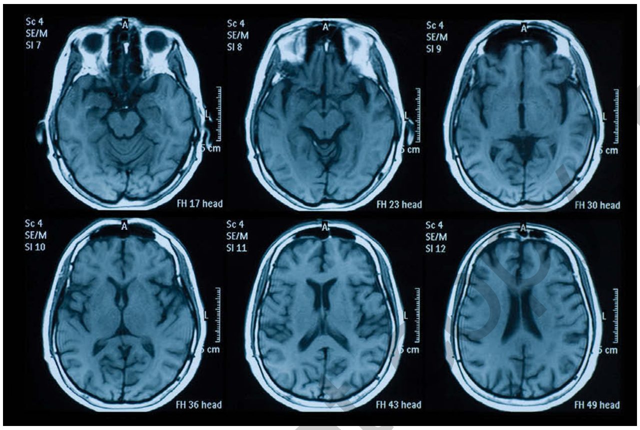
The EEG helps neuroscientists both diagnose brain dysfunction and understand normal brain functioning.

BSIP/Universal Images Group via Getty Images

A three-dimensional picture of the brain, including abnormalities in brain tissue, can be obtained through a **computerized tomography scan (CT scan)**. CT scanners use computers to detect how highly focused beams of X-rays change as they pass through the body. CT scans are most often used by physicians to detect tumors or injuries to the brain, but they can also be used to determine whether there is a physical basis for some chronic behavioral or psychological disorder.

Other imaging devices are designed to obtain a snapshot of the brain *at work*. These techniques help the researcher determine how tasks, such as reading a book, affect individual parts of the brain. In **positron emission tomography (PET)**, the patient ingests a harmless radioactive substance, which is then absorbed into the cells of active brain regions. When the person is performing a task, such as speaking or reading, the working areas of the brain absorb more of the ingested radioactive material. The PET scanner then develops a picture that reveals how the radioactive substance has distributed itself over time. It is assumed that those parts of the brain with the most concentrated traces of radioactive material probably play a significant role in the task being performed.

Another popular technique is **magnetic resonance imaging (MRI)**. MRI has two main advantages over PET scanning: It doesn't require the participant to ingest any chemicals, and it's capable of producing extremely detailed, three-dimensional images of the brain. Functional MRI uses the MRI technology to map changes in blood flow or oxygen use as the patient thinks or behaves. Functional MRI, like PET scanning, helps researchers determine where specific kinds of processing may occur in the brain. So far, this popular new technique has helped to isolate the brain regions associated with visual processing, language, attention, memory, and even social interactions (see C. A. Hill et al., 2017). There is some evidence to suggest that functional MRI may even help psychologists distinguish between true and false memories: When we falsely remember something that didn't occur, the blood flow patterns in the brain are somewhat different from those seen when we remember an actual event (Karanian & Slotnick, 2018; Schacter et al., 2011).



MRIs can be used to construct detailed images of the brain.

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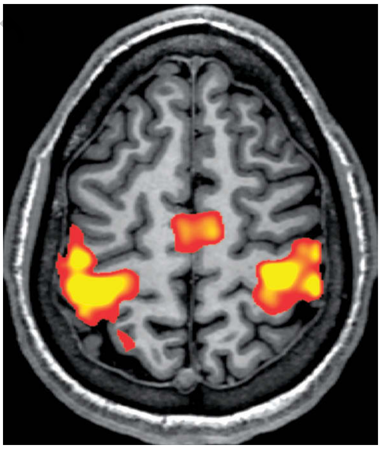

Functional MRIs help neuroscientists determine brain function by recording how blood oxygen use changes in different parts of the brain during performance of a task.

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Functional MRI is a powerful investigative tool, and we'll refer to it often throughout this text. But like other investigative tools, it has limitations. The analysis of neuroimaging data typically requires one to use complex statistical techniques to filter out the relevant patterns of activation, and not everyone agrees about the best way to summarize the data. Concerns have been raised as well about the reproducibility of the results, partly because the number of participants who are "scanned" is usually small (Gilmore et al., 2017), and the results may differ from one test session to the next (Elliott et al., 2020). Extra care needs to be taken with neuroimaging data because it can produce an "illusion of explanatory depth" (R. E. Rhodes, 2014). Bolstering an argument with a picture of brain activation tends to make people evaluate the explanation more favorably, even if the picture adds little to the value of the scientific argument (see Weisberg et al., 2018). For a summary of the different brain investigation techniques, see Concept Review 3.2.

CONCEPT REVIEW 3.2
BRAIN INVESTIGATION TECHNIQUES

Technique	Overview	What Can It Show?
Brain damage and lesion	Associate areas of brain damage with changes in behavioral function.	The areas of the brain that may be responsible for different functions.
Electrical brain stimulation	Uses electrical or chemical stimulation to excite brain areas.	How activation of certain brain regions affects behavior.
TMS (transcranial magnetic stimulation)	Special coils are used to generate magnetic fields that, in turn, direct electrical current to target areas in the brain.	This stimulation can be used to selectively activate or disrupt performance on an ongoing task.
EEG (electroencephalograph)	Uses electrodes to record gross electrical activity of the brain.	How overall activity in the brain changes during certain activities, such as sleeping, and may allow for detection of disorders.
CT (computerized tomography) scan	Passes X-rays through the body at various angles and orientations.	Tumors or injuries to the brain, as well as the structural bases for chronic behavioral or psychological disorders.
PET (positron emission tomography) scan	A radioactive substance is ingested; active brain areas absorb the substance; the PET scanner reveals distribution of the substance.	How various tasks (such as reading a book) affect different parts of the brain.
MRI (magnetic resonance imaging)	Monitors systematic activity of atoms in the presence of magnetic fields and radio-wave pulses.	A three-dimensional view of the brain, serving as a diagnostic tool for brain abnormalities, such as tumors. Functional MRI allows for observation of brain function.

Brain Structures and Their Functions

Let's now turn our attention to the brain itself. Remember, it's here that mental processes are represented through the simultaneous activities of billions of individual neurons. Particular regions in the brain contribute unique features to an experience, helping to create a psychological whole. Your perception of a cat is controlled not by a single cell, or even by a single group of cells, but rather by different brain areas that detect the color of the fur or recognize a characteristic meow.

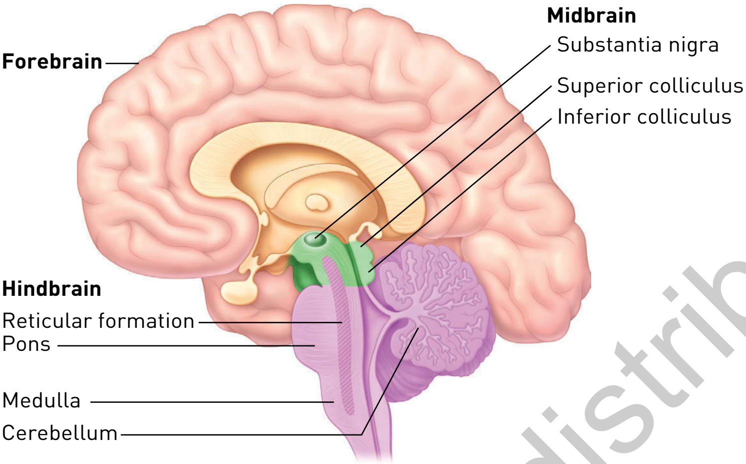
We'll divide our discussion of the brain into sections that correspond to the brain's three major anatomical regions: the *hindbrain*, the *midbrain*, and the *forebrain*.

The Hindbrain: Basic Life Support

The **hindbrain** is the most primitive part of the brain, and it sits right where the spinal cord and brain merge (see Figure 3.9). *Primitive* is an appropriate term for two reasons. First, structures in the hindbrain act as the basic life-support system for the body—no creative thoughts or complex emotions originate here. Second, from the standpoint of evolution, the hindbrain is the oldest part of the brain. Similar structures, with similar functions, can be found throughout the animal kingdom. You can think of the hindbrain as a kind of base camp, with structures that are situated farther up in the brain controlling increasingly more complex mental processes. Not surprisingly, damage to the hindbrain seriously affects our ability to survive.

FIGURE 3.9 ■ The Hindbrain and Midbrain

The hindbrain acts as the basic life-support system for the body, controlling such things as heart rate, blood pressure, and respiration. The midbrain contains structures that help coordinate and relay information to higher centers.



Carolina Hrejsa/Body Scientific Intl.

As Figure 3.9 shows, the hindbrain contains several important substructures. The *medulla* and the *pons* are associated with the control of heart rate, breathing, blood pressure, and reflexes such as vomiting, sneezing, and coughing. Both areas serve as pathways for neural impulses traveling to and from the spinal cord (the word *pons* means "bridge"). These areas are particularly sensitive to the lethal effects of drugs such as alcohol, barbiturates, and cocaine. The hindbrain also contains the *reticular formation*, a network of neurons and nerves linked to the control of general arousal, sleep, and consciousness.

Finally, at the base of the brain sits a structure that resembles a smaller version of the brain—a kind of "brainlet." This is the **cerebellum** (which means "little brain"), a structure involved in the preparation, selection, and coordination of complex motor movements such as hitting a golf ball, playing the piano, or learning how to use and manipulate tools (J. W. Lewis, 2006). No one is certain about the exact role the cerebellum plays in movement—for instance, it may be a critical component of how we learn to time motor movements (Teki et al., 2011). The cerebellum has been linked to a host of tasks, including language, memory, reasoning, and perhaps even social awareness (Schmahmann, 2019). Again, exactly how the cerebellum contributes to these activities remains a mystery—at least the details haven't been worked out—but it appears to be involved in some way.

The cerebellum is thought to be involved in the coordination of complex motor movements, such as playing the piano.

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The Midbrain: Neural Relay Stations

The **midbrain** lies deep within the brain atop the hindbrain. Perhaps because of its central position, structures in the midbrain receive input from multiple sources, including the sense organs. The tectum and its component structures, the superior colliculus and inferior colliculus, serve as important relay stations for visual and auditory information and help coordinate reactions to sensory events in the environment (such as moving the head in response to a sudden sound).

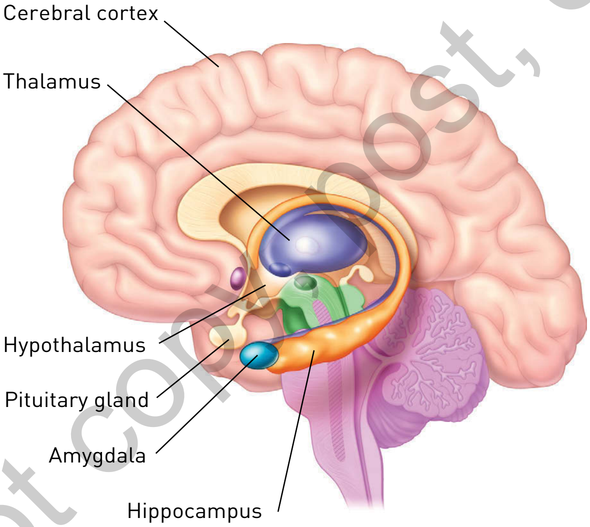
The midbrain also contains a group of neurons, the *substantia nigra*, that release the neurotransmitter dopamine from their terminal buttons. As you saw earlier in the chapter, dopamine seems to be involved in a number of physical and psychological disorders. For example, the rigidity of movement that characterizes Parkinson's disease apparently results from decreased levels of dopamine in the brain. Indeed, the death of neurons in the substantia nigra is believed to be the cause of the disorder. Exactly why this portion of the midbrain degenerates is not known, although both genetic and environmental factors play a role (Przedborski, 2005); recent evidence suggests that the immune system probably plays a role as well, although much remains to be discovered (see De Virgilio et al., 2016).

The Forebrain: Higher Mental Functioning

Moving up past the midbrain we encounter the **forebrain** (see Figure 3.10). The most recognizable feature of the forebrain is the **cerebral cortex**, which is the grayish matter full of fissures, folds, and crevices that covers the outside of the brain (*cortex* is Latin for "bark"). The cortex is quite large in humans, accounting for approximately 80% of the total volume of the human brain (Kolb & Whishaw, 2009). We'll look at the cerebral cortex in depth in a minute. Beneath the cerebral cortex sit the thalamus, the hypothalamus, and the limbic system. The **thalamus** is positioned close to the midbrain and is an important gathering point for input from the various senses. Indeed, the thalamus is the main processing center for sensory input prior to its being sent to the upper regions of the cortex. Besides acting as an efficient relay center, the thalamus is where information from the various senses is combined in some way.

FIGURE 3.10 ■ The Forebrain

The forebrain includes structures such as the limbic system and the cerebral cortex. Structures in the limbic system are thought to be involved in motivation, emotion, and memory. The cerebral cortex controls higher mental processes.



Carolina Hrejsa/Body Scientific Intl.

The **hypothalamus**, which lies just below the thalamus, is important in motivation, particularly the regulation of eating, drinking, body temperature, and sexual behavior. In experiments on nonhuman animals, stimulating regions of the hypothalamus kick-starts a variety of behaviors. For example, male and female rats will show characteristic sexual responses when one portion of the hypothalamus is stimulated, whereas damage to another region of the hypothalamus can seriously affect regular eating behavior. Neuroimaging studies have shown that the hypothalamus becomes active when monkeys are exposed to sexually arousing odors from receptive females (Ferris et al., 2001). Some have even suggested that neural circuits in the hypothalamus play an important role in sexual preference and attraction (Poeppl et al., 2016). The hypothalamus also controls the release of hormones by the pituitary gland; you'll read about the actions of hormones shortly when we discuss the endocrine system.

The **limbic system** is made up of several interrelated brain structures, including the amygdala and the hippocampus. The *amygdala* is a small, almond-shaped piece of brain (from the Greek word meaning "almond") that's linked to a number of motivational and emotional behaviors, including fear, aggression, and defensive actions. Destruction of portions of the amygdala in nonhuman animals can produce an extremely passive animal—one that will do nothing in response to provocation. Neuroimaging studies in humans have found that activation in the amygdala increases when people look at faces showing fear, anger, sadness, or even happiness (Yang et al., 2002); moreover, people with damage to the amygdala sometimes have difficulty recognizing emotions like sadness in facial expressions (Adolphs, 2009). Imaging studies have also suggested a link between anxiety disorders and activation of the amygdala (Sah, 2017).

The *hippocampus* (Greek for "seahorse," which it resembles anatomically) is important for the formation of memories, particularly our memory for specific personal events. People with severe damage to the hippocampus can live in a kind of perpetual present—they are aware of the world around them, and they recognize people and things known to them prior to the damage, but they remember almost nothing new. These patients act as if they are continually awakening from a dream; experiences slip away, and they recall nothing from only moments before. Memory depends on networks that extend beyond the hippocampus (Aly & Ranganath, 2018), but there is wide agreement that the hippocampus is vital to the formation of memory records. It may also play an important role in spatial navigation—our ability to find our way from one place to another—which, of course, depends on memory as well (Jeffry, 2018). We'll consider the hippocampus and the role it plays in memory in more detail in Chapter 8.

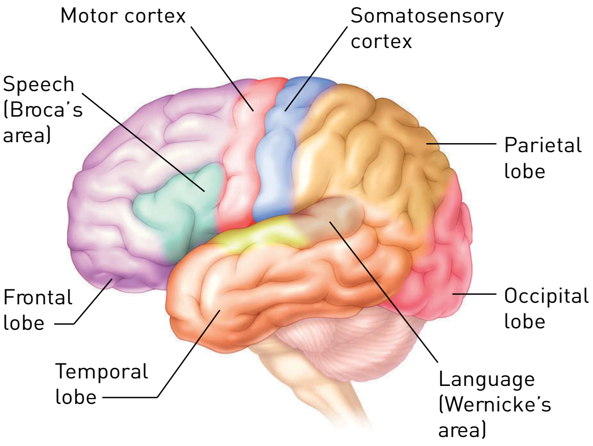
The Cerebral Cortex

With the cerebral cortex, we finally find the seat of higher mental processes. Thoughts, the sense of self, the ability to reason and solve problems—each arises from neurons firing in patterns somewhere in specialized regions of the cerebral cortex. The cortex is divided into two hemispheres, left and right. The left hemisphere controls the sensory and motor functions for the right side of the body, and the right hemisphere controls these functions for the left side of the body. A structure called the corpus callosum, which we'll discuss later, serves as a communication bridge between the two hemispheres.

Each hemisphere can be further divided into four parts, or lobes: the *frontal, temporal, parietal*, and *occipital lobes* (see Figure 3.11). These lobes control particular body functions, such as visual processing by the occipital lobe and language processing by the frontal and temporal lobes. As usual, a slight warning is in order here: Although researchers have discovered that particular areas in the brain seem to control highly specialized functions, there is almost certainly considerable overlap of function in the brain. The brain consists of team players—no single component is likely to work alone.

FIGURE 3.11 ■ The Cerebral Cortex

The cerebral cortex is divided into two hemispheres—left and right—each consisting of four lobes. The lobes are specialized to control particular functions, such as visual processing in the occipital lobe and language processing in the frontal and temporal lobes.



Carolina Hrejsa/Body Scientific Intl.

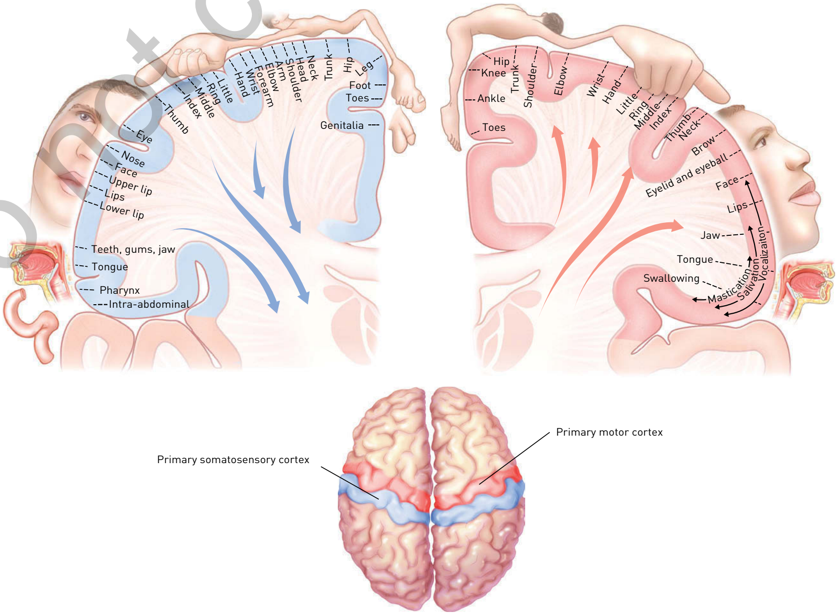
The **frontal lobes** are the largest lobes in the cortex and act as the brain's "executive" in charge of planning and coordinating voluntary behavior and decision making. Many higher-order cognitive functions originate here, including problem solving, certain kinds of remembering, and even socialization and personality. Damage to the frontal lobe can lead to withdrawal from the social world, ignoring of friends and relatives, and a refusal to do much of anything (Ramachandran, 2011). The frontal lobes were once the site of a famous surgical operation, the prefrontal lobotomy, which was performed on people suffering from severe and untreatable psychological disorders. The operation was performed to calm the patient and reduce symptoms, which it sometimes did, but the side effects were severe. Patients lost their ability to take initiative or make plans, and they often appeared to lose their social inhibitions. For these reasons, the operation fell out of favor as an acceptable treatment for psychological disorders.

The frontal lobes also contain the *motor cortex*, which controls voluntary muscle movements, as well as areas involved in language production. Broca's area, which is involved in speech production, is located in a portion of the left frontal lobe in most people. The motor cortex sits at the rear of the frontal lobe in both hemispheres; axons from the motor cortex project down to motor neurons in the spinal cord and elsewhere. If neurons in this area of the brain are stimulated electrically, muscle contractions—the twitch of a finger or the jerking of a foot—can occur. Researchers have also discovered an intriguing relation between body parts and regions of the motor cortex. There is a mapping, or *topographic* organization, in which adjacent areas of the body, such as the hand and the wrist, are activated by adjacent neurons in the motor cortex. The motor cortex also contains *mirror neurons*, which may play an important role in empathy and our ability to take the perspectives of others. For more on mirror neurons, take a look at the accompanying Practical Solutions box.

The **parietal lobe** contains the *somatosensory cortex*, which enables us to experience the sensations of touch, temperature, and pain. A lover's kiss on the cheek excites neurons that lie close to those that would be excited by the same kiss to the lips. In addition, as Figure 3.12 demonstrates, there is a relationship between sensitivity to touch (or the ability to control a movement) and size of the representation in the cortex. Those areas of the body that show particular sensitivity to touch, or are associated with fine motor control (such as the face, lips, and fingers), have relatively large areas of neural representation in the cortex. It's not surprising, as a consequence, that we display affection by kissing on the lips rather than, say, rubbing our backs together!

FIGURE 3.12 ■ Cortex Specialization

The motor cortex is at the back of the frontal lobe in each cerebral hemisphere. In a systematic body-to-brain relationship, adjacent parts of the body are activated by neurons in adjacent areas of the cortex. The somatosensory cortex, in the parietal lobe of each hemisphere, controls the sense of touch; again, there is a systematic mapping arrangement. Notice that in each type of cortex, the size of the cortical representation is related to the sensitivity of the body part.



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The parietal lobe is closely identified with our sense of touch and the general integration of sensory information, but like the other brain areas we've considered, it serves a variety of roles in human thought and action. Imaging data suggest that the parietal lobe is involved in language processing and perhaps even social cognition—our ability to infer the beliefs and intentions of other people (Bzdok et al., 2016). Other studies suggest that the parietal lobe, along with other brain areas, is important in imagining and thinking about the future. The ability to project ourselves into the future, imagining how we might act or react to a future threat or encounter, is an extremely adaptive human characteristic (Schacter et al., 2017).

The **temporal lobes**, which lie on the sides of the cortex (think "temples"), are involved in processing auditory information received from the left and right ears. As you'll see in Chapter 5, there is a close relationship between the activity of particular neurons in the temporal lobe and the perception of certain frequencies of sound. As noted earlier, one region of the temporal lobe, Wernicke's area, is involved in language comprehension (the ability to understand what someone is saying). A person with damage to Wernicke's area might be able to repeat a spoken sentence aloud with perfect diction and control yet not understand a word of it; brain-imaging studies also reveal that Wernicke's area becomes active when people are asked to perform tasks that require meaningful verbal processing; it may be the area that modulates the recognition of individual words (Ardila et al., 2016). For most people, speech is localized in the temporal lobe of the left hemisphere.

Finally, at the far back of the brain sit the **occipital lobes**, where most visual processing occurs. It is here that information received from receptor cells in the eyes is analyzed and turned into visual images. The brain paints an image of the external world through a remarkable division of labor. There appear to be processing stations in the occipital lobe designed to integrate separate signals about color, motion, and form (Sincich & Horton, 2005). Not surprisingly, damage to the occipital lobe produces highly specific visual problems—you might lose the ability to recognize an object moving in a particular direction, a color, or even a face (Gainotti & Marra, 2011). We'll consider the organization of this part of the brain in more detail in Chapter 5.

CONCEPT REVIEW 3.3
BRAIN AREAS, STRUCTURES, AND FUNCTIONS

Brain Area	General Function	Structures and Specific Function
Hindbrain	Basic life support	*Medulla* and *pons*: associated with the control of heart rate, breathing, and certain reflexes
		Reticular formation: control of general arousal, sleep, and some movement of the head
		Cerebellum: involved in preparation, selection, and coordination of complex motor movement
Midbrain	Houses neural relay stations	*Tectum* (components are superior colliculus and inferior colliculus): relay stations for visual and auditory information
		Substantia nigra: group of neurons that release the neurotransmitter dopamine
Forebrain	Higher mental functions	*Thalamus*: initial gathering point for sensory input; information combined and relayed here
		Hypothalamus: helps regulate eating, drinking, body temperature, and sexual behavior
		Hippocampus: important to the formation of memories
		Amygdala: linked to fear, aggression, and defensive behaviors
		Cerebral cortex: the seat of higher mental processes, including sense of self and the ability to reason and solve problems

PRACTICAL SOLUTIONS: MIRROR NEURONS AND SOLVING THE "OTHER MIND PROBLEM"

One of the unique characteristics of people, compared to most other animal species, is our keen ability to solve the "other mind problem." We have an unparalleled capacity to get inside the heads of others—to imagine what they're thinking, how they're feeling, and what they're likely to do next. Neuroscientists now believe that they have discovered a key element in the brain that produces this ability: *mirror neurons*. As you've learned in this chapter, neuroimaging studies have revealed that regions in the motor cortex become active when we engage in simple motor movements, such as biting into an apple or clapping our hands. However, the startling discovery is that neurons in these same regions become active when we simply *observe* someone else performing the same actions. The same systems in the brain that are activated by performing an action—waving good-bye—are activated when we watch someone else perform the same task.

Watching someone else's experiences may activate some of the same neural systems in the observer.

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Give it a little thought, and this finding makes sense: Watch someone get stuck with a needle, and what do you do? You're likely to make a face, turn away, or even grab your arm. Watch a good movie, and what happens? You jump, cover your eyes, laugh, and even cry in response to a bunch of two-dimensional images flashing on a screen. You feel the pain, even though you're just sitting in a seat. The discovery of mirror neurons suggests that, well, you really are experiencing the events you're watching—at least in some sense. Mirror neurons help us solve the "other mind problem" and may also be the basis for empathy, our ability to identify and relate to the thoughts and feelings of others (Iacoboni, 2009).

The evidence for such claims is controversial but compelling nonetheless. Brain-imaging studies have shown that when we witness the emotions of others, some of the same emotion systems in our brain get activated. If you watch someone else experience disgust—for example, smelling a disgusting odor—your own "disgust systems" in the brain get activated as well; in fact, if you've recently been contaminated by something, watching other people wash their hands can provide a sense of relief (Jalal & Ramachandran, 2017). Several studies have found relationships (correlations) between the activation of mirror neuron systems and behavioral measures of empathy and one's level of competence in social situations (see Gallese et al., 2011; Iacoboni, 2009). Results like these suggest that mirror neurons play a fundamental role in a variety of social functions (Glenberg, 2011). Some have even suggested that damage to mirror neuron systems in the brain may be partly responsible for autism spectrum disorder, a developmental disorder marked by a reluctance or an inability to interact well with other people (Ramachandran, 2011). Again, though, the evidence is controversial, and it's not clear at this point whether activity in mirror neurons is the cause or the result of social interaction—that is, the behavior of mirror neurons may be the result of some form of social learning (see R. Cook et al., 2014).

Psychologists and neuroscientists agree: Mirror neurons exist in the human brain and may well contribute to a range of important mental and social human capabilities. It's exciting stuff, because mirror neurons sit at the juncture between psychology and neuroscience, but we are a long way from understanding the details. A tremendous amount of research effort is currently ongoing, so there are reasons to be hopeful that we'll see significant progress in the coming decades.

The Divided Brain

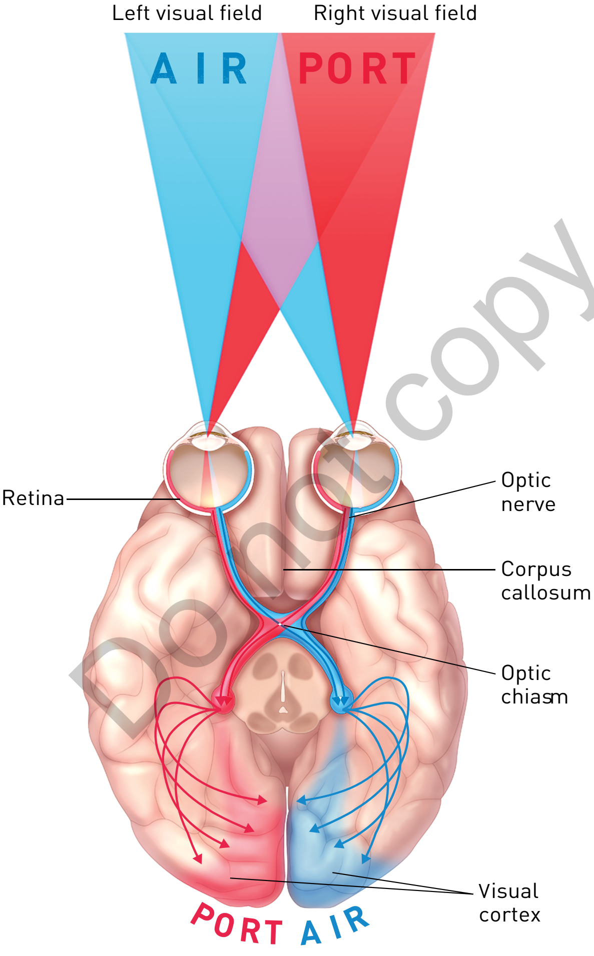
The division of labor in the brain is particularly striking in the study of the two separate halves, or hemispheres, of the cerebral cortex. Although the brain is designed to operate as a whole, the hemispheres are *lateralized*, which means that each side is responsible for performing unique and independent functions. This doesn't mean that people are "left-brained" or "right-brained," as some pop psychologists have argued; it simply means that certain functions are controlled primarily by either the right or the left hemisphere. For example, as you've seen, the right hemisphere of the brain controls the movements of the left side of the body; the left hemisphere governs the right side. This means that stimulating a region of the motor cortex in the left cerebral hemisphere will cause a muscle on the right side of the body to twitch. Similarly, if cells in the occipital lobe of the right cerebral hemisphere are damaged, a blind spot will develop in the left portion of the visual world. Lateralization undoubtedly serves some adaptive functions. For example, it may allow the brain to divide its labor in ways that produce more efficient processing.

Information received through the eyes travels to one side of the brain or the other (see Figure 3.13). If you're looking straight ahead, an image coming from the left side of your body (the left visual field) falls on the inside half of the left eye and the outside half of the right eye; receptor cells in these locations transmit their images to the back of the right cerebral hemisphere. Both eyes project information directly to each hemisphere, as the figure shows, but information from the left visual field goes to the right hemisphere and vice versa.

Under normal circumstances, if an object approaches you from your left side, the information eventually arrives on both sides of your brain. There are two reasons for this. First, if you turn your head or eyes to look at the object—from left to right—its image is likely to fall on both the inside and the outside halves of each eye over time. It might start off on the inside half of the left eye, but as your eyes turn, the outside half will soon receive the message. Second, as noted earlier, a major communication bridge—the corpus callosum—connects the two brain halves. Information arriving at the right hemisphere, for example, is transported to the left hemisphere via the **corpus callosum** in well under a tenth of a second. This transfer process occurs automatically and requires no head or eye turning.

FIGURE 3.13 ■ Visual Processing in the Two Hemispheres

Images originating in the left visual field are projected to the right hemisphere, and information appearing in the right visual field is projected to the left hemisphere. Most language processing occurs in the left hemisphere, so split-brain patients can vocally report only stimuli that are shown in the right visual field. Here the subject can say only *port*, the word available for processing in the left hemisphere.



Carolina Hrejsa/Body Scientific Intl.

Splitting the Brain

Both sides of the brain need to receive information about objects in the environment. To understand why, imagine what visual perception is like for someone without a corpus callosum—someone with a "split brain." Suppose an object suddenly appears in the person's left visual field. There's no time to move the head or eyes, only enough for a reflexive response. Our patient will be incapable of a coordinated response because the image will be registered only in the right hemisphere, which contains the machinery to control only the left side of the body. The split-brain patient will also be unable to name the menacing object because the language comprehension and production centers are located, typically, on the left side of the brain.

Patients like the one just described really do exist; there are people with split brains. Some were born without a corpus callosum; others had their communication gateway cut on purpose by surgeons seeking to reduce the spread of epileptic seizures. The two hemispheres of split-brain patients are not broken or damaged by the operation. Information simply cannot easily pass from one side of the brain to the other. In fact, the behavior of most split-brain patients is essentially normal because most input from the environment still reaches both sides of their brain. These patients can turn their head and eyes freely as they interact with the environment, allowing information to fall on receptor regions that transmit to both hemispheres. The abnormal nature of their brain becomes apparent only under manufactured conditions.

In a classic study by Gazzaniga and colleagues (1965), a variety of images (pictures, words, or symbols) were presented quickly to either the left or the right visual field of split-brain patients. Just like with our hypothetical patient, when an image was shown to the right visual field, it was easily named because it could be processed by the language centers of the left hemisphere. For left visual field presentations, the patients remained perplexed and silent. It was later learned, however, that their silence did not mean that the brain failed to process the image. If the split-brain patients were asked to point to a picture of the object just shown, they could do so, but only with the left hand (Gazzaniga & LeDoux, 1978). The brain had received the input but could not respond verbally. In another case, Gazzaniga and his colleagues presented a picture to the right hemisphere that triggered a negative mood. The patient denied seeing anything, because the picture wasn't available to the language centers in the left hemisphere, but she complained of being upset—in fact, she blamed the experimenters for upsetting her (Gazzaniga, 2008)!

Hemispheric Specialization

The two hemispheres of the cerebral cortex are clearly specialized to perform certain kinds of tasks. The right hemisphere, for example, appears to play a more important role in spatial tasks, such as fitting together the pieces of a puzzle or orienting oneself spatially in an environment. Patients with damage to the right hemisphere characteristically have trouble with spatial tasks, as do split-brain patients who must assemble a puzzle with their right hand. The right hemisphere is also better at recognizing faces and may play a more important role in recognizing the intentions of other people (see Volz & Gazzaniga, 2017).

The left hemisphere—perhaps in part because of the lateralized language centers—contributes more to verbal tasks such as reading and writing. We also use the left hemisphere to solve problems and to create consistent "explanations" of the world. Gazzaniga (2008) calls the left hemisphere the "interpreter" because it smooths over inconsistencies in our actions and creates coherent stories about our behavior. Show the command "walk" to the right hemisphere of a split-brain patient, and they are likely to get up and walk. Ask them why they are walking, and they are likely to fabricate an answer—for example, "I'm thirsty, so I'm going to find a drink." The language centers don't receive the command, so the left hemisphere makes up a story to "interpret" the patient's behavior.

Still, a great deal of cooperation and collaboration goes on between the hemispheres. They interact continuously, and most mental processes, even language to a certain extent, depend on activity in both sides of the brain. In addition, a number of the phenomena observed with split-brain patients also occur in normal people under certain testing conditions (Pinto et al., 2017). You think and behave with a whole brain, not a fragmented one. If one side of the brain is damaged, regions in the other hemisphere can sometimes take over the lost functions. Specialization in the brain exists because it's sometimes adaptive for the two hemispheres to work independently—much in the same way that it's beneficial for members of a group to divide components of a difficult task rather than trying to cooperate on every small activity.

KNOWLEDGE CHECK 3.2

Now test what you've learned about research into brain structures and their functions. Fill in each blank with one of the following terms: *EEG, PET scan, hindbrain, midbrain, forebrain, cerebellum, hypothalamus, cortex, frontal lobes, limbic system, corpus callosum*. (You will find the answers in the Appendix.)

1. A primitive part of the brain that controls basic life-support functions such as heart rate and respiration: ________

2. A structure thought to be involved in a variety of motivational activities, including eating, drinking, and sexual behavior: ________

3. The portion of the cortex believed to be involved in higher-order thought processes (such as planning) as well as the initiation of voluntary motor movements: ________

4. A structure near the base of the brain involved in coordination of complex activities such as walking and playing the piano: ________

5. A device used to monitor the gross electrical activity of the brain: ________

REGULATING GROWTH AND INTERNAL FUNCTIONS: EXTENDED COMMUNICATION

The human body has two communication systems. The first, the nervous system, starts and controls most behaviors—thoughts, voluntary movements, and perceptions of the external world. But the body also has long-term communication needs. The body must initiate and control growth and provide long-term regulation of numerous internal biological systems. Consequently, a second communication system has developed: a network of glands called the **endocrine system**, which uses the bloodstream, rather than neurons, as its main information courier. Chemicals called **hormones** are released into the blood by the various endocrine glands and control a variety of internal functions.

The word *hormone* comes from the Greek *hormon*, which means "to set into motion." Hormones play a role in many basic, life-sustaining activities in the body. Hunger, thirst, sexual behavior, and the fight-or-flight response are all regulated in part by an interplay between the nervous system and hormones released by the endocrine glands. The fact that the body has two communication systems rather than one makes sense from an adaptive standpoint. One system, communication among neurons, governs transmissions that are quick and detailed; the other, the endocrine system, initiates the slower but more widespread and longer-lasting effects. In the following section, we'll consider the endocrine system in more detail and then consider how hormones influence some fundamental differences between men and women.

The Endocrine System

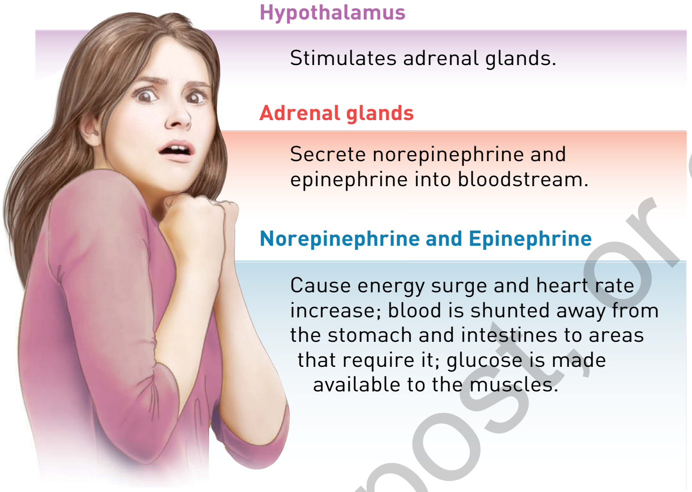
The chemical communication system of the endocrine glands differs in some important ways from the rapid-fire electrochemical activities of the nervous system. Communication in the nervous system tends to be localized, which means that a given neurotransmitter usually affects only cells in a small area. Hormones have widespread effects. Because hormones are carried by the blood, they travel throughout the body and interact with numerous target sites. In contrast to neurotransmitters, hormones also have long-lasting effects. Whereas neural communication operates in the blink of an eye, the endocrine system can produce effects lasting minutes, hours, or even days. In some animals, for example, it is circulating hormones that prepare them for seasonal migration or hibernation. This means that the endocrine system provides the body with a mechanism for both widespread and long-term communication that cannot be produced by interactions among neurons.

Although the endocrine and nervous systems communicate in different ways, their activities are closely coordinated. Structures in the brain (especially the hypothalamus) stimulate or inhibit the release of hormones by the glands; once released, these chemicals then feed back and affect the firing rates of neural impulses. The feedback loop balances and controls the regulatory activities of the body. The hypothalamus is of importance because it controls the pituitary gland. The **pituitary gland**, a kind of master gland, controls the secretion of hormones in response to signals from the hypothalamus; these hormones, in turn, regulate the activity of many of the other vital glands in the endocrine system. It is the pituitary gland, for example, that signals the testes in males to produce *testosterone* and the ovaries in females to produce *estrogen*—both of critical importance in sexual behavior and reproduction.

The endocrine system also helps us react to stressful situations. Suppose you're walking home alone, and two shadowy figures suddenly emerge from an alleyway and move in your direction. You draw in your breath, your stomach tightens, and your rapidly beating heart seems ready to explode from your chest. These whole-body reactions, critical in preparing you to fight or flee, are created by signals from the brain that lead to increased activity of the endocrine glands. The hypothalamus signals the *adrenal glands* (located above the kidneys) to begin secreting such hormones as *norepinephrine* and *epinephrine* into the blood. These hormones, in turn, produce energizing effects on the body, increasing heart rate and directing blood and oxygen flow to energy-demanding cells throughout the body. The body is now prepared for action, enhancing the likelihood of survival (see Figure 3.14).

FIGURE 3.14 ■ The Fight-or-Flight Response

In potentially dangerous situations, the endocrine system releases hormones that produce energizing effects in the body, increasing our chances of survival through fighting back or running away.



Carolina Hrejsa/Body Scientific Intl.

Do Men and Woman Have Different Brains?

Prior to birth, hormones released by the pituitary gland determine whether a child ends up with male or female sex organs. At puberty, an increase in sex hormones (testosterone and estrogen) leads males to develop facial hair and deep speaking voices, and females to develop breasts and begin menstruation. It is now suspected that hormones released during development affect the basic wiring patterns of men's and women's brains as well. Evidence suggests that men and women may think differently as the result of sex-specific activities of the endocrine system.

The ability of women and men to perform certain tasks changes as the levels of sex hormones increase or decrease in the body. Women traditionally perform better than men on some tests of verbal ability, and their performance can improve with high levels of estrogen in their body. Similarly, men show slightly better performance on some spatial tasks (such as imagining that three-dimensional objects are rotating), and their performance seems to be related to their testosterone levels. There is even evidence that females who developed in the womb with a male co-twin perform better on spatial memory tasks than females who developed with a female co-twin, presumably because of prenatal exposure to testosterone (D. I. Miller & Halpern, 2014). The evidence is correlational, which means we can't be sure it's the hormones that are causing the performance changes, but the data suggest there may be sex-based differences in some types of mental processing. It is important to understand, though, that these are average group differences and don't apply to all individuals.

It's also the case that girls who have been exposed to an excess of androgens (a group of hormones that include testosterone) during the initial stages of prenatal development, either because of a genetic disorder or from chemicals ingested by the mother during pregnancy, tend to engage in play activities that are more traditionally associated with boys (e.g., Hines et al., 2016). In one study reported by Kimura (1992), researchers at UCLA compared the choice of toys by girls who either had or had not been exposed to excess androgens during early development. The girls who had been exposed tended to prefer the typical masculine activities—smashing trucks and cars together, for example—more than the control girls did.

Male and female brains also show anatomical differences, although such differences have often been exaggerated historically (Shields, 1975). Animal studies have confirmed that male and female rat brains are different; moreover, the differences are attributable, in part, to the early influence of hormones (Zilkha et al., 2017). For humans, imaging studies have revealed sex-based differences in the thickness of cortical tissue, at least at certain points of development, and cortical thickness may be related to the performance of certain cognitive tasks, at least for women (Kurth et al., 2018). Other structural differences exist as well—for example, the amygdala is larger in men—and these differences cannot be accounted for by overall differences in brain volume (Ritchie et al., 2018). Interesting differences have also been found in response to brain damage. For example, damage can sometimes lead to specific deficits in knowledge categories, such as loss in knowledge about plants; women rarely, if ever, show selective deficits in plant knowledge, which may stem from how evolution has selectively shaped the development of male and female brains (Laiacona et al., 2006).

The evidence supporting sex-based differences in brain anatomy and mental functioning is provocative and needs to be investigated further. Hormones released by the endocrine system are known to produce permanent changes early in human development, and it's certainly possible that actions later in life are influenced by these changes. But no direct causal link has yet been established between anatomical differences and the variations in intellectual functioning that are sometimes found between men and women. In fact, some researchers have argued that sex-based differences in brain organization may cause men and women to act more similarly than they would otherwise (De Vries & Boyle, 1998).

In addition, the performance differences between women and men on certain laboratory tasks aren't very large and don't reflect general ability. Sex-based differences are extremely small and can, in some instances, be accounted for by experience (see Hyde, 2016). For example, boys tend to get more experience on spatial tasks than girls, due to sports and video games, which might help explain male spatial advantages. There are also significant cultural differences in cognitive abilities—for example, sex differences in math and science are absent in some cultures—which further supports sex-based similarities in cognitive ability (Hyde, 2014). To repeat a theme discussed in Chapter 1, it is difficult to separate the effects of biology (nature) from the ongoing influences of the environment (nurture). Men and women are faced with different environmental demands and cultural expectations during their lifetimes. Without question, those demands help determine the actions they take, and produce many of the behavioral differences that we see between the sexes.

Finally, it's worth emphasizing that the presence of male or female sex organs at birth doesn't necessarily define one's gender identity—that is, people's psychological sense of their gender. Transgender and gender-nonconforming (TGNC) people are those who have a gender identity that does not correspond to their sex assigned at birth. Some studies have suggested that sex hormones during prenatal development play a role in the development of transgender identity, along with some genetic predisposition, but, as we'll discuss elsewhere in the text, gender identity is a complex phenomenon, likely reflecting an interplay of biological, environmental, and cultural factors (see S. M. Rosenthal, 2016).

The presence of male or female sex organs at birth doesn't necessarily determine one's gender identity.

EZEQUIEL BECERRA/AFP via Getty Images

KNOWLEDGE CHECK 3.3

Now test your knowledge about the differences between the endocrine system and the nervous system. For each statement, decide whether the endocrine system or the nervous system is the most appropriate to apply. (You will find the answers in the Appendix.)

1. Communication effects tend to be localized, affecting only a small area: ________
2. Responsible for whole-body reactions, such as the fight-or-flight response: ________
3. The major determinant of sexual, but not necessarily gender, identity: ________
4. Communicates through the release of epinephrine and norepinephrine: ________
5. Operates quickly, with time scales bordering on the blink of an eye: ________

ADAPTING AND TRANSMITTING THE GENETIC CODE

Brains tend to act in regular and predictable ways. When you read a book, a neuroimaging scan is certain to reveal activity in the occipital lobe of your cortex. If a stroke occurs in the left cerebral hemisphere, there's a good chance you'll find paralysis occurring on the right side of the body. But behavior, the main interest of psychology, remains remarkably difficult to predict. People react differently to the same event—even if they're siblings raised in the same household. How do we explain this remarkable diversity of behavior, given that everyone carries around a similar 3- to 4-pound mass of brain tissue?

One answer is that no two brains are exactly alike. The patterns of neural activity that determine how we think and act are uniquely determined by our individual experiences and by the genetic material we've inherited from our parents. Most of us have no trouble accepting that experience is important, but genetic influences are a little tougher to accept. Sure, hair color, eye color, and blood type may be expressions of fixed genetic influences, but how can genetics govern intelligence, personality, or emotionality?

Recognizing that heredity has a role is a given to the psychologist. You'll find references to genetic influences throughout this book—on a whole host of topics. But it's also important to remember that the genetic code serves two adaptive functions. First, genes provide us with a flexible plan, a recipe of sorts, for our physical and psychological development. Second, genes provide a means through which we're able to pass on physical and psychological characteristics to our offspring, thereby helping to maintain qualities that have adaptive significance.

Natural Selection and Adaptations

Let's return briefly to the topic of natural selection, first addressed in Chapter 1. Charles Darwin proposed the mechanism of natural selection to explain how species change, or evolve, over time. He recognized that certain traits, physical or psychological, can help an organism's reproductive "fitness" and that these features, in turn, are likely to be passed forward from one generation to the next. If a bird is born with a special capacity to store, remember, and relocate seeds, then its chances of living long enough to mate and produce offspring increase. If the bird's offspring share the same capacity for obtaining food, then over many generations the seed-storing trait is likely to become a stable characteristic of the species. It becomes an **adaptation**, or a feature selected for by nature because it increases the chances of the organism to survive and multiply.

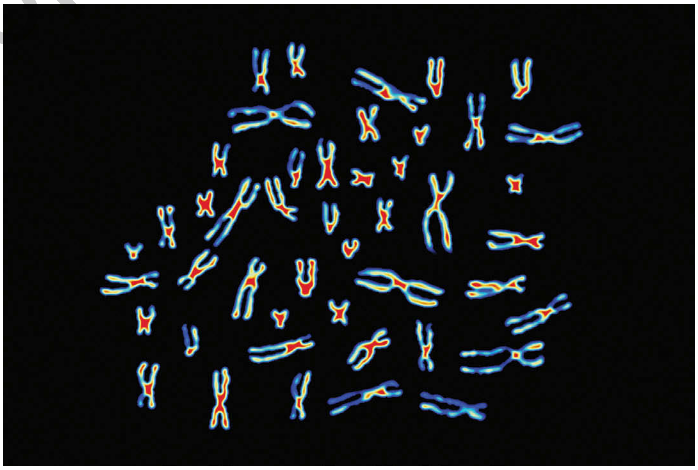
Virtually all scientists accept that natural selection is the main mechanism for producing lasting change within and across species. However, not all features of the body and mind are necessarily adaptations. Consider your ability to read and write. These are highly adaptive psychological abilities, yet neither could have evolved through natural selection. Both developed relatively recently in human history—too short a time period for evolutionary change—and emerged long after the human brain had achieved its current size and form (S. J. Gould, 2000). On the other hand, the human eye and the psychological experience of perception are almost certainly specific adaptations molded through generations of evolutionary change (D. D. Hoffman, 2016).

How do we identify which features of our body and mind are adaptations? This is a tough one, particularly with respect to mental processes. As noted in Chapter 1, evolutionary psychologists are convinced that we're born with a number of psychological adaptations (see D. M. Buss, 2019); others believe that our thought processes are shaped largely by the environment—that is, by how we're taught and by the cultural messages we receive (Rose & Rose, 2000). To qualify as an adaptation, one must satisfy several criteria. First, it is necessary to show that the psychological trait can be inherited or passed along across generations through reproduction. Second, at some point in the past, the trait must have been present in some members of the species and not others. Finally, the trait must have been "selected" by nature because it was adaptive—it helped the individual survive or reproduce. Getting this kind of evidence is difficult, if not impossible, for most of the psychological adaptations of interest to evolutionary psychologists (Richardson, 2007). However, the situation is not hopeless. Evolutionary psychologists are constantly gathering evidence that seems to support the existence of psychological adaptations.

For natural selection to produce an adaptation, there needs to be a mechanism for ensuring that variations, or differences, are present within a species. If all the members of a species are the same, then there are no special features for nature to select. There also needs to be some way to guarantee that an adaptive feature can pass from one generation to the next. During Darwin's time, the mechanism for ensuring variability and inheritance was unknown; Darwin made his case by documenting the abundance of variability and inherited characteristics that exist in nature. It was later learned that the mechanism that enables natural selection is the genetic code.

Genetic Principles

Let's briefly review some of the basic principles of genetics. How is the genetic code stored, and what are the factors that produce genetic variability? The genetic message resides within *chromosomes*, which are thin, threadlike strips of DNA. Human cells, except for sperm cells and the unfertilized egg cell, contain a total of 46 chromosomes, arranged in 23 pairs. Half of each chromosome pair is contributed originally by the mother through the egg, and the other half arrives in the father's sperm. **Genes** are segments of a chromosome that contain instructions for influencing and creating hereditary characteristics. For example, each person has a gene that helps determine height or hair color and another that may determine susceptibility to disorders such as muscular dystrophy or even Alzheimer's disease.



The genetic record we inherit from our parents shapes our physical and psychological characteristics.

Scott Camazine / Science Source

Because humans have *23 pairs* of chromosomes, they have two genes for most developmental characteristics, or traits. People have two genes, for example, for hair color, blood type, and the possible development of facial dimples. If both genes are designed to produce the same trait (such as nearsightedness), the characteristic will likely develop (you'll need glasses). But if the two genes differ—for example, the father passes along the gene for nearsightedness, but the mother's gene is for normal distance vision—the trait is determined by the *dominant gene*; in the case of vision, the "normal" gene will dominate the *recessive gene* for nearsightedness.

The fact that a dominant gene will mask the effects of a recessive gene means that everybody has genetic material that's not expressed in physical or psychological characteristics. A person may see perfectly but still carry around the recessive gene for faulty distance vision. This is the reason parents with normal vision can produce a nearsighted child, or why two brown-haired parents can produce a child with blond hair—it is the combination of genes that determines the inherited characteristics.

Another important distinction is between the **genotype**, which is the actual genetic message, and the **phenotype**, which is the trait's observable characteristics. The phenotype, such as good vision or brown hair, is controlled mainly by the genotype, but it can be strongly influenced by the environment. A person's height and weight are shaped largely by the genotype, but environmental factors such as diet and physical health contribute significantly to the final phenotype. This is an important point to remember: Genes provide the materials from which characteristics develop, but the environment shapes the final product. As stressed in Chapter 1, it's nature via nurture. The environment provides the means through which nature can express itself (Ridley, 2003). There is also a growing research field, called *epigenetics*, that is investigating how the environment leads to modifications in gene expression that, in turn, can affect the extent to which heredity plays a role in physical and behavior traits. Again, these are not modifications in the underlying DNA sequence but changes in gene expression.

Across individuals, variations in the genetic message itself arise because there are trillions of different ways that the genetic information from each parent can be combined at fertilization. Each egg or sperm cell contains a random half of each parent's 23 chromosome pairs. According to the laws of probability, this means that some 8 million (2^{23}) different combinations can reside in either an egg cell or a sperm cell. The meeting of egg and sperm is also a matter of chance, which means that the genetic material from both parents can be combined in some 64 trillion ways—and this is from a single set of parents!

Clearly, there are many ways by which a trait, or combination of traits, can emerge and produce a survival "advantage" for one person over another. But variation in the genetic code can also occur by chance in the form of a **mutation**. A mutation is a spontaneous change in the genetic material that occurs during the gene replication process. Most genetic mutations are harmful to the organism, but occasionally they lead to traits that confer a survival advantage to the organism. Mutations, along with the variations produced by unique combinations of genetic material, are key ingredients for natural selection—together, they introduce novelty, or new traits, into nature.

Genes and Behavior

Now let's return to the link between genetics and psychology—what is the connection between genotypes, phenotypes, and behavior? In some sense, all behavior is influenced by genetic factors because genes help determine the structure and function of the brain. At the same time, no physical or mental trait will ever be determined entirely by genetic factors—the environment always plays some role. But can we predict the psychological traits of an individual by knowing something about the individual's genetic record? Susceptibility to the psychological disorder schizophrenia is a case in point. Natural children of parents with schizophrenia (where either one has the disorder or both do) have a greater chance of developing the disorder themselves, when compared to the children of normal parents. This is the case even if the children are adopted at birth and never raised in an abnormal environment. So, genes probably influence the chances that these children will develop the disorder.

The genetic recipe helps explain physical and sometimes behavioral similarities among family members.

iStockPhoto/monkeybusinessimages

One way to study the link between genes and behavior is to investigate family histories in detail. In **family studies**, researchers look for similarities and differences among biological (blood) relatives to determine the influence of heredity. As you've just seen, the chances of developing schizophrenia increase with a family history. There are many other traits that seem to run in families as well (e.g., intelligence and personality). The trouble with family studies, however, is that members of a family share more than just common genes. They are also exposed to similar environmental experiences, so it's difficult to separate the relative roles of nature and nurture in behavior. Family studies can be useful sources of information—it helps to know that someone is at a greater than average risk of developing schizophrenia—but they can't be used to establish true links between genes and behavior.

In **twin studies**, researchers compare traits between *identical* twins, who share essentially the same genetic material, and *fraternal* twins, who were born at the same time but whose genetic overlap is only roughly 50% (fraternal twins can even be of different sexes). In studies of intelligence, identical twins tend to have much more similar intelligence scores than fraternal twins, even when environmental factors are considered (Bouchard, 1997). Identical twins make ideal research subjects because researchers can control for genetic factors. Because these twins have virtually the same genetic makeup, emerging from a single fertilized egg, any physical or psychological differences that arise during development are likely due to environmental factors. Similarly, if identical twins are raised in different environments but still show similar traits, it's a strong indication that genetic factors are involved in expression of the trait. Neither of these assumptions is foolproof—it's quite possible that identical twins, even if raised in different households, still experience more similar environments than fraternal twins. People who look alike are often treated by the world in similar ways, even if they don't know each other. But twin studies have been a valuable source of information in psychological science, as you'll see in subsequent chapters.

Quantitative Techniques

New techniques may help solve some of the problems just discussed. One new quantitative technique, called *genome-wide complex trait analysis* (GCTA), uses the genetic similarities between unrelated individuals to estimate similarities in psychological traits, such as intelligence or personality (see Plomin & Deary, 2015). No need for twins, or even related individuals; instead, this technique is using recent advances in our understanding of the human genome to explore whether people with similar patterns in their DNA tend to have similar psychological traits. One obvious advantage of this technique is that genetic influences can be calculated from the DNA of thousands or even potentially millions of individuals.

You've been given only a brief introduction to "behavioral genetics" in this section, and we'll be returning to the connection between heredity and environment throughout the book. For now, recognize that how you think and act is indeed influenced by the code stored in your body's chromosomes. Through the random processes that occur at fertilization, nature guarantees diversity within the species. Everyone receives a unique genetic message that, in combination with environmental factors, helps determine brain structure as well as human psychology. From an evolutionary standpoint, diversity is of great importance because it increases the chances that at least some members of a species will have the necessary tools to deal successfully with the problems of survival and reproduction.

KNOWLEDGE CHECK 3.4

To check on your understanding of genetics, choose whether each of the following statements is true or false. (You will find the answers in the Appendix.)

1. Reading and writing are examples of adaptations and therefore result from the mechanism of natural selection. *True or False*?
2. The actual genetic information inherited from one's parents is known as one's genotype. *True or False*?
3. If the two inherited genes for a specific trait differ, the recessive gene plays a stronger role. *True or False*?

4. Psychologists can study genetic effects on a variety of characteristics, such as intelligence or susceptibility to schizophrenia, by studying identical twins raised in different environments. *True or False*?

THE PROBLEMS SOLVED: WHAT BIOLOGICAL SYSTEMS ARE FOR

The human brain, along with the rest of the nervous system, is a biological solution to problems produced by constantly changing environments. Fortunately, out of these biological solutions arise those features that make up the human mind, including intellect, emotion, and artistic creativity. In this chapter, we've considered four central problems of adaptation.

Communicating Internally: Connecting World and Brain

Networks of individual cells, called neurons, establish a marketplace of information called the nervous system. To communicate internally, the nervous system uses an electrochemical language. Messages travel electrically within a neuron, usually from dendrite to soma to axon to terminal button, and then chemically from one neuron to the next. Combining electrical and chemical components creates a quick, efficient, and extremely versatile communication system. Neurotransmitters regulate the rate at which neurons fire by producing excitatory or inhibitory messages, and the resulting patterns of activation shape how we think and act.

Initiating Behavior: A Division of Labor

To accomplish the remarkable variety of functions it controls, the nervous system divides its labor. Using sophisticated techniques, including brain-imaging devices, researchers have begun to map out the regions of the brain that support particular psychological and life-sustaining functions. At the base of the brain, in the hindbrain region, structures control such basic processes as respiration, heart rate, and the coordination of muscle movements. Higher up are regions that control motivational processes such as eating, drinking, and sexual behavior. Finally, in the cerebral cortex, more complex mental processes—such as thought, sensations, and language—are represented. Some functions in the brain appear to be lateralized, which means that they're controlled primarily by one cerebral hemisphere or the other. Through the development of specialized regions of cells, the human brain has become capable of extremely adaptive reactions to its changing environment.

Regulating Growth and Internal Functions: Extended Communication

To solve its widespread and long-term communication needs, the body uses the endocrine system to release chemicals called hormones into the bloodstream. These chemical messengers serve a variety of regulatory functions, influencing growth and development, hunger, thirst, and sexual behavior, in addition to helping the body prepare for action. Hormones released early in development and into adulthood may partly explain some of the behavioral differences between men and women.

Adapting and Transmitting the Genetic Code

Adaptations are traits that arise through the mechanism of natural selection. Although it's difficult to establish which psychological traits are truly adaptations, psychologists acknowledge that our thoughts and behaviors are influenced by genetic factors. The combination of genes inherited from our parents, along with influences from the environment, determines our individual characteristics. Psychologists often try to disentangle the relative contributions of genes and the environment by conducting twin studies, comparing the behaviors and abilities of identical and fraternal twins raised in similar or dissimilar environments. When identical twins show similar characteristics, even though they have been raised in quite different settings, psychologists assume that the underlying genetic code is playing an influential role.

THINKING ABOUT RESEARCH

A summary of a research study in psychology is given in this section. As you read the summary, think about the following questions:

1. Which of the techniques used to study brain function are involved in this study?
2. Besides these two techniques, how might other investigative tools be used to address the question of interest, using the same experimental procedures?
3. Do you think the brain needs different structures to control learning and remembering? How does learning differ from remembering?
4. Can you think of problems researchers might have interpreting results that arise when healthy and amnesic patients are compared in a study?

Article Reference: Palombo, D. J., Hayes, S. M., Reid, A. G., & Verfaellie, M. (2019). Hippocampal contributions to value-based learning: Converging evidence from fMRI and amnesia. *Cognitive, Affective, & Behavioral Neuroscience, 19*, 523–536.

Purpose of the Study: This study investigated whether the hippocampus, which is known to be involved in remembering, also plays a role in value-based learning. Research participants were asked to learn about the value of stimuli, in this case whether people were likely to win money or not. This study is important because it uses two of the techniques discussed in this chapter to investigate brain function—brain imaging and brain damage. The authors proposed that if the hippocampus is involved in learning about value, then (a) it will become activated during a value-learning task (as measured by brain imaging) and (b) people with selective damage to the hippocampus will have difficulty learning the same task.

Method of the Study: Two experiments were conducted. In the first, 30 healthy people were "scanned" (using functional MRI technology) while trying to learn whether particular people had a history of winning money in a game. On each trial, a schematic image of a person was shown, identified by a colored jumpsuit, and the participant was asked, "Does this person win money?" The participant was required to respond "Yes" or "No," and then feedback was given (e.g., "The man wins $1!"). Each of the images was shown repeatedly over trials, with a certain probability of winning money, so the participant gradually learned which of the images corresponded to a "winner" or a "loser." Control participants were shown the same images but were not required to learn anything. In the second experiment, the same task was used, but the investigators tested participants who suffered from severe memory impairments caused by damage to hippocampal regions of the brain.

Results of the Study: In Experiment 1, the imaging data revealed that the hippocampus was indeed activated during the value-learning game, more so for the participants who were required to learn and remember the winners and losers. In Experiment 2, supporting the conclusions of Experiment 1, the amnesic patients had great difficulty with the task, even though they had no trouble performing a perceptual discrimination task involving the same stimuli (a task that does not depend on hippocampal activation).

Conclusions of the Study: The present study confirmed that the hippocampus plays a role in value-based learning. By showing the same effects with two different investigative techniques, using the same experimental task, the investigators were able to provide strong and converging evidence about involvement of a particular brain structure in a learning task.

KNOWLEDGE CHECK: CHAPTER SUMMARY

(You'll find the answers in the Appendix.)

COMMUNICATING INTERNALLY: CONNECTING WORLD AND BRAIN

- The field of (1) ___ studies the connection between the brain and behavior.
- Neurons receive (2) ___ and transmit information (3) ___.
- A neuron consists of (4) ___, a soma, (5) an ___, and terminal buttons. Sensory neurons carry information through the spinal cord to the brain. (6) ___ convey information between internal

processing sites. (7) ___ neurons carry messages from the central nervous system to the muscles and glands that produce a (8) ___ response.

- Within a neuron, messages travel electrically from one point to another. From one neuron to another, messages travel (9) ___, through neurotransmitters.
- Groups of neurons operating simultaneously create an (10) ___ pattern that underlies both conscious experiences and complex behaviors.

INITIATING BEHAVIOR: A DIVISION OF LABOR

- We think, feel, and function physically because of a biological division of labor.
- The central nervous system consists of the brain and (11) ___, which communicate to the rest of the body through bundles of (12) ___, or nerves. The peripheral nervous system, which includes the (13) ___ and (14) ___ systems, sends sensory information to the brain, moves muscles, and regulates (15) ___ function.
- Studying brain damage and (16) ___ can reveal brain function. Chemical injection and (17) ___ let scientists stimulate the brain. They can also observe the brain through noninvasive techniques, including monitoring electrical brain activity using an (18) ___ and using X-rays (CT scanning) and neuroimaging devices such as (19) ___ and magnetic resonance imaging (MRI) ___ to create three-dimensional pictures or live snapshots of the brain.
- The (20) ___ provides basic life support, through the medulla, (21) ___, reticular formation, and cerebellum. The (22) ___ relays sensory messages. Higher mental functioning takes place in the (23) ___ using the cerebral cortex, thalamus, hypothalamus, and (24) ___ system.
- The two hemispheres (halves) ___ of the cerebral cortex are (25) ___; that is, each side is responsible for somewhat different functions.

REGULATING GROWTH AND INTERNAL FUNCTIONS: EXTENDED COMMUNICATION

- Endocrine glands release (26) ___ into the blood that interact with the nervous system to regulate such basic activities as the fight-or-flight response.
- The (27) ___ gland releases hormones that determine sexual identity before birth and direct sexual maturity at puberty. Activities in the (28) ___ system may account for basic differences in the ways females and males think and behave.

ADAPTING AND TRANSMITTING THE GENETIC CODE

- Gene-based physical and psychological traits that increase the chances for (29) ___, or of finding a mate, can be selected for by nature and become adaptations. (30) ___, especially psychological ones, can be difficult to identify.
- Inside the cell are 23 pairs of (31) ___, threadlike strips of DNA. (32) ___ are segments of chromosomes that contain instructions for creating or influencing a particular hereditary characteristic. Genes can be dominant or (33) ___.
- (34) ___ studies identify similarities and differences that may reveal the influence of heredity. In (35) ___ studies, researchers compare the behavioral traits of identical twins, who have the same genetic material, and (36) ___ twins, who have only about half their genes in common. Traits that aren't accounted for by genetics are attributed to (37) ___ influences.

CRITICAL THINKING QUESTIONS

1. Do you think it's possible that personality is completely localized in one portion of the brain? If so, then how can you explain the fact that someone's personality can seem to change depending on the situation?

2. Other than as a treatment for epilepsy, can you think of any situations in which having a split brain might be more beneficial than a unified brain?
3. Initiation of the fight-or-flight response clearly has adaptive value. Can you think of any circumstances in which this response might lower the chances of an adaptive response?
4. Do you think a trait can be universal, economical, and adaptive but still be a result primarily of the environment? How can we ever be certain that a trait is an adaptation?

KEY TERMS

acetylcholine (p. 70)
action potential (p. 68)
adaptation (p. 91)
autonomic system (p. 74)
axon (p. 67)
central nervous system (p. 74)
cerebellum (p. 80)
cerebral cortex (p. 81)
computerized tomography scan (CT scan) (p. 77)
corpus callosum (p. 86)
dendrites (p. 67)
dopamine (p. 70)
electroencephalograph (EEG) (p. 77)
endocrine system (p. 88)
endorphins (p. 72)
family studies (p. 94)
forebrain (p. 81)
frontal lobe (p. 83)
gamma-aminobutyric acid (GABA) (p. 71)
genes (p. 92)
genotype (p. 93)
glial cells (p. 66)
glutamate (p. 70)
hindbrain (p. 79)
hormones (p. 88)
hypothalamus (p. 81)
interneurons (p. 65)
limbic system (p. 81)
magnetic resonance imaging (MRI) (p. 78)
midbrain (p. 80)
motor neurons (p. 66)
mutation (p. 93)
myelin sheath (p. 66)
nerves (p. 74)
neurons (p. 65)
neuroscience (p. 64)
neurotransmitters (p. 69)
occipital lobe (p. 84)
optogenetics (p. 77)
parietal lobe (p. 83)
peripheral nervous system (p. 74)
phenotype (p. 93)
pituitary gland (p. 88)
positron emission tomography (PET) (p. 78)
reflexes (p. 66)
refractory period (p. 73)
resting potential (p. 68)
sensory neurons (p. 65)
serotonin (p. 71)
soma (p. 67)
somatic system (p. 74)
synapse (p. 67)
temporal lobe (p. 84)
terminal buttons (p. 67)
thalamus (p. 81)
transcranial magnetic stimulation (TMS) (p. 77)
twin studies (p. 94)