

3

Biology and Behavior

Ask & Answer

3.1 How Does the Nervous System Operate? 76

3.2 What Are the Basic Brain Structures and Their Functions? 89

3.3 How Does the Brain Communicate with the Body? 104

3.4 How Does the Brain Change? 109

3.5 What Is the Genetic Basis of Psychological Science? 115

IN 2012, JACK OSBOURNE, THE SON OF OZZY AND SHARON OSBOURNE, was 26 years old (**FIGURE 3.1**). Two weeks after the birth of his daughter Pearl, he noticed a disturbing problem with his vision. He told *People* magazine (July 9, 2012) about an experience he had at a gas station: “I was talking to the attendant, and all of a sudden a black dot appeared in my vision . . . I was like, ‘That’s weird.’ The next day I woke up and the dot had turned into a cigar shape.” Eventually his vision deteriorated to the point that Jack could barely see out of his right eye. After a series of tests, physicians determined that Jack was in the early stages of multiple sclerosis (MS). On his mother’s television talk show *The Talk* (June 21, 2012), Osbourne said: “I guess I’ve been having symptoms for the last three or four years, but I didn’t realize it. . . . I had problems with my bladder, problems with my stomach, and then, about two years ago, my legs went numb for two months, and I just thought I had pinched a nerve.”

Multiple sclerosis is a disorder of the nervous system that is typically diagnosed between the ages of 20 and 40. It affects the brain and spinal cord, so that movements become jerky and victims lose the ability to coordinate their actions. Movement, coordination, vision, and cognition gradually deteriorate until they become severely impaired. MS affects about 2.5 million people throughout the world. The exact cause has not been identified, but research indicates that genetics and environment are important contributing factors. Although MS is incurable, symptoms are now manageable in some forms of the disease.



FIGURE 3.1
Multiple Sclerosis as a Disorder of the Nervous System

Jack Osbourne is one of millions of people with multiple sclerosis. This disease damages nerve cells in the brain.

neurons

The basic units of the nervous system; cells that receive, integrate, and transmit information in the nervous system. They operate through electrical impulses, communicate with other neurons through chemical signals, and form neural networks.

central nervous system (CNS)

The brain and the spinal cord.

Learning Objectives

- Distinguish between the two basic divisions of the nervous system.
- Distinguish between the functions of distinct types of neurons.
- Describe the structure of the neuron.
- Describe the electrical and chemical changes that occur when neurons communicate.
- Identify the major neurotransmitters and their primary functions.

Looking closely at multiple sclerosis helps us understand how the nervous system is critical in our ability to think and behave normally. In MS, damage to nerve cells limits their ability to send signals to other nerve cells and to receive signals from other nerve cells. To picture how a nerve cell communicates, imagine the plastic around a wire such as the cord for a lamp. Like the lamp cord, one part of the nerve cell is covered. The cord is covered not by plastic but by a fatty layer, which helps the cell to transmit signals to other nerve cells and other parts of the body. In MS, the fatty layer deteriorates, short-circuiting normal communication between nerve cells. And normal communication between nerve cells makes all thought, feeling, and behavior possible.

So, to know what makes us who we are, we need to understand how the nervous system works. We need to understand physiological processes and the genetic underpinnings of those processes. We also need to understand how aspects of our biology interact with our environments: How does nurture influence nature, and how does nature influence nurture?

As technology has advanced over the past three decades, researchers have learned a great deal about the biological basis of brain activity. Brain imaging techniques have shed light on the functions of different brain regions. Genetic analysis has revealed how certain disorders are passed from one generation to the next, made it possible to predict who will develop specific disorders, and helped identify the functions of specific genes related to psychological processes. You are about to learn how psychological activity is related to several aspects of biology, including genes, the endocrine system, and the nervous system.

3.1 How Does the Nervous System Operate?

The nervous system is responsible for everything people think, feel, or do. Essentially, each of us *is* a nervous system. The basic units of this system are the nerve cells, called **neurons** (**FIGURE 3.2**). These cells receive, integrate, and transmit information in the nervous system. Complex networks of neurons sending and receiving signals are the functional basis of all psychological activity. Although the actions of single neurons are simple to describe, human complexity results from billions of neurons. Each neuron makes contact with tens of thousands of other neurons. Neurons do not communicate randomly or arbitrarily, however. They communicate selectively with other neurons to form circuits, or *neural networks*. These networks develop through maturation and experience and repeated firing. In other words, permanent alliances form among groups of neurons.

The Nervous System Has Two Basic Divisions

Neural networks are linked, and together they form the nervous system. The entire nervous system is divided into two basic units: the central nervous system and the

peripheral nervous system. The **central nervous system (CNS)** consists of the brain and the spinal cord, both of which contain massive numbers of neurons (**FIGURE 3.3**). The **peripheral nervous system (PNS)** consists of all the other nerve cells in the rest of the body. The CNS and PNS are anatomically separate, but their functions are highly interdependent. The PNS sends a variety of information to the CNS. The CNS organizes and evaluates that information and then directs the PNS to perform specific behaviors or make bodily adjustments.

As discussed more fully later in this chapter, the PNS includes the somatic and autonomic nervous systems. The somatic component of the PNS is involved in voluntary behavior, such as when you reach for an object to see how it feels. The autonomic component of the PNS is responsible for the less voluntary actions of your body, such as controlling heart rate and other bodily functions.

Neurons Are Specialized for Communication

Neurons are specialized for communication. That is, unlike other cells in the body, nerve cells are excitable: They are powered by electrical impulses and communicate with other nerve cells through chemical signals. During the reception phase, neurons take in the chemical signals from neighboring neurons. During integration, incoming signals are assessed. During transmission, they pass their own signals to yet other receiving neurons.

TYPES OF NEURONS The three basic types of neurons are sensory neurons, motor neurons, and interneurons (**FIGURE 3.4**). **Sensory neurons** detect information from the physical world and pass that information along to the brain, usually through the spinal cord. To get a sense of how fast that process can work, think of the last time you touched something hot or accidentally pricked yourself with a sharp object, such as a tack. Those signals triggered your body's nearly instantaneous response and sensory

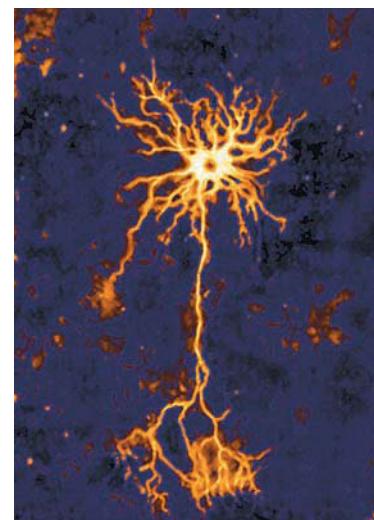


FIGURE 3.2
Human Neuron

Neurons like this one are the basic units of the human nervous system.

peripheral nervous system (PNS)

All nerve cells in the body that are not part of the central nervous system. The peripheral nervous system includes the somatic and autonomic nervous systems.

sensory neurons

One of the three types of neurons; these neurons detect information from the physical world and pass that information to the brain.

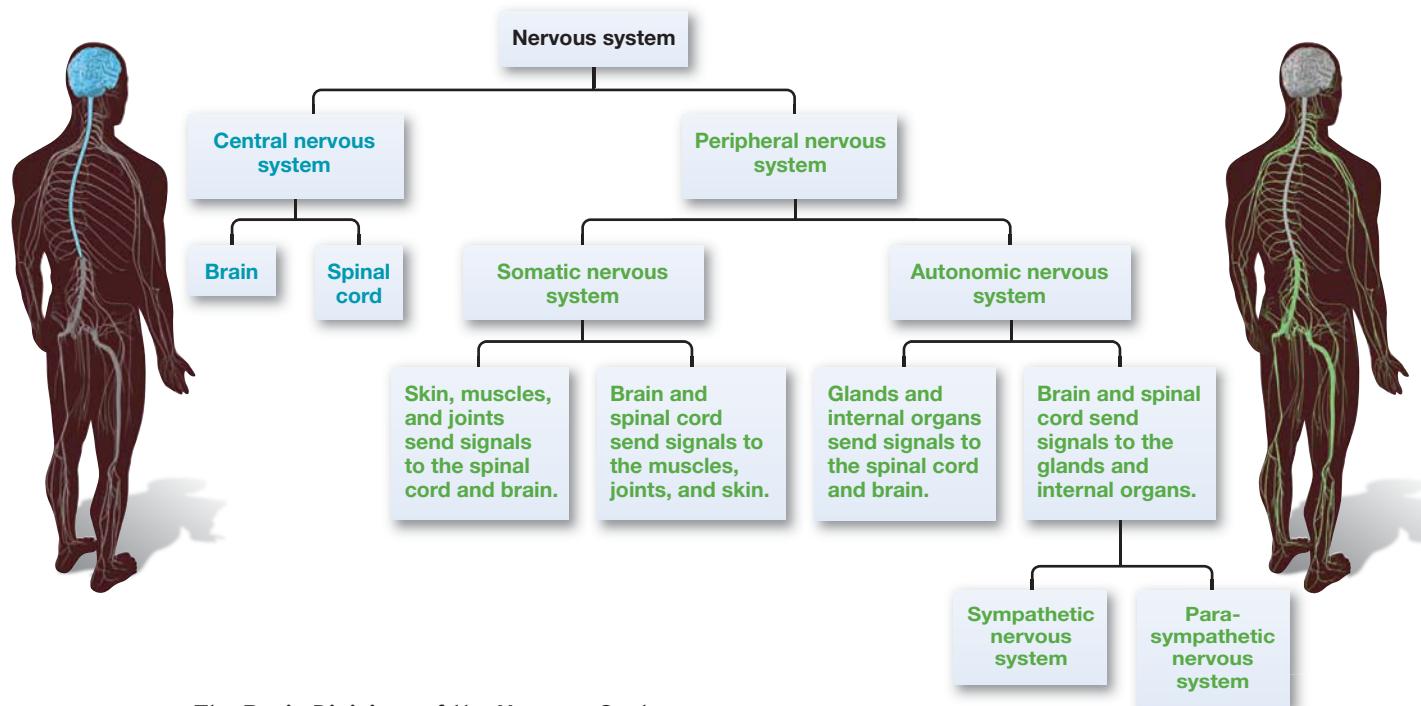
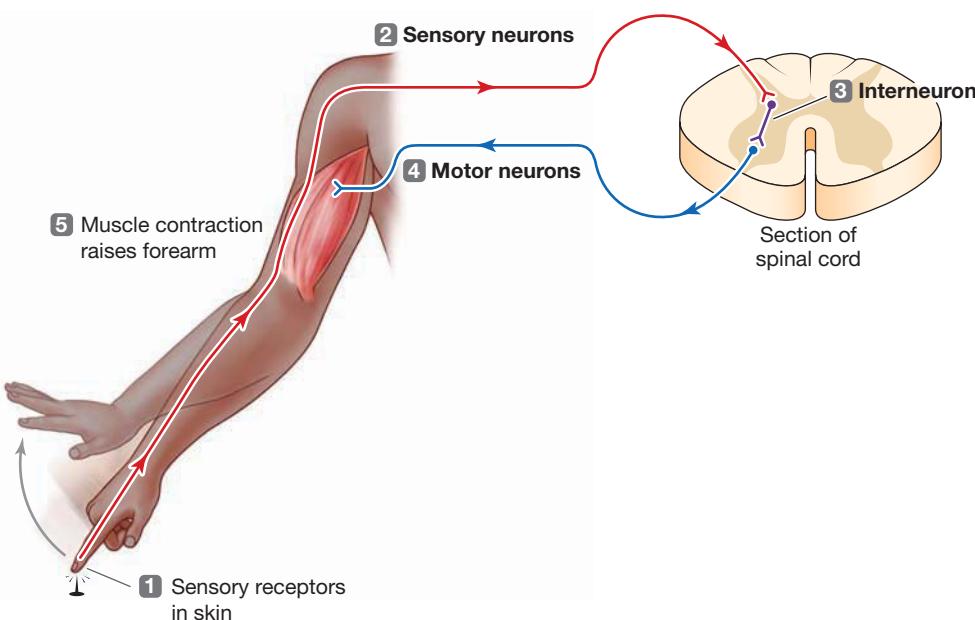


FIGURE 3.3 The Basic Divisions of the Nervous System

FIGURE 3.4**The Three Types of Neurons**

(Red line) Receptors send signals to the brain for processing. Those signals travel through sensory neurons and the spinal cord. **(Blue line)** To produce a response, a signal is sent from the brain to the body through the spinal cord and motor neurons.



experience of the impact. The sensory nerves that provide information from the skin and muscles are called *somatosensory nerves*. (This term comes from the Greek for “body sense.” It means sensations experienced from within the body.)

Motor neurons direct muscles to contract or relax, thereby producing movement. **Interneurons** communicate within local or short-distance circuits. That is, interneurons integrate neural activity within a single area rather than transmitting information to other brain structures or to the body organs.

Sensory and motor neurons work together to control movement. For instance, if you are using a pen to take notes as you read these words, you are contracting and relaxing your hand muscles and finger muscles to adjust your fingers’ pressure on the pen. When you want to use the pen, your brain sends a message via motor neurons to your finger muscles so they move in specific ways. Receptors in both your skin and your muscles send back messages through sensory neurons to help determine how much pressure is needed to hold the pen. This symphony of neural communication for a task as simple as using a pen is remarkable, yet most of us employ motor control so easily that we rarely think about it. In fact, our *reflexes*, automatic motor responses, occur before we even think about those responses. For each reflex action, a handful of neurons simply convert sensation into action.

motor neurons

One of the three types of neurons; these neurons direct muscles to contract or relax, thereby producing movement.

interneurons

One of the three types of neurons; these neurons communicate within local or short-distance circuits.

dendrites

Branchlike extensions of the neuron that detect information from other neurons.

cell body

The site in the neuron where information from thousands of other neurons is collected and integrated.

axon

A long narrow outgrowth of a neuron by which information is transmitted to other neurons.

NEURON STRUCTURE In addition to performing different functions, neurons have a wide assortment of shapes and sizes. A typical neuron has four structural regions that participate in communication functions: the dendrites, the cell body, the axon, and the terminal buttons (**FIGURE 3.5**). The **dendrites** are short, branchlike appendages that detect chemical signals from neighboring neurons. In the **cell body**, also known as the *soma* (Greek for “body”), the information received via the dendrites from thousands of other neurons is collected and integrated.

Once the incoming information from many other neurons has been integrated in the cell body, electrical impulses are transmitted along a long, narrow outgrowth known as the **axon**. Axons vary tremendously in length, from a few millimeters to more than a meter. The longest axons stretch from the spinal cord to the big toe. You have heard the term *nerve*, as in Jack Osbourne’s reference to a “pinched nerve.” In

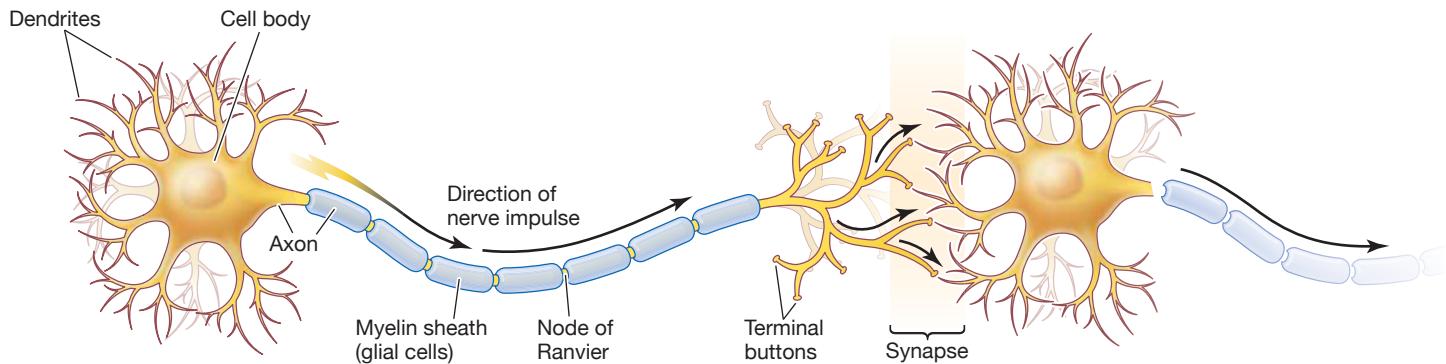


FIGURE 3.5
Neuron Structure

Messages are received by the dendrites, processed in the cell body, transmitted along the axon, and sent to other neurons via chemical substances released from the terminal buttons across the synapse. (The myelin sheath, glial cells, and the nodes of Ranvier are discussed on pp. 81-82.)

in this context, a nerve is a bundle of axons that carry information between the brain and other specific locations in the body. At the end of the axon are knoblike structures called **terminal buttons**.

The site where chemical communication occurs between neurons is called the **synapse**. Neurons communicate by sending chemicals into the synapse, a tiny gap between the axon of the “sending” neuron and the dendrites of the “receiving” neurons. Chemicals leave one neuron, cross the synapse, and pass signals along to other neurons’ dendrites.

The neuron is covered with a *membrane*, a fatty barrier that does not dissolve in the watery environment inside and outside the neuron. The membrane is semipermeable. In other words, some substances move in or out of the membrane, and some do not. Located on the membrane are *ion channels*. These specialized pores allow *ions* to pass in and out of the cell when the neuron transmits signals down the axon. Ions are molecules, some charged negatively and some charged positively. By controlling the movement of ions, the membrane plays an important role in communication between neurons: It regulates the concentration of electrically charged molecules that are the basis of the neuron’s electrical activity.

The Resting Membrane Potential Is Negatively Charged

When a neuron is resting, not active, the electric charge inside and outside the membrane is different. This difference is the **resting membrane potential**. The difference in the electrical charge occurs because the ratio of negative to positive ions is greater inside the neuron than outside it. Therefore, the electrical charge inside the neuron is slightly more negative than the electrical charge outside—typically -70 millivolts (about $\frac{1}{20}$ the charge of a AA battery). When a neuron has more negative ions inside than outside, the neuron is described as being *polarized*. The polarized state of the resting neuron creates the electrical energy necessary to power the firing of the neuron.

THE ROLES OF SODIUM AND POTASSIUM IONS Two types of ions that contribute to a neuron’s resting membrane potential are *sodium ions* and *potassium ions*. Although other ions are involved in neural activity, sodium and potassium are most important for this discussion.

terminal buttons

At the ends of axons, small nodules that release chemical signals from the neuron into the synapse.

synapse

The gap between the axon of a “sending” neuron and the dendrites of a “receiving” neuron; the site at which chemical communication occurs between neurons.

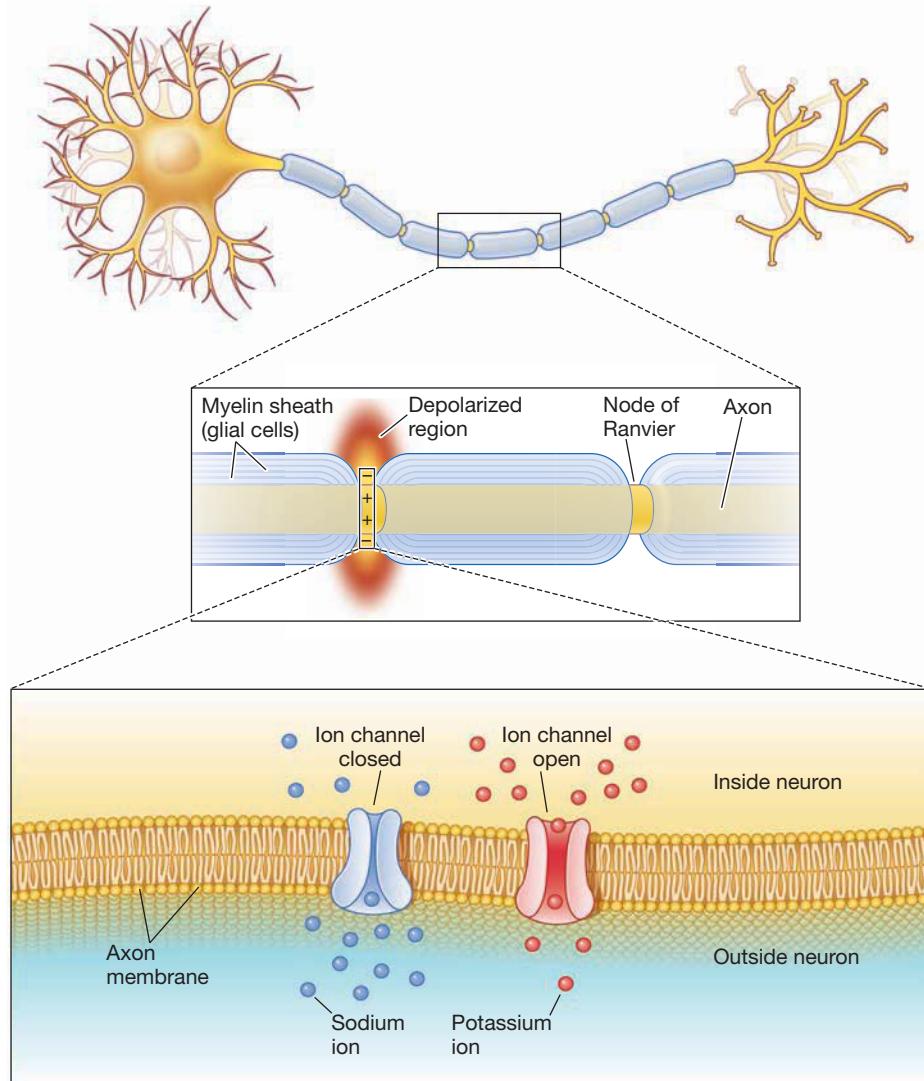
resting membrane potential

The electrical charge of a neuron when it is not active.

FIGURE 3.6

Resting Membrane Potential

A neuron at rest is polarized: It has a more negative electrical charge inside than outside. The passage of negative and positive ions inside and outside the membrane is regulated by ion channels, such as those located at the nodes of Ranvier.



Ions pass through the neuron membrane at the ion channels (**FIGURE 3.6**). Each channel matches a specific type of ion: Sodium channels allow sodium ions but not potassium ions to pass through the membrane, and potassium channels allow passage of potassium ions but not sodium ions. The flow of ions through each channel is controlled by a gating mechanism. When a gate is open, ions flow in and out of the cell membrane. A closed gate prevents their passage. Ion flow is also affected by the cell membrane's selective permeability. That is, much like a bouncer at an exclusive nightclub, the membrane allows some types of ions to cross more easily than others. Partially as a result of this selective permeability of the cell membrane, more potassium than sodium is inside the neuron.

Another mechanism in the membrane that contributes to polarization is the *sodium-potassium pump*. This pump increases potassium and decreases sodium inside the neuron, activity that helps maintain the resting membrane potential.

Action Potentials Cause Neural Communication

Neural communication depends on a neuron's ability to respond to incoming stimulation. The neuron responds by changing electrically and then passing along signals to

other neurons. An **action potential**, also called *neural firing*, is the electrical signal that passes along the axon. This signal causes the terminal buttons to release chemicals that transmit signals to other neurons. The following sections examine some factors that contribute to the firing of an action potential.

action potential

The electrical signal that passes along the axon and subsequently causes the release of chemicals from the terminal buttons.

CHANGES IN ELECTRICAL POTENTIAL LEAD TO ACTION A neuron receives chemical signals from nearby neurons through its dendrites. By affecting polarization, these chemical signals tell the neuron whether to fire. The signals arrive at the dendrites by the thousands and are of two types: excitatory and inhibitory. *Excitatory signals* depolarize the cell membrane (i.e., decrease polarization by decreasing the negative charge inside the cell). Through depolarization, these signals increase the likelihood that the neuron will fire. *Inhibitory signals* hyperpolarize the cell (i.e., increase polarization by increasing the negative charge inside the cell). Through hyperpolarization, these signals decrease the likelihood that the neuron will fire. Excitatory and inhibitory signals received by the dendrites are combined within the neuron. If the total amount of excitatory input surpasses the neuron's firing threshold (-55 millivolts), an action potential is generated.

When a neuron fires, the sodium gates in the cell membrane open. The open gates allow sodium ions to rush into the neuron. This influx of sodium causes the inside of the neuron to become slightly more positively charged than the outside. A fraction of a second later, potassium channels open to allow the potassium ions inside the cell membrane to rush out. This change from a negative charge to a positive one inside the neuron is the basis of the action potential. As the sodium ion channels close, the sodium ions stop entering the cell. Similarly, as the potassium ion channels close, potassium ions stop exiting the cell. Thus, during this process, the electrical charge inside the cell starts out slightly negative in its initial resting state. As the cell fires and allows more positive ions inside, the charge becomes positive. Through natural restoration, including the activity of the sodium-potassium pump, the charge then returns to its slightly negative resting state (**FIGURE 3.7**).

ACTION POTENTIALS SPREAD ALONG THE AXON When the neuron fires, the cell membrane's depolarization moves along the axon like a wave. Sodium ions rush through their channels, causing adjacent sodium channels to open. Thus, like toppling dominoes, sodium ion channels open in a series. The action potential always moves down the axon away from the cell body to the terminal buttons. These

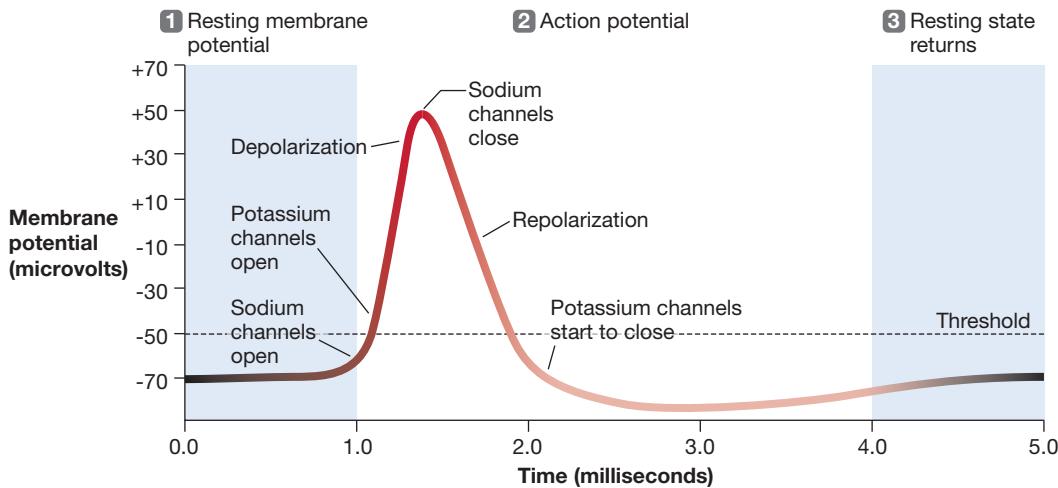


FIGURE 3.7
Action Potential

The electrical charge inside the neuron starts out slightly negative (resting membrane potential, -70 millivolts). As the neuron fires, it allows more positive ions inside the cell (depolarization). It then returns to its slightly negative resting state.

electrical signals travel quickly down most axons because of the fatty **myelin sheath** that encases and insulates many axons like the plastic tubing around wires in an electrical cord (see Figure 3.5).

The myelin sheath is made up of *glial cells*, commonly called *glia* (Greek for “glue”). The sheath grows along an axon in short segments. Between these segments are small gaps of exposed axon called the **nodes of Ranvier** (after the researcher who first described them). Because of the insulation provided by the myelin sheath, the action potential skips quickly along the axon. It pauses briefly to be recharged at each node along the axon. The entire process takes about $\frac{1}{1,000}$ of a second, permitting the fast and frequent adjustments required for coordinating motor activity. For those axons without myelin, sodium channels along each part of the membrane must open. Action potentials are still generated, but the speed of conduction is decreased greatly.

Recall from the chapter opener that Jack Osbourne’s vision was affected because multiple sclerosis destroys the myelin sheath. Sensory and motor neurons must maintain their myelin to generate fast signals over long distances. Think of how fast you are able to remove your hand from a hot surface to avoid being burned. That speed of movement is the result of myelin, which allows you to feel the heat and reflexively remove your hand. Sensory and motor axons that have no insulation cannot transmit their action potentials as quickly or efficiently. The loss of myelin means that visual information is disrupted and motor actions become jerky and uncoordinated.

ALL-OR-NONE PRINCIPLE Any one signal received by the neuron has little influence on whether the neuron fires. Normally, a neuron is barraged by thousands of excitatory and inhibitory signals, and its firing is determined by the number and frequency of those signals. If the sum of excitatory and inhibitory signals leads to a positive change in voltage that exceeds the neuron’s firing threshold, an action potential is generated.

A neuron either fires or it does not. It works like a light switch that is either on or off, not like a dimmer switch. The **all-or-none principle** dictates that a neuron fires with the same potency each time. In other words, it does not fire in a way that can be described as weak or strong. What is affected by the strength of the stimulation is how often the neuron fires: The stronger the stimulation, the more frequently it fires action potentials.

For the sake of comparison, suppose you are playing a video game in which you fire missiles by pressing a button. Every time you press the button, a missile is launched at the same velocity as the previous one. It makes no difference how hard you press the button. If you keep your finger on the button, additional missiles fire in rapid succession. Likewise, if a neuron in the visual system, for example, receives information that a light is bright, it might respond by firing more rapidly and more often than when it receives information that the light is dim. Regardless of whether the light is bright or dim, the strength of the firing will be the same every time.

myelin sheath

A fatty material, made up of glial cells, that insulates some axons to allow for faster movement of electrical impulses along the axon.

nodes of Ranvier

Small gaps of exposed axon, between the segments of myelin sheath, where action potentials take place.

all-or-none principle

The principle that when a neuron fires, it fires with the same potency each time; a neuron either fires or not—it cannot partially fire, although the frequency of firing can vary.

Neurotransmitters Bind to Receptors Across the Synapse

As noted earlier, neurons do not touch one another. They are separated by a small space known as the synapse, the site of chemical communication between neurons. Action potentials cause neurons to release chemicals from their terminal buttons. These chemicals travel across the synapse and are received by other neurons’ dendrites. The neuron that sends the signal is called the *presynaptic neuron*, and the one that receives the signal is called the *postsynaptic neuron*.

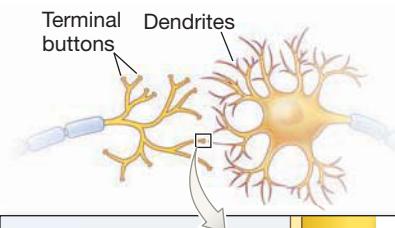
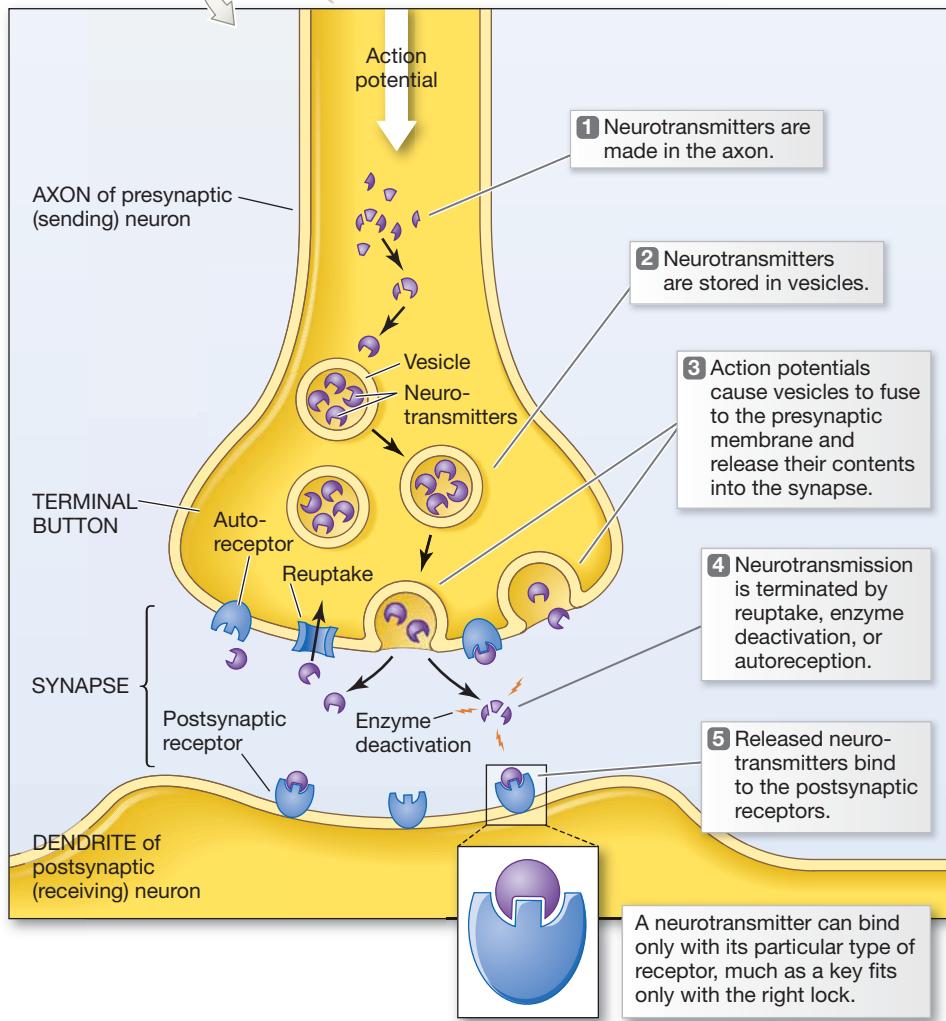


FIGURE 3.8 How Neurotransmitters Work



How do these chemical signals work (**FIGURE 3.8**)? Inside each terminal button are **neurotransmitters**, chemicals that are made in the axon and stored in vesicles (small, fluid-filled sacs). When released by the vesicles, the neurotransmitters convey signals across the synapse to postsynaptic cells.

After an action potential travels to the terminal button, it causes the vesicles to attach to the presynaptic membrane and release their neurotransmitters into the synapse. These neurotransmitters then travel across the synapse and attach themselves, or *bind*, to receptors on the postsynaptic neuron. **Receptors** are specialized protein molecules located on the postsynaptic membrane that specifically respond to the chemical structure of the neurotransmitter available in the synapse. The binding of a neurotransmitter with a receptor can cause ion channels to open or close more tightly, producing an excitatory or an inhibitory signal in the postsynaptic neuron. As mentioned previously, an excitatory signal encourages the neuron to fire. An inhibitory signal discourages it from firing.

neurotransmitters

Chemical substances that transmit signals from one neuron to another.

receptors

In neurons, specialized protein molecules on the postsynaptic membrane; neurotransmitters bind to these molecules after passing across the synapse.

NEUROTRANSMITTERS BIND WITH SPECIFIC RECEPTORS More than 60 chemicals convey information in the nervous system. Different neurotransmitters influence emotion, thought, or behavior. In much the same way as a lock opens only with the correct key, each receptor can be influenced by only one type of neurotransmitter.

Once a neurotransmitter is released into the synapse, it continues to bind with receptors and continues to exert an inhibitory or excitatory effect. It also blocks new signals until its influence is terminated. The three major events that terminate the neurotransmitter's influence in the synapse are *reuptake*, *enzyme deactivation*, and *autoreception*. **Reuptake** occurs when the neurotransmitter is taken back into the presynaptic terminal buttons. An action potential prompts terminal buttons to release the neurotransmitter into the synapse and then take it back for recycling. The cycle of reuptake and release repeats continuously. **Enzyme deactivation** occurs when an enzyme destroys the neurotransmitter in the synapse. Different enzymes break down different neurotransmitters. Neurotransmitters can also bind with receptors on the presynaptic neuron. These *autoreceptors* monitor how much neurotransmitter has been released into the synapse. When an excess is detected, the autoreceptors signal the presynaptic neuron to stop releasing the neurotransmitter.

All neurotransmitters have excitatory or inhibitory effects on action potentials. They do so by affecting the polarization of the postsynaptic cells. The effects are a function of the receptors that the neurotransmitters bind to. Recall the lock and key idea, in which a specific neurotransmitter binds only with certain receptors. The receptor always has a specific response, either excitatory or inhibitory. The same neurotransmitter can send excitatory or inhibitory postsynaptic signals, depending on the particular receptor's properties. In other words, the effects of a neurotransmitter are not a property of the chemical. Instead, the effects are a function of the receptor to which the neurotransmitter binds. Any neurotransmitter can be excitatory or inhibitory. Alternatively, it can produce radically different effects, depending on the properties of the receptor and on the receptor's location in the brain.

Neurotransmitters Influence Mental Activity and Behavior

Much of what we know about neurotransmitters has been learned through the systematic study of how drugs and toxins affect emotion, thought, and behavior. Drugs and toxins can alter a neurotransmitter's action in many ways. For example, they can alter how a neurotransmitter is synthesized. They can raise or lower the amount of a neurotransmitter released from the terminal buttons. Or, by blocking reuptake, they can change the way a neurotransmitter is deactivated in the synapse and therefore affect the concentration of the neurotransmitter.

Drugs and toxins that enhance the actions of neurotransmitters are known as *agonists*. Drugs and toxins that inhibit these actions are known as *antagonists*. Drugs and toxins can also mimic neurotransmitters and bind with their receptors as if they were the real thing (**FIGURE 3.9**). Addictive drugs such as heroin, for example, have their effects because they are chemically similar to naturally occurring neurotransmitters. The receptors cannot differentiate between the ingested drug and the real neurotransmitter released from a presynaptic neuron. That is, although a neurotransmitter fits a receptor the way a key fits a lock, the receptor/lock cannot tell a real neurotransmitter/key from a forgery—either will open it.

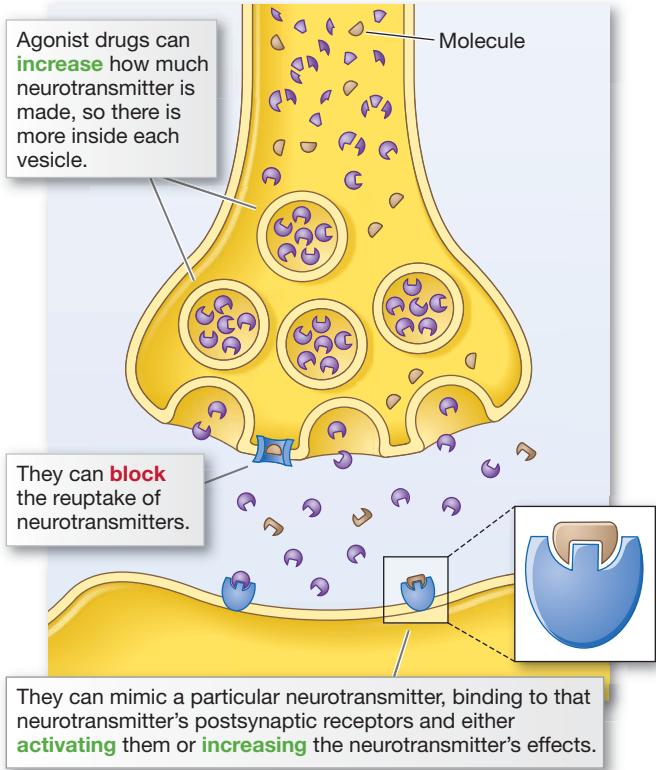
reuptake

The process whereby a neurotransmitter is taken back into the presynaptic terminal buttons, thereby stopping its activity.

acetylcholine (ACh)

The neurotransmitter responsible for motor control at the junction between nerves and muscles; it is also involved in mental processes such as learning, memory, sleeping, and dreaming.

Agonists



Antagonists

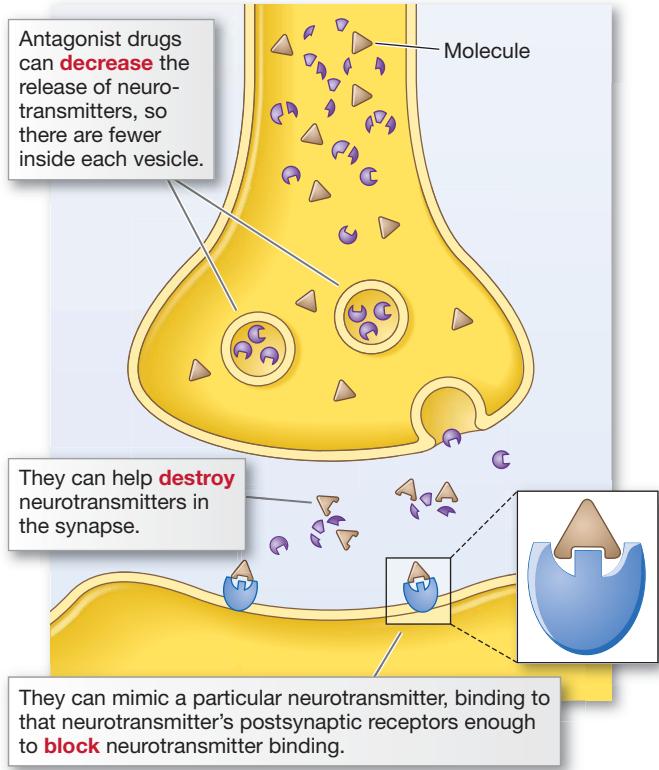


FIGURE 3.9 How Drugs Work

Researchers often inject agonists or antagonists into animals to assess how neurotransmitters affect behavior. The goal is to develop drug treatments for many psychological and medical disorders. For instance, researchers can test the hypothesis that a certain neurotransmitter in a specific brain region leads to increased eating. Injecting an agonist into that brain region should increase eating. Injecting an antagonist should decrease eating.

TYPES OF NEUROTRANSMITTERS There are many kinds of neurotransmitters. Eight of them are particularly important in understanding how we think, feel, and behave (**TABLE 3.1**).

The neurotransmitter **acetylcholine (ACh)** is responsible for motor control at the junctions between nerves and muscles. After moving across synapses, ACh (pronounced A-C-H) binds with receptors on muscle cells, making the muscles contract or relax. For instance, ACh excites skeletal muscles and inhibits heart muscle. As is true of all neurotransmitters, whether ACh's effects will be excitatory or inhibitory depends on the receptors.

Botulism, a form of food poisoning, is caused by Botulinum toxin. This neurotoxin inhibits the release of ACh. The resulting paralysis of muscles leads to difficulty in chewing, difficulty in breathing, and often death. Because of its ability to paralyze muscles, very small doses of Botulinum toxin are used for cosmetic surgery. Physicians inject the toxin, popularly known as Botox, into the eyebrow region, paralyzing muscles that produce certain wrinkles (**FIGURE 3.10**). Because the effects wear off over time, a new dose of Botox needs to be injected every two to four months. If too much Botox is



FIGURE 3.10
Acetylcholine and Botox

Acetylcholine (ACh) is responsible for motor control between nerves and muscles. Botox inhibits the release of ACh, paralyzing muscles. Here, a woman receives a Botox injection to remove wrinkles in her forehead.

TABLE 3.1 Common Neurotransmitters and Their Major Functions

NEUROTRANSMITTER	PSYCHOLOGICAL FUNCTIONS
Acetylcholine	Motor control over muscles Learning, memory, sleeping, and dreaming
Epinephrine	Energy
Norepinephrine	Arousal, vigilance, and attention
Serotonin	Emotional states and impulsiveness Dreaming
Dopamine	Reward and motivation Motor control over voluntary movement
GABA (gamma-aminobutyric acid)	Inhibition of action potentials Anxiety reduction
Glutamate	Enhancement of action potentials Learning and memory
Endorphins	Pain reduction Reward

epinephrine

A monoamine neurotransmitter responsible for bursts of energy after an event that is exciting or threatening.

norepinephrine

A monoamine neurotransmitter involved in states of arousal and attention.

serotonin

A monoamine neurotransmitter important for a wide range of psychological activity, including emotional states, impulse control, and dreaming.

dopamine

A monoamine neurotransmitter involved in motivation, reward, and motor control over voluntary movement.

GABA

Gamma-aminobutyric acid; the primary inhibitory transmitter in the nervous system.

glutamate

The primary excitatory transmitter in the nervous system.

injected, however, the result can be an expressionless face, because Botox paralyzes the facial muscles used to express emotions, as in smiling and frowning.

Acetylcholine is also involved in complex mental processes such as learning, memory, sleeping, and dreaming. Because ACh affects memory and attention, drugs that are ACh antagonists can cause temporary amnesia. In a similar way, Alzheimer's disease, a condition characterized primarily by severe memory deficits, is associated with diminished ACh functioning (Geula & Mesulam, 1994). Drugs that are ACh agonists may enhance memory and decrease other symptoms, but so far drug treatments for Alzheimer's have experienced only marginal success.

Four transmitters (epinephrine, norepinephrine, serotonin, and dopamine) are grouped together because each has the same basic molecular structure. Together they are called *monoamines*. Their major functions are to regulate arousal, regulate feelings, and motivate behavior.

The neurotransmitter **epinephrine** was initially called *adrenaline*. This name is the basis for the phrase *adrenaline rush*, a burst of energy caused by the release of epinephrine that binds to receptors throughout the body. This energy boost is part of a system that prepares the body for dealing with threats from an environment (the fight-or-flight response, discussed in Chapter 11, "Health and Well-Being"). **Norepinephrine** is involved in states of arousal and alertness. It is especially important for vigilance, a heightened sensitivity to what is going on around you. Norepinephrine appears useful for fine-tuning the clarity of attention.

Serotonin is involved in a wide range of psychological activities. It is especially important for emotional states, impulse control, and dreaming. Low levels of serotonin are associated with sad and anxious moods, food cravings, and aggressive behavior. Some drugs block serotonin reuptake and thus leave more serotonin at the synapse to bind with the postsynaptic neurons. These drugs are used to treat a wide array of mental and behavioral disorders, including depression, obsessive-compulsive disorders, eating disorders, and obesity (Tollefson, 1995). One class of drugs that specifically target serotonin is prescribed widely to treat depression. These drugs,

which include Prozac, are referred to as *selective serotonin reuptake inhibitors*, or *SSRIs*.

Dopamine serves many significant brain functions, especially motivation and reward. Many theorists believe dopamine communicates which activities may be rewarding. For example, eating when hungry, drinking when thirsty, and having sex when aroused activate dopamine receptors and therefore are experienced as pleasurable. When we see food, dopamine activity motivates us to want to eat it. Dopamine activation is also involved in motor control and planning. It helps guide behavior toward things—objects and experiences—that will lead to additional reward.

A lack of dopamine may be involved in problems with movement, and dopamine depletion is implicated in Parkinson's disease. Parkinson's is a degenerative and fatal neurological disorder marked by muscular rigidity, tremors, and difficulty initiating voluntary action. It affects about 1 in every 200 older adults and occurs in all known cultures. The actor Michael J. Fox is one of the many famous people who have developed this disease (**FIGURE 3.11**). Most people with Parkinson's do not experience symptoms until after age 50, but as Fox's case makes clear, the disease can occur earlier in life.

With Parkinson's disease, the dopamine-producing neurons slowly die off. In the later stages of the disorder, people suffer from cognitive and mood disturbances. Injections of one of the chief building blocks of dopamine, *L-DOPA*, help the surviving neurons produce more dopamine. When used to treat Parkinson's disease, L-DOPA often produces a remarkable, though temporary, recovery.

A promising development in Parkinson's research is *deep brain stimulation*. This procedure involves surgically implanting electrodes deep within the brain and then using mild electrical stimulation in the regions affected by the disorder, much the way a pacemaker stimulates the heart. Deep brain stimulation of motor regions of the brains of Parkinson's patients reverses many of the movement problems associated with the disease (DeLong & Wichmann, 2008). Researchers have reported successful results from this treatment, lasting as long as eleven years (Rizzzone et al., 2014). Although DBS helps with the motor symptoms of Parkinson's, other symptoms of the disease progressively become worse over time.

GABA (gamma-aminobutyric acid) is the primary inhibitory neurotransmitter in the nervous system. It is more widely distributed throughout the brain than most other neurotransmitters. Without the inhibitory effect of GABA, synaptic excitation might get out of control and spread through the brain chaotically. Epileptic seizures may be caused by low levels of GABA (Upton, 1994). Drugs that are GABA agonists are widely used to treat anxiety disorders. For instance, benzodiazepines, which include drugs such as Valium and Xanax, help people relax. Ethyl alcohol—the type people drink—also facilitates GABA transmission, which is why alcohol is typically experienced as relaxing.

In contrast, **glutamate** is the primary excitatory transmitter in the nervous system and is involved in fast-acting neural transmission throughout the brain. Glutamate receptors aid learning and memory by strengthening synaptic connections. Excessive glutamate release can lead to overexcitement of the brain, which can produce seizures as well as destruction of neurons. Overexcitement caused by excess glutamate is



FIGURE 3.11
A Public Figure with Parkinson's
Michael J. Fox was diagnosed with Parkinson's disease in 1991 and disclosed his condition to the public in 1998. He has since created the Michael J. Fox Foundation, which advocates for research toward finding a cure for Parkinson's.

endorphins

Neurotransmitters involved in natural pain reduction and reward.



FIGURE 3.12
Exercise and Endorphins

Endorphins are involved in both pain reduction and reward, and scientists think that endorphin production can be stimulated by strenuous exercise. An endurance event, such as a marathon or a speed skating competition, will yield an enormous endorphin rush. Here, the final leg runner in the Saudi men's 4 × 400 relay team, Yousef Ahmed Masrahi, celebrates after finishing first in the men's relay final at the 16th Asian Games in Guangzhou on November 26, 2010.

linked to many diseases and types of brain damage. For example, much of the damage inflicted to the brain following a stroke or trauma to the brain is caused by the excessive release of glutamate that naturally occurs following brain injury (Choi & Rothman, 1990; Dhawan et al., 2011).

Endorphins are involved in both natural pain reduction and reward (**FIGURE 3.12**).

In the early 1970s, researchers established that opiate drugs such as heroin and morphine bind to receptors in the brain, and this finding led to the discovery of naturally occurring substances in the body that bind to those sites (Pert & Snyder, 1973). Called *endorphins* (short for *endogenous morphine*), these substances are part of the body's natural defense against pain.

Pain is useful because it signals to animals, human and nonhuman, that they are hurt or in danger and therefore should try to escape or withdraw. Pain can also interfere with adaptive functioning, however. If pain prevents animals from engaging in behaviors such as eating, competing, and mating, the animals fail to pass along their genes. Endorphins' painkilling, or analgesic, effects help animals perform these behaviors even when they are in pain. In humans, the administration of drugs, such as morphine, that bind with endorphin receptors reduces the subjective experience of pain. Apparently, morphine alters the way pain is experienced rather than blocking the nerves that transmit pain signals: People still feel pain, but they report detachment and do not care about the pain (Foley, 1993).

Summing Up

How Does the Nervous System Operate?

- Neurons are the nervous system's basic units. Their task is to receive, process, and pass information to other neurons.
- The nervous system is divided into two basic units: The central nervous system consists of the brain and spinal cord. The peripheral nervous system consists of all nerve cells beyond the brain and spinal cord.
- A neuron receives information at the dendrites and processes that information in its cell body. If the information is excitatory, the neuron will generate an action potential, or "fire." Firing sends a signal down the axon to release neurotransmitters into the synapse.
- Many neurons are insulated by a myelin sheath, which surrounds the axon and allows the action potential to travel rapidly.
- When a neuron is in a resting state, it is negatively charged. Whether a neuron fires depends on the combination of excitatory and inhibitory signals it receives. Receiving excitatory signals encourages the neuron to fire. Receiving inhibitory signals discourages it from firing.
- The intensity of the excitatory signal affects the frequency of neural firing but not its strength. Neurons fire on an all-or-none basis.
- After firing, ion channels close and the neuron returns to its negative resting state. Action potentials are terminated by the removal of neurotransmitters from the synapse. This removal occurs through reuptake, enzyme deactivation, or the actions of autoreceptors.
- Substances that enhance the actions of neurotransmitters are agonists. Substances that inhibit the actions of neurotransmitters are antagonists.
- Eight neurotransmitters are especially important for psychological research: Acetylcholine is involved in motor control and mental processes, such as memory. Epinephrine and norepinephrine are associated with energy, arousal, and attention. Serotonin is important for emotional states, impulse control, and dreaming. Dopamine is involved in reward, motivation, and motor control. GABA and glutamate are related to general inhibition and excitation. Endorphins are important in pain reduction.

Measuring Up

1. Neurons communicate by electrochemical signal. Imagine that a neurotransmitter binds to a postsynaptic receptor. What would happen afterward? Put the following steps in the correct order so they describe this process.

- An action potential is generated down the axon.
- Neurotransmitters are released into the synapse.
- Through reuptake, the neurotransmitter returns to the presynaptic neuron.
- Sodium channels open.

2. Match each major neurotransmitter with its major functions.

Neurotransmitter	Major functions
a. norepinephrine	1. emotional states, impulse control, dreaming
b. glutamate	2. reward, motivation, voluntary muscle control
c. acetylcholine	3. generates excitatory action potentials, facilitates learning and memory
d. serotonin	4. arousal, vigilance, attention
e. endorphins	5. motor control, learning, memory, sleeping, dreaming
f. dopamine	6. reward, pain reduction
g. GABA	7. energy
h. epinephrine	8. inhibits action potentials, reduces anxiety

(2) a; 4; b; 3; c; 5; d; 1; e; 6; f; 2; g; 8; h; 7.

ANSWERS: (1) d, a, b, c.

3.2 What Are the Basic Brain Structures and Their Functions?

The brain is best viewed as a collection of interacting neural circuits. These circuits have accumulated and developed throughout human evolution. As our ancestors adapted to their environments, the brain has evolved specialized mechanisms to regulate breathing, food intake, body fluids, and sexual and social behavior, as well as sensory systems to aid in navigation and assist in recognizing friends and foes. Everything we are and do is orchestrated by the brain and, for more rudimentary actions, by the spinal cord (**FIGURE 3.13**). Early in life, overabundant connections form among the brain's neurons. Subsequently, life experiences help "prune" some of these connections to strengthen the rest, much as pruning weak or nonproductive branches will strengthen a fruit tree.

The brain's basic structures and their functions enable people to accomplish feats such as seeing, hearing, remembering, and interacting with others. Understanding these relationships also helps us understand psychological disorders.

EARLY RESEARCHERS DEBATED THE RELATIONSHIP BETWEEN STRUCTURE AND FUNCTION By the beginning of the nineteenth century, anatomists understood the brain's basic structure reasonably well. But debates raged over how the brain produced mental activity. Did different parts do different things? Or were all areas of the brain equally important in cognitive activities such as problem solving and memory?

Learning Objective

- Identify the basic structures of the brain and their primary functions.

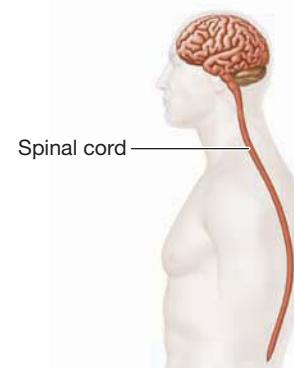


FIGURE 3.13
The Brain and the Spinal Cord
This drawing illustrates the brain's exterior and its connection with the spinal cord. The view is from the left side of the body.



FIGURE 3.14
Phrenology

In a phrenological map, each region of the skull is associated with a feature. Each association is meant to reflect a process occurring in the brain under the skull.

Broca's area

A small portion of the left frontal region of the brain, crucial for the production of language.

In the early nineteenth century, the neuroanatomist Franz Gall and his assistant, the physician Johann Spurzheim, hypothesized about the effects of mental activity on brain anatomy. Gall and Spurzheim proposed that if a person used a particular mental function more than other mental functions, the part of the brain where the emphasized function was performed would grow. This growth would produce a bump in the overlying skull. By carefully feeling the skull, one could describe the personality of the individual. This practice came to be known as *phrenology* (FIGURE 3.14).

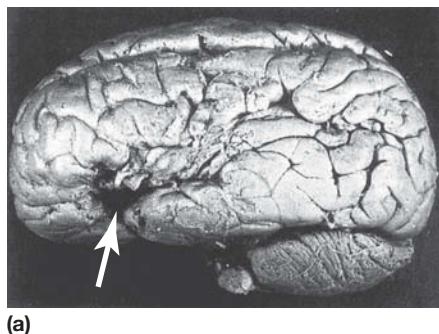
Gall was a physician, not a scientist. He noted correlations, but he did not practice the scientific method and sought only to confirm, not disprove, his ideas. In any case, at the time, the technology was not available to test this theory scientifically. Phrenology soon fell into the hands of frauds and quacks, but it helped spread the seemingly scientific principle that brain functions were localized.

The first strong scientific evidence that brain regions perform specialized functions came from the work of the nineteenth-century physician and anatomist Paul Broca (Finger, 1994). One of Broca's patients had lost the ability to say anything other than the word *tan*, though he could still understand language. After the patient died, in 1861, Broca performed an autopsy. When he examined the patient's brain, Broca found a large area of damage in a section of the front left side. This observation led him to conclude that this particular region was important for speech. Broca's theory has survived the test of time. This left frontal region, crucial for the production of language, became known as **Broca's area** (FIGURE 3.15).

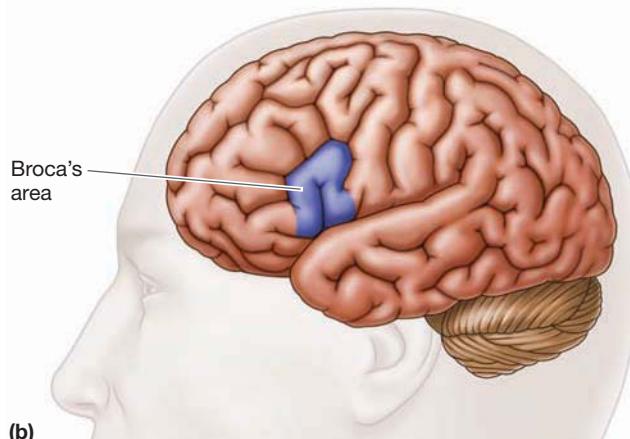
For most of human history, theorists and researchers have not had methods for studying ongoing mental activity in the working brain. In the 1980s, the invention of brain imaging methods changed that situation swiftly and dramatically. As discussed in the following section, the new imaging techniques have advanced our understanding of the human brain the way the development of telescopes advanced our understanding of astronomy—and the brain's structures and functions may be as complex as distant galaxies.

Scientists Can Now Watch the Working Brain

Psychologists collect data about the ways people's bodies respond to particular tasks or events. For instance, when people are frightened, their muscles become tense and



(a)



(b)

FIGURE 3.15 **Broca's Area**

(a) Paul Broca studied a patient's brain and identified the damaged area as crucial for speech production.

(b) This illustration shows the location of Broca's area.

their hearts beat faster. Other bodily systems influenced by mental states include blood pressure, blood temperature, perspiration rate, breathing rate, and pupil size. Measurements of these systems are examples of *psychophysiological assessment*. In this type of testing, researchers examine how bodily functions (physiology) change in association with behaviors or mental states (psychology).

Police investigators often use *polygraphs*, popularly known as “lie detectors,” to assess some bodily states (FIGURE 3.16). The assumption behind these devices is that people who are lying experience more arousal and therefore are more likely to show physical signs of stress. This method is not precise, however, and so lie detectors do not accurately measure whether someone is lying. (The limitations of lie detectors are discussed further in the “What to Believe? Using Psychological Reasoning” feature in Chapter 10.)



FIGURE 3.16

Polygraph

A polygraph (lie detector) measures changes in bodily functions (e.g., heart rate, perspiration rate, blood pressure) related to behaviors or mental states. These changes are *not* reliable measures of lying.

ELECTROPHYSIOLOGY *Electrophysiology* is a data collection method that measures electrical activity in the brain. Small electrodes on the scalp act like small microphones that pick up the brain’s electrical activity instead of sounds. The device that measures brain activity is an **electroencephalograph** (EEG; FIGURE 3.17). This measurement is useful because different behavioral states produce different and predictable EEG patterns. As a measure of specific cognitive states, however, the EEG is limited. Because the recordings (*electroencephalograms*) reflect all brain activity, they are too “noisy” or imprecise to isolate specific responses to particular stimuli. A more powerful way of examining how brain activity changes in response to a specific stimulus involves conducting many trials with a single individual and averaging across the trials. Because this method enables researchers to observe patterns associated with specific events, it is called *event-related potential* (ERP).

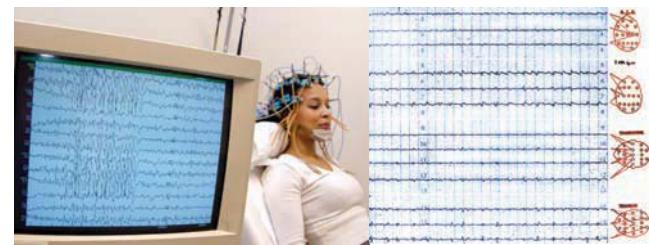


FIGURE 3.17

Electroencephalograph (EEG)

An electroencephalograph (EEG) measures the brain’s electrical activity.

BRAIN IMAGING The brain’s electrical activity is associated with changes in the flow of blood carrying oxygen and nutrients to the active brain regions. *Brain imaging* methods measure changes in the rate, or speed, of the flow of blood to different regions of the brain. By keeping track of these changes, researchers can monitor which brain areas are active when people perform particular tasks or experience particular events. Imaging is a powerful tool for uncovering where different systems reside in the brain and how different brain areas interact to process information.

- **Positron emission tomography (PET)** After the injection of a relatively harmless radioactive substance into the bloodstream, a **positron emission tomography (PET)** scan enables researchers to find the most active brain areas (FIGURE 3.18). The increased blood flow carrying the radioactive material leads these regions to emit more radiation. One downside of PET is the need to inject a radioactive substance into the body. For safety reasons, researchers limit the use of this technology.
- **Magnetic resonance imaging (MRI)** With **magnetic resonance imaging (MRI)**, a powerful magnetic field is used to momentarily disrupt the brain’s

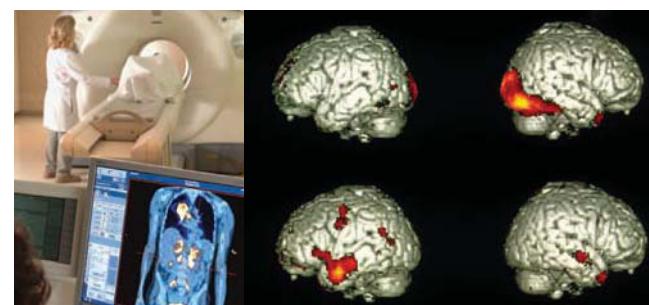


FIGURE 3.18

Positron Emission Tomography

Positron emission tomography (PET) scans the brain’s metabolic activity.



FIGURE 3.19
Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) produces a high-resolution image of the brain.

magnetic resonance imaging (MRI)

A method of brain imaging that uses a powerful magnetic field to produce high-quality images of the brain.

functional magnetic resonance imaging (fMRI)

An imaging technique used to examine changes in the activity of the working human brain by measuring changes in the blood's oxygen levels.

transcranial magnetic stimulation (TMS)

The use of strong magnets to briefly interrupt normal brain activity as a way to study brain regions.



FIGURE 3.20 Functional Magnetic Resonance Imaging

Functional magnetic resonance imaging (fMRI) maps mental activity by assessing the blood's oxygen level in the brain.

magnetic forces (**FIGURE 3.19**). During this process, energy is released from brain tissue in a form that can be measured by detectors surrounding the head. Because different types of brain tissue release energy differently, the researchers can produce a high-resolution image of the brain. (The amount of energy released is very small, so having an MRI is not dangerous. Nor is there any danger in being exposed to the magnetic field at the levels used in research.) MRI is extremely valuable for providing information about the structure of the brain. For instance, it can be used to

determine the location of brain damage or of a brain tumor.

- **Functional magnetic resonance imaging (fMRI)** Functional magnetic resonance imaging (fMRI) makes use of the brain's blood flow to map the working brain (**FIGURE 3.20**). Whereas PET measures blood flow directly by tracking a radioactive substance, fMRI measures blood flow indirectly by assessing changes in the blood's oxygen level. As with all brain imaging methods, the participant performs a task that differs from the first one in only one way and that reflects the particular mental function of interest. The researchers then compare images to examine differences in blood flow and therefore brain activity.

TRANSCRANIAL MAGNETIC STIMULATION One limitation of brain imaging is that the findings are necessarily correlational. We know that certain brain regions are active while a task is performed. We do not know whether each brain region is necessary for that particular task. To see whether a brain region is important for a task, researchers ideally want to compare performances when that area is working effectively and when it is not. **Transcranial magnetic stimulation (TMS)** uses a very fast but powerful magnetic field to disrupt brain activity momentarily in a specific brain region (**FIGURE 3.21**). This technique has its limitations, particularly that it can be used only for short durations to examine brain areas close to the scalp. When used along with imaging, however, it is a powerful method for examining which brain regions are necessary for specific psychological functions.

The following sections discuss specific brain areas. While these areas do not work in isolation, each one is linked with particular mental processes and particular behaviors.

The Brain Stem Houses the Basic Programs of Survival

The spinal cord is a rope of neural tissue. As shown in Figure 3.13, the cord runs inside the hollows of the vertebrae from just above the pelvis up into the base of the skull. One of its functions is the coordination

of reflexes, such as the reflexive movement of your leg when a doctor taps your knee or the reflexive movement of your arm when you jerk your hand away from a flame. The cord's most important function is to carry sensory information up to the brain and carry motor signals from the brain to the body parts below to initiate action.

In cross section, the spinal cord is seen to be composed of two distinct tissue types: the *gray matter*, which is dominated by neurons' cell bodies, and the *white matter*, which consists mostly of axons and the fatty myelin sheaths that surround them. Gray matter and white matter are clearly distinguishable throughout the brain as well. In the brain, gray matter consists mostly of neuron bodies that have nonmyelinated axons and communicate only with nearby neurons. White matter consists mostly of myelinated axons that travel between brain regions.

In the base of the skull, the spinal cord thickens and becomes more complex as it transforms into the **brain stem** (FIGURE 3.22). The brain stem consists of the *medulla oblongata*, the *pons*, and the *midbrain*. It houses the nerves that control the most basic functions of survival, such as heart rate, breathing, swallowing, vomiting, urination, and orgasm. A significant blow to this region can cause death. As a continuous extension of the spinal cord, the brain stem also performs functions for the head similar to those that the spinal cord performs for the rest of the body. Many reflexes emerge from here, analogous to the spinal reflexes; gagging is one example.

The brain stem also contains a network of neurons, known collectively as the *reticular formation*. The reticular formation projects up into the *cerebral cortex* (outer portion of the brain—discussed shortly) and affects general alertness. It is also involved in inducing and terminating the different stages of sleep (as discussed in Chapter 4, “Consciousness”).

The Cerebellum Is Essential for Movement

The **cerebellum** (Latin, “little brain”) is a large protuberance connected to the back of the brain stem (FIGURE 3.23). Its size and convoluted surface make it look like an extra brain. The cerebellum is extremely important for proper motor function, and damage to its different parts produces very different effects. For example, damage to the little nodes at the very bottom causes head tilt, balance problems, and a loss of smooth compensation of eye position for head movement.

Try turning your head while looking at this book. Notice that your eyes remain focused on the material. Your eyes would not be able to do that if an injury affected the bottom of your cerebellum. Damage to the ridge that runs up the back of the cerebellum would affect your walking. Damage to the bulging lobes on either side would cause a loss of limb coordination, so you would not be able to perform tasks such as reaching smoothly to pick up a pen.

The cerebellum’s most obvious role is in motor learning and motor memory. It seems to be “trained” by the rest of the nervous system and operates independently and unconsciously. For example, the cerebellum allows you to ride a bicycle effortlessly while planning your next meal. In fact, the cerebellum may be involved in cognitive processes such as making plans, remembering events, using language, and experiencing emotion.



FIGURE 3.21
Transcranial Magnetic Stimulation

Transcranial magnetic stimulation (TMS) momentarily disrupts brain activity in a specific brain region.

brain stem

An extension of the spinal cord; it houses structures that control functions associated with survival, such as heart rate, breathing, swallowing, vomiting, urination, and orgasm.

cerebellum

A large, convoluted protuberance at the back of the brain stem; it is essential for coordinated movement and balance.

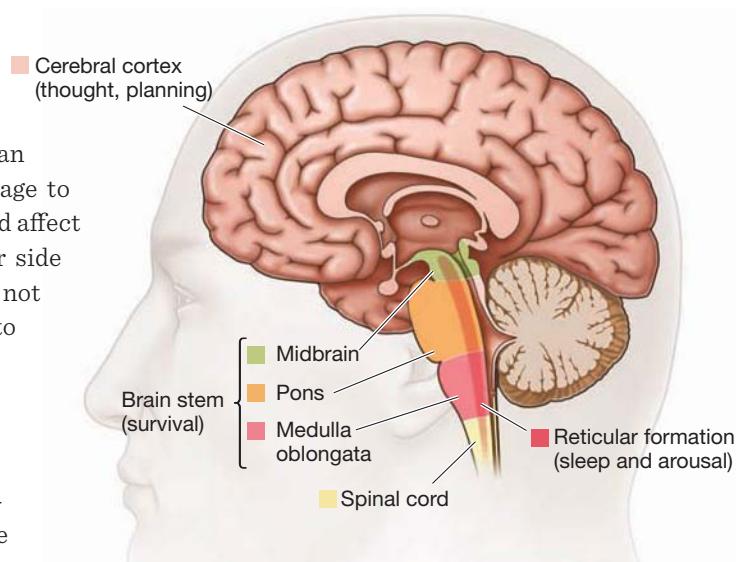


FIGURE 3.22 **The Brain Stem**

This drawing shows the brain stem and its parts, in relation to the cerebral cortex.

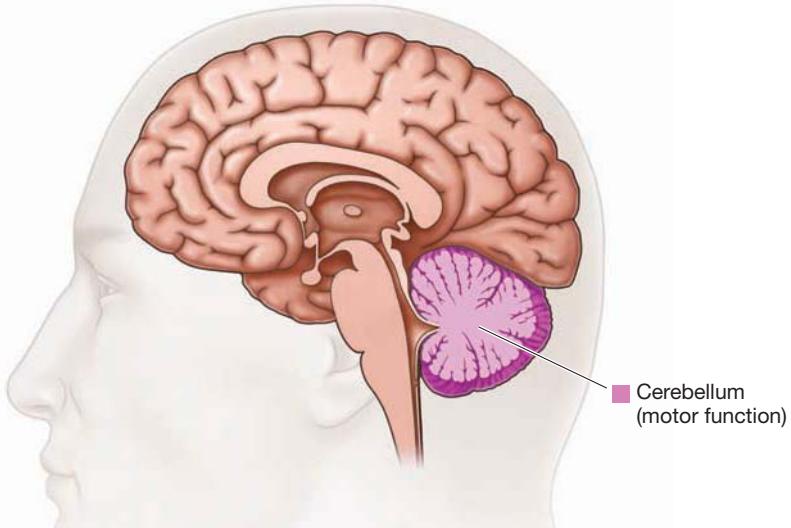


FIGURE 3.23 The Cerebellum

The cerebellum is located at the back of the brain: It is below the cerebral cortex and behind the brain stem.

thalamus

The gateway to the brain; it receives almost all incoming sensory information before that information reaches the cortex.

hypothalamus

A brain structure that is involved in the regulation of bodily functions, including body temperature, body rhythms, blood pressure, and blood glucose levels; it also influences our basic motivated behaviors.

hippocampus

A brain structure that is associated with the formation of memories.

amygdala

A brain structure that serves a vital role in learning to associate things with emotional responses and in processing emotional information.

basal ganglia

A system of subcortical structures that are important for the planning and production of movement.

Subcortical Structures Control Emotions and Appetitive Behaviors

Above the brain stem and cerebellum is the *forebrain*, which consists of the two cerebral hemispheres (left and right; **FIGURE 3.24**). From the outside, the most noticeable feature of the forebrain is the cerebral cortex. Below the cerebral cortex are the *subcortical* regions, which are so named because they lie under the cortex. Subcortical structures that are important for understanding psychological functions include the hypothalamus, the thalamus, the hippocampus, the amygdala, and the basal ganglia. Some of these structures belong to the *limbic system*.

Limbic is the Latin word for “border,” and this system serves as the border between the evolutionarily older parts of the brain (the brain stem and the cerebellum) and the evolutionarily newer part (the cerebral cortex). The brain structures in the limbic system are especially important for controlling appetitive behaviors (such as eating and drinking) and emotions (as discussed in Chapter 10, “Emotion and Motivation”).

THALAMUS The **thalamus** is the gateway to the cortex: It receives almost all incoming sensory information, organizes it, and relays it to the cortex. The only exception to this rule is the sense of smell. The oldest and most fundamental sense, smell has a direct route to the cortex. During sleep, the thalamus partially shuts the gate on incoming sensations while the brain rests. (The thalamus is discussed further in Chapter 5, “Sensation and Perception.”)

HYPOTHALAMUS The **hypothalamus** is the brain’s master regulatory structure. It is indispensable to the organism’s survival. Located just below the thalamus, it receives input from almost everywhere in the body and brain, and it projects its influence to almost everywhere in the body and brain. It affects the functions of many internal organs, regulating body temperature, body rhythms, blood pressure, and blood glucose levels. It is also involved in many motivated behaviors, including thirst, hunger, aggression, and lust.

HIPPOCAMPUS AND AMYGDALA The **hippocampus** takes its name from the Greek for “sea horse,” because of its sea horse shape. This structure plays an important role in the formation of new memories. It seems to do this important work by creating new interconnections within the cerebral cortex with each new experience.

The hippocampus may be involved in how we remember the arrangements of places and objects in space, such as how streets are laid out in a city or how furniture is positioned in a room. An interesting study to support this theory focused on London taxi drivers. Maguire and colleagues (2003) found that one region of the hippocampus was much larger in taxi drivers’ brains than in most other London

drivers' brains. Moreover, the volume of gray matter in the hippocampal region was highly correlated with the number of years of experience as a taxi driver. Is a person with a large hippocampus more likely to drive a taxi? Or does the hippocampus grow as the result of navigational experience? Recall from Chapter 2 that correlation does not prove causation. The Maguire study did not conclude that the hippocampus changes with experience. However, there is evidence that the hippocampus is important for navigating in our environments (Nadel et al., 2013).

The **amygdala** takes its name from the Latin for “almond,” because it has an almond shape. This structure is located immediately in front of the hippocampus. The amygdala is involved in learning about biologically relevant stimuli, such as those important for survival (Whalen et al., 2013). It plays a special role in responding to stimuli that elicit fear. The emotional processing of frightening stimuli in the amygdala is a hardwired circuit that has developed over the course of evolution to protect animals from danger. The amygdala is also involved in evaluating a facial expression's emotional significance (Adolphs et al., 2005). It appears to be part of a system that automatically directs visual attention to the eyes when evaluating facial expressions (Kennedy & Adolphs, 2010). Imaging studies have found that the amygdala activation is especially strong in response to a fearful face (Whalen et al., 1998).

The amygdala also intensifies the function of memory during times of emotional arousal. For example, a frightening experience can be seared into your memory for life, although (as discussed further in Chapter 7, “Memory”) your memory of the event may not be completely accurate. Research also shows that emotional arousal can influence what people attend to in their environments (Schmitz, De Rosa, & Anderson, 2009).

THE BASAL GANGLIA The **basal ganglia** are a system of subcortical structures crucial for planning and producing movement. These structures receive input from the entire cerebral cortex. They send that input to the motor centers of the brain stem. Via the thalamus, they also send the input back to the motor planning area of the cerebral cortex. Damage to the basal ganglia can produce symptoms that range from the tremors and rigidity of Parkinson's disease to the involuntary writhing movements of Huntington's disease. In addition, damage to the basal ganglia can impair the learning of movements and habits, such as automatically looking for cars before you cross the street.

One structure in the basal ganglia, the *nucleus accumbens*, is important for experiencing reward and motivating behavior. As discussed in Chapter 6, nearly every pleasurable experience—from eating food you like to looking at a person you find attractive— involves dopamine activity in the nucleus accumbens and makes you want the thing or person you are experiencing. The more desirable objects are, the more they activate basic reward circuitry in our brains.

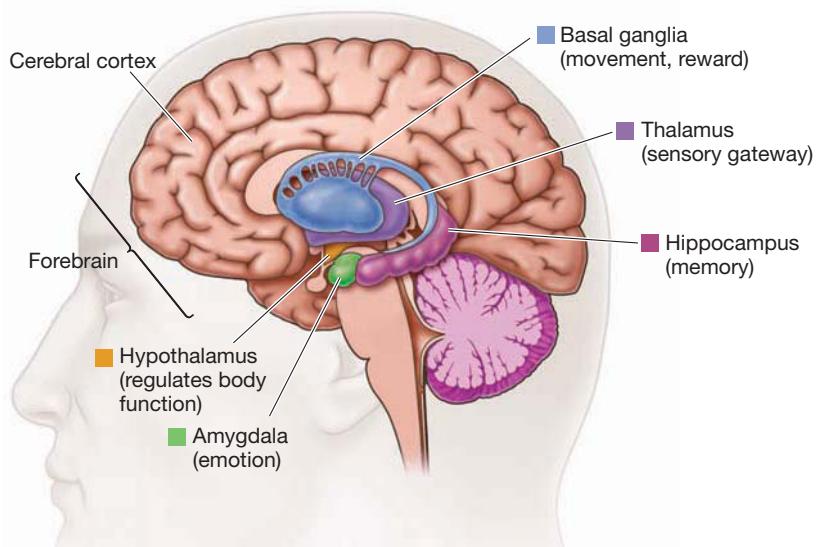


FIGURE 3.24 The Forebrain and the Subcortical Regions

The subcortical regions are below the forebrain. They are responsible for many aspects of emotion and motivation.

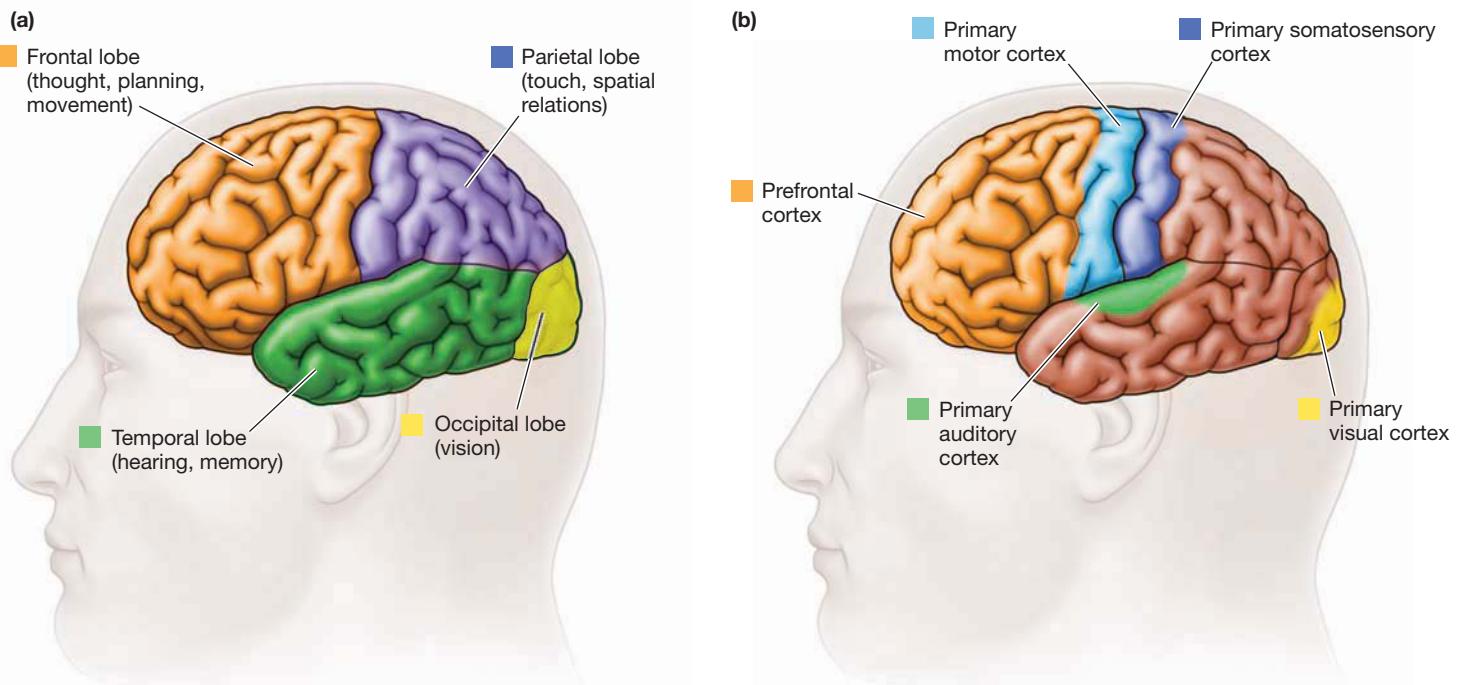


FIGURE 3.25 The Cerebral Cortex

(a) This diagram identifies the lobes of the cerebral cortex.

(b) The colored areas mark important regions within those lobes.

cerebral cortex

The outer layer of brain tissue, which forms the convoluted surface of the brain; the site of all thoughts, perceptions, and complex behaviors.

corpus callosum

A massive bridge of millions of axons that connects the hemispheres and allows information to flow between them.

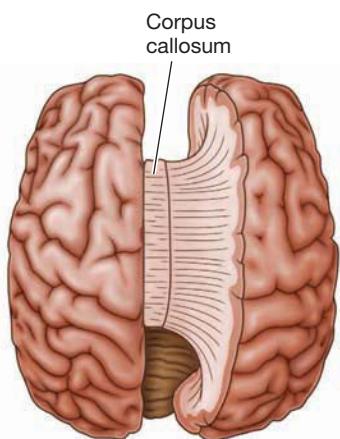


FIGURE 3.26

The Corpus Callosum

In this top view of the brain, the right cerebral hemisphere has been pulled away to expose the corpus callosum. This fibrous structure connects the two hemispheres of the cerebral cortex.

The Cerebral Cortex Underlies Complex Mental Activity

The **cerebral cortex** is the outer layer of the cerebral hemispheres and gives the brain its distinctive wrinkled appearance. (*Cortex* is Latin for “bark”—the kind on trees. The cerebral cortex does not feel like bark, however. It has the consistency of a soft-boiled egg.) Each hemisphere has its own cortex. In humans, the cortex is relatively enormous—the size of a large sheet of newspaper—and folded in against itself many times so as to fit within the skull. It is the site of all thoughts, detailed perceptions, and complex behaviors. It enables us to comprehend ourselves, other people, and the outside world. By extending our inner selves into the world, it is also the source of culture and communication. Each cerebral hemisphere has four “lobes”: the occipital, parietal, temporal, and frontal lobes (FIGURE 3.25). The **corpus callosum**, a massive bridge of millions of axons, connects the hemispheres and allows information to flow between them (FIGURE 3.26).

The **occipital lobes** are at the back portion of the head. Devoted almost exclusively to vision, they include many visual areas. By far, the largest of these areas is the **primary visual cortex**, the major destination for visual information. Visual information is typically organized for the cerebral cortex in a way that preserves spatial relationships. That is, the image relayed from the eye is “projected” more or less faithfully onto the primary visual cortex. As a result, two objects near one another in a visual image will activate neurons near one another in the primary visual cortex. Surrounding the primary visual cortex is a patchwork of secondary visual areas that process various attributes of the visual image, such as its colors, forms, and motions.

The **parietal lobes** are devoted partially to touch. Their labor is divided between the cerebral hemispheres. The left hemisphere receives touch information from

the right side of the body, and the right hemisphere receives touch information from the left side of the body. In each parietal lobe, this information is directed to the *primary somatosensory cortex*, a strip in the front part of the lobe, running from the top of the brain down the sides. The primary somatosensory cortex groups nearby sensations: For example, sensations on the fingers are near sensations on the palm. The result, covering the primary somatosensory area, is a distorted representation of the entire body: the *somatosensory homunculus* (the latter term is Greek for “little man”). The homunculus is distorted because more cortical area is devoted to the body’s more sensitive areas, such as the face and the fingers (**FIGURE 3.27A**).

occipital lobes

Regions of the cerebral cortex—at the back of the brain—important for vision.

parietal lobes

Regions of the cerebral cortex—in front of the occipital lobes and behind the frontal lobes—important for the sense of touch and for attention to the environment.

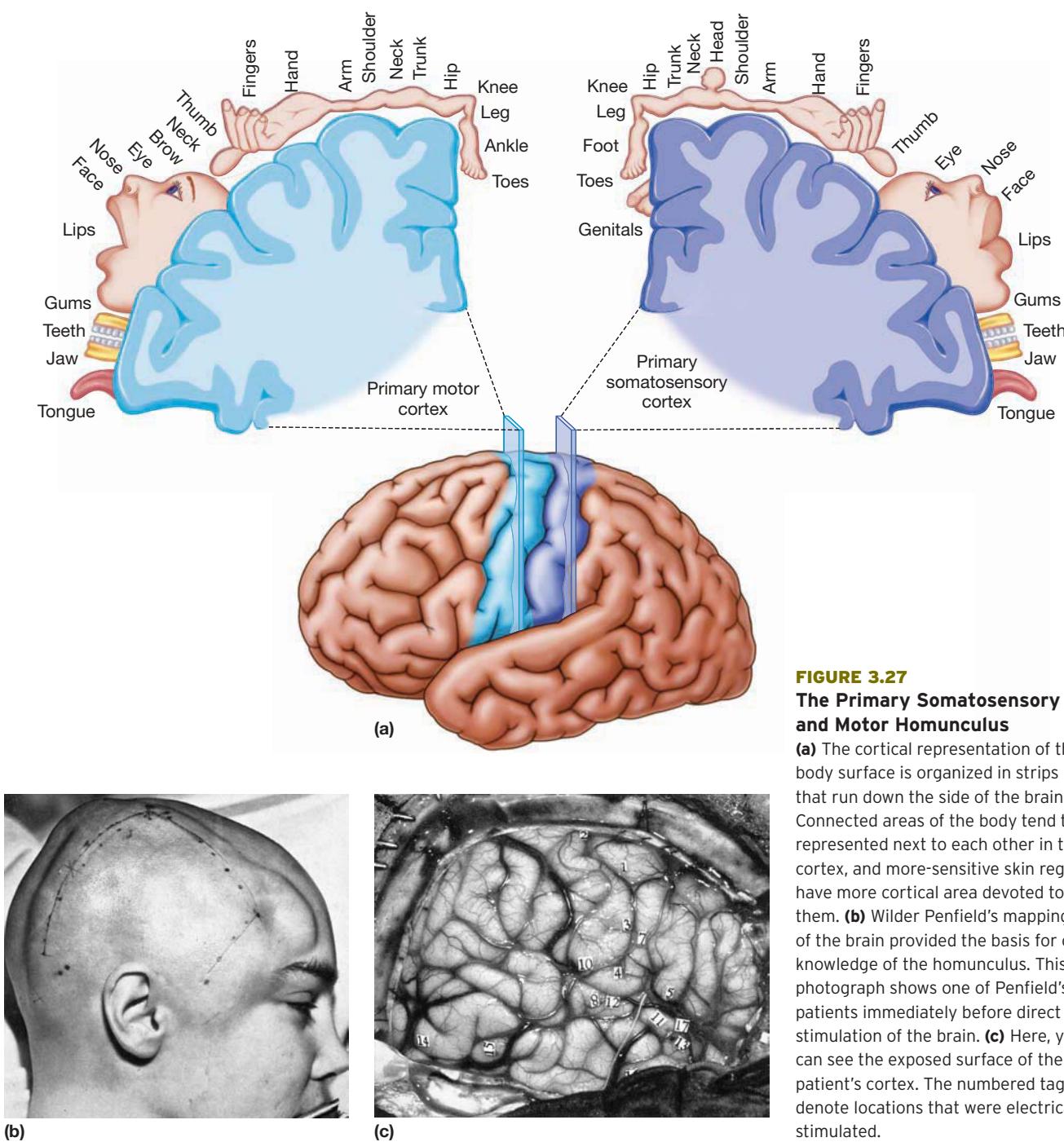


FIGURE 3.27

The Primary Somatosensory and Motor Homunculus

(a) The cortical representation of the body surface is organized in strips that run down the side of the brain. Connected areas of the body tend to be represented next to each other in the cortex, and more-sensitive skin regions have more cortical area devoted to them. **(b)** Wilder Penfield's mappings of the brain provided the basis for our knowledge of the homunculus. This photograph shows one of Penfield's patients immediately before direct stimulation of the brain. **(c)** Here, you can see the exposed surface of the patient's cortex. The numbered tags denote locations that were electrically stimulated.



FIGURE 3.28
Hemineglect

This drawing, made by a hemineglect patient, omits much of the flower's left side.

temporal lobes

Regions of the cerebral cortex—below the parietal lobes and in front of the occipital lobes—important for processing auditory information, for memory, and for object and face perception.

frontal lobes

Regions of the cerebral cortex—at the front of the brain—important for movement and higher-level psychological processes associated with the prefrontal cortex.

prefrontal cortex

The frontmost portion of the frontal lobes, especially prominent in humans; important for attention, working memory, decision making, appropriate social behavior, and personality.

This homunculus is based on brain mappings by the pioneering neurological researcher Wilder Penfield. Penfield created these mappings as he examined patients who were to undergo surgery for epilepsy (**FIGURE 3.27B**). The idea behind this work was to perform the surgery without damaging brain areas vital for functions such as speech. After a local anesthetic was applied to the scalp and while the patient was awake, Penfield would electrically stimulate regions of the brain and ask the patient to report what he or she was experiencing (**FIGURE 3.27C**). Penfield's studies provided important evidence about the amount of brain tissue devoted to each sensory experience.

The parietal lobe is also involved in attention. A stroke or other damage to the right parietal region can result in the neurological disorder *hemineglect*. Patients with this syndrome fail to notice anything on their left side even though their eyes work perfectly well. Looking in a mirror, they will shave or put makeup on only the right side of their face. If two objects are held up before them, they will see only the one on the right. Asked to draw a simple object, they will draw only its right half (**FIGURE 3.28**).

The **temporal lobes** hold the *primary auditory cortex*, the brain region responsible for hearing. Also within the temporal lobes are specialized visual areas (for recognizing detailed objects such as faces), plus the hippocampus and the amygdala (both critical for memory, as discussed earlier). At the intersection of the temporal and occipital lobes is the *fusiform face area*. Its name comes from the fact that this area is much more active when people look at faces than when they look at other things. In contrast, other regions of the temporal lobe are more activated by objects, such as houses or cars, than by faces. Damage to the fusiform face area can cause specific impairments in recognizing people but not in recognizing objects.

The **frontal lobes** are essential for planning and movement. The rearmost portion of the frontal lobes is the *primary motor cortex*. The primary motor cortex includes neurons that project directly to the spinal cord to move the body's muscles. Its responsibilities are divided down the middle of the body, like those of the sensory areas: For example, the left hemisphere controls the right arm, whereas the right hemisphere controls the left arm. The rest of the frontal lobes consists of the **prefrontal cortex**, which occupies about 30 percent of the brain in humans. Scientists have long thought that what makes humans unique in the animal kingdom is our extraordinarily large prefrontal cortex. However, there is evidence that what separates humans from other animals is not how much of the brain the prefrontal cortex occupies but rather the complexity and organization of prefrontal circuits—the way different regions within the prefrontal cortex are connected (Bush & Allman, 2004; Schoenemann, Sheehan, & Glotzer, 2005).

Parts of the prefrontal cortex are responsible for directing and maintaining attention, keeping ideas in mind while distractions bombard people from the outside world, and developing and acting on plans. The entire prefrontal cortex is indispensable for rational activity. It is also especially important for many aspects of human social life, such as understanding what other people are thinking, behaving according to cultural norms, and contemplating one's own existence. It provides both the sense of self and the capacity to empathize with others or feel guilty about harming them.

THE PREFRONTAL CORTEX IN CLOSE-UP Psychologists have learned a great deal of what they know about the functioning of different brain regions through the careful study of people whose brains have been damaged by disease or injury. Perhaps the most famous historical example of brain damage is the case of Phineas Gage. Gage's case provided the basis for the first modern theories of the prefrontal cortex's role in both personality and self-control.

In 1848, Gage was a 25-year-old foreman on the construction of Vermont's Rutland and Burlington Railroad. One day, he dropped a tool called a tamping iron, which was over a yard long and an inch in diameter. The iron rod hit a rock, igniting some blasting powder. The resulting explosion drove the rod into his cheek, through his frontal lobes, and clear out through the top of his head (**FIGURE 3.29**). Gage was still conscious as he was hurried back to town on a cart, and he was able to walk, with assistance, upstairs to his hotel bed. He wryly remarked to the awaiting physician, "Doctor, here is business enough for you." He said he expected to return to work in a few days. In fact, Gage lapsed into unconsciousness and remained unconscious for two weeks. Afterward, his condition steadily improved. Physically, he recovered remarkably well.

Unfortunately, Gage's accident led to major personality changes. Whereas the old Gage had been regarded by his employers as "the most efficient and capable" of workers, the new Gage was not. As one of his doctors later wrote, "The equilibrium or balance, so to speak, between his intellectual faculties and animal propensities seems to have been destroyed. He is fitful, irreverent, indulging at times in the grossest profanity . . . impatient of restraint or advice when it conflicts with his desires. . . . A child in his intellectual capacity and manifestations, he has the animal passions of a strong man" (Harlow, 1868, p. 340). In summary, Gage was "no longer Gage."

Unable to get his foreman's job back, Gage exhibited himself in various New England towns and at the New York Museum (owned by the circus showman P. T. Barnum). He worked at the stables of the Hanover Inn at Dartmouth College. In Chile, he drove coaches and tended horses. After a decade, his health began to decline, and in 1860 he started having epileptic seizures and died within a few months. Gage's recovery was initially used to argue that the entire brain works uniformly and that the healthy parts of Gage's brain had taken over the work of the damaged parts. However, the medical community eventually recognized that Gage's psychological impairments had been severe and that some areas of the brain in fact have specific functions.

Reconstruction of Gage's injury through examination of his skull has made it clear that the prefrontal cortex was the area most damaged by the tamping rod (Damasio, Grabowski, Frank, Galaburda, & Damasio, 1994). Recent studies of patients

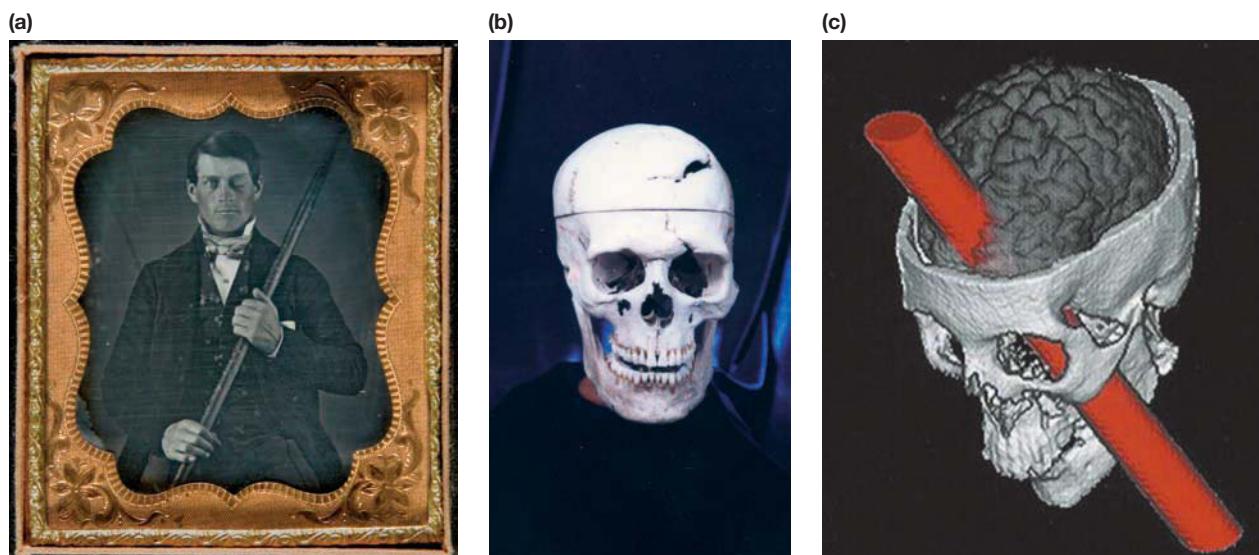


FIGURE 3.29 Phineas Gage

Analysis of Gage's damaged skull provided the basis for the first modern theories about the role of the prefrontal cortex in both personality and self-control. (a) This photo shows Gage holding the rod that passed through his skull. (b) Here, you can see the hole in the top of Gage's skull. (c) This computer-generated image reconstructs the rod's probable path through the skull.



FIGURE 3.30

Lobotomy

This photo shows Dr. Walter Freeman performing a lobotomy in 1949. Freeman is inserting an ice pick-like instrument under the upper eyelid of his patient to cut the nerve connections in the front part of the brain.

with injuries to this brain region reveal that it is particularly concerned with social phenomena, such as following social norms, understanding what other people are thinking, and feeling emotionally connected to others. People with damage to this region do not typically have problems with memory or general knowledge, but they often have profound disturbances in their ability to get along with others.

In the late 1930s, António Egas Moniz developed the *lobotomy*, a form of brain surgery that deliberately damaged the prefrontal cortex (**FIGURE 3.30**). Why would a surgeon want to perform this procedure? At the beginning of the 20th century, there was a significant increase in the number of patients living in mental institutions, and psychiatrists sought a physical means of treating these patients. The lobotomy generally left patients lethargic, emotionally flat, and therefore much easier to manage. It also left them disconnected from their social surroundings. Most lobotomies were performed in the late 1940s and early 1950s. In 1949, Egas Moniz received the Nobel Prize for developing the procedure, which was phased out with the arrival of drugs to treat psychological disorders.

Splitting the Brain Splits the Mind

Studying people who have undergone brain surgery has given researchers a better understanding of the conscious mind. For example, on rare occasions when epilepsy does not respond to modern medications, surgeons may remove the part of the brain in which the seizures begin. Another strategy, pioneered in the 1940s and sometimes still practiced when other interventions have failed, is to cut connections within the brain to try to isolate the site where the seizures begin. After the procedure, a seizure that begins at that site is less likely to spread throughout the cortex.

The major connection between the hemispheres that may readily be cut without damaging the gray matter is the corpus callosum (see Figure 3.26). When this massive fiber bundle is severed, the brain's halves are almost completely isolated from each other. The resulting condition is called **split brain**. This surgical procedure has provided many important insights into the basic organization and specialized functions of each brain hemisphere (**FIGURE 3.31**).

What is it like to have your brain split in half? Perhaps the most obvious thing about split-brain patients after their operations is how normal they are. Unlike patients after other types of brain surgery, split-brain patients have no immediately apparent problems. In fact, some early investigations suggested the surgery had not affected the patients in any discernible way. They could walk normally, talk normally, think clearly, and interact socially. In the 1960s, this book's coauthor Michael Gazzaniga, working with the Nobel laureate Roger Sperry, conducted a series of tests on split-brain patients. The results were stunning: Just as the brain had been split in two, so had the mind!

The hemispheres normally work together. Images from the visual field's left side (left half of what you are looking at) go to the right hemisphere. Images from the visual field's right side go to the left hemisphere (**FIGURE 3.32**). The left hemisphere also controls the right hand, and the right hemisphere controls the left hand. In a healthy person, the corpus callosum allows the hemispheres to communicate so that the right brain knows what the left is doing. By contrast, in split-brain patients, the hemispheres are separated, so this communication cannot take place—the hemispheres function as completely independent entities. This division allows researchers to independently examine the function of each hemisphere without the influence of the other. The researchers can provide information to, and receive information from, a single hemisphere at a time.

split brain

A condition that occurs when the corpus callosum is surgically cut and the two hemispheres of the brain do not receive information directly from each other.

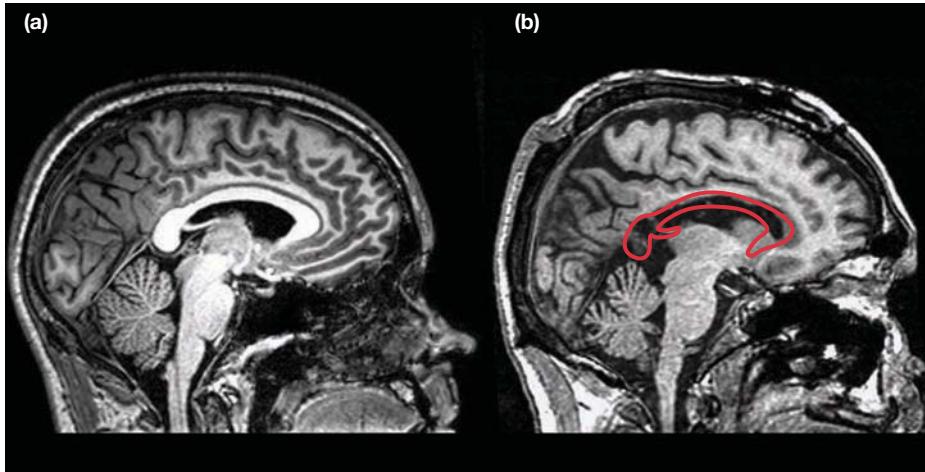


FIGURE 3.31

Split Brain

(a) This image shows the brain of a normal person whose corpus callosum is intact. (b) This image shows the brain of a patient whose corpus callosum has been cut (area indicated by the red outline). With the corpus callosum severed, the two hemispheres of the brain are almost completely separated.

Psychologists have long known that in most people the left hemisphere is dominant for language. If a split-brain patient sees two pictures flashed on a screen briefly and simultaneously—one to the visual field's right side and one to the left side—the patient will report that only the picture on the right was shown. Why is this? The left hemisphere (or “left brain”), with its control over speech, sees only the picture on the right side. It is the only picture a person with a split brain can talk about.

In many split-brain patients, the right hemisphere has no discernable language capacity. The mute right hemisphere (or “right brain”), having seen the picture on the left, is unable to articulate a response. However, the right brain can act on its perception: If the picture on the left was of a spoon, the right hemisphere can easily pick out an actual spoon from a selection of objects. It uses the left hand, which is controlled by the right hemisphere. Still, the left hemisphere does not know what the right one saw.

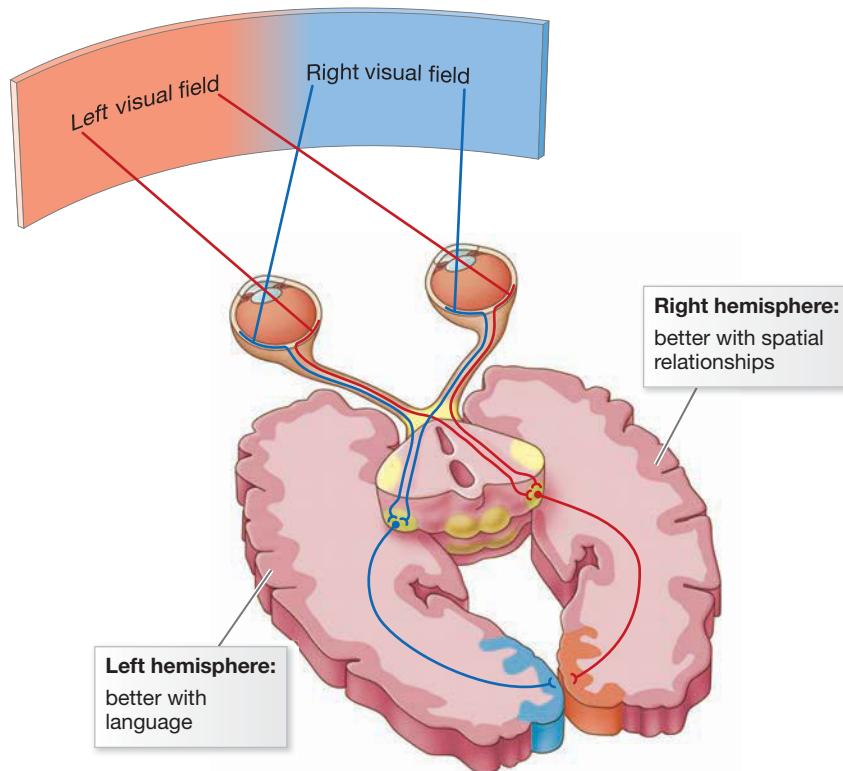


FIGURE 3.32

Visual Input

Images from the left side go to the brain's right hemisphere. Images from the right side go to the left hemisphere.

What to Believe? Using Psychological Reasoning

Failing to Notice Source Credibility: Are There “Left Brain” and “Right Brain” Types of People?

Many psychologists are leery about dealing with the popular press. They want psychological studies to become known by the public, but they do not want the findings to be garbled by the media. Seeing their research twisted in the press can be maddening in part because it overshadows the very findings the scientists have so proudly obtained. One of the authors of this textbook knows about such problems from personal experience.

As noted in the text, Michael Gazzaniga and Roger Sperry conducted research on the activity of the two hemispheres after the corpus callosum was severed. When the hemispheres have been surgically disconnected and are separately examined, each hemisphere displays different abilities. This discovery provided a wealth of data, but the media has gone far beyond Gazzaniga and Sperry's early findings.

You have probably heard the idea that some people are “left brain” logical types and others are “right brain” artistic types. According to this popular notion, people differ to the extent that their right or left hemispheres dominate their thinking styles. Left-brain thinkers are said to be more analyti-

The evidence is overwhelming: People are not either left-brain or right-brain dominant.

cal, rational, and objective. Right-brain thinkers are said to be more creative and to view the world more holistically and subjectively. Moreover, a dominant left brain supposedly suppresses right-brain creativity, so people could become more creative and passionate if their right hemisphere were released.

This false idea has permeated society (**FIGURE 3.33**). Multiple tests are available, particularly on the Internet, to determine whether you are left- or right-brain dominant. Countless pop psychology books give advice on living better by emphasizing your particular brain style or drawing on the other style. Teachers have been heavily influenced by the idea (Alferink & Farmer-Dougan, 2010). They have been urged to develop different classroom plans

for left-brain thinkers than for right-brain thinkers, and they have been encouraged to liberate the “more creative” right brain. According to one recent study, nearly 90 percent of teachers in the U.K. and the Netherlands believe in the idea of left-brain versus right-brain thinking (Dekker et al., 2012).

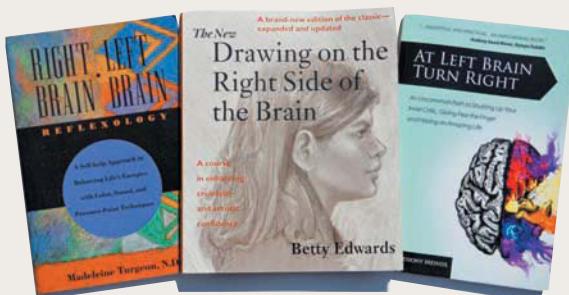


FIGURE 3.33 Left Brain Versus Right Brain

The media has helped promote the false ideas that individuals are dominant on one side of the brain or the other and that such different styles are important for classroom learning.

As noted in Chapter 1, the media loves a good story. To make scientific studies attention grabbing, journalists often oversimplify research findings and apply them in ways that go far beyond what can be concluded from the evidence. In this case, the evidence is overwhelming: People are not either left-brain or right-brain dominant (Hines, 1987).

The hemispheres are specialized for certain functions, such as language or spatial relationships. However, each hemisphere is capable of carrying out most cognitive processes, though sometimes in different ways. Most cognitive processes involve the coordinated efforts of both hemispheres. A recent study that examined brain activity in over 1,000 individuals ages 7 to 29 found no differences between people in the extent to which their right or left hemisphere was active (Nielsen et al., 2013). In contrast to the theory that a liberated right brain leads to better learning, some evidence suggests that people who perform best at math are those whose two hemispheres work most closely together (Prescott et al., 2010).

Of course, whenever you read media stories about psychological findings, you need to think about the source of your information. If you are really interested in the finding, consider looking up the original article to see if the journalist represented that article accurately. This advice is especially important if you plan to use the information in your life. Findings from psychological science often have practical implications for daily living, but the value of research can be spoiled if the media outlet spreading the information gets it wrong.

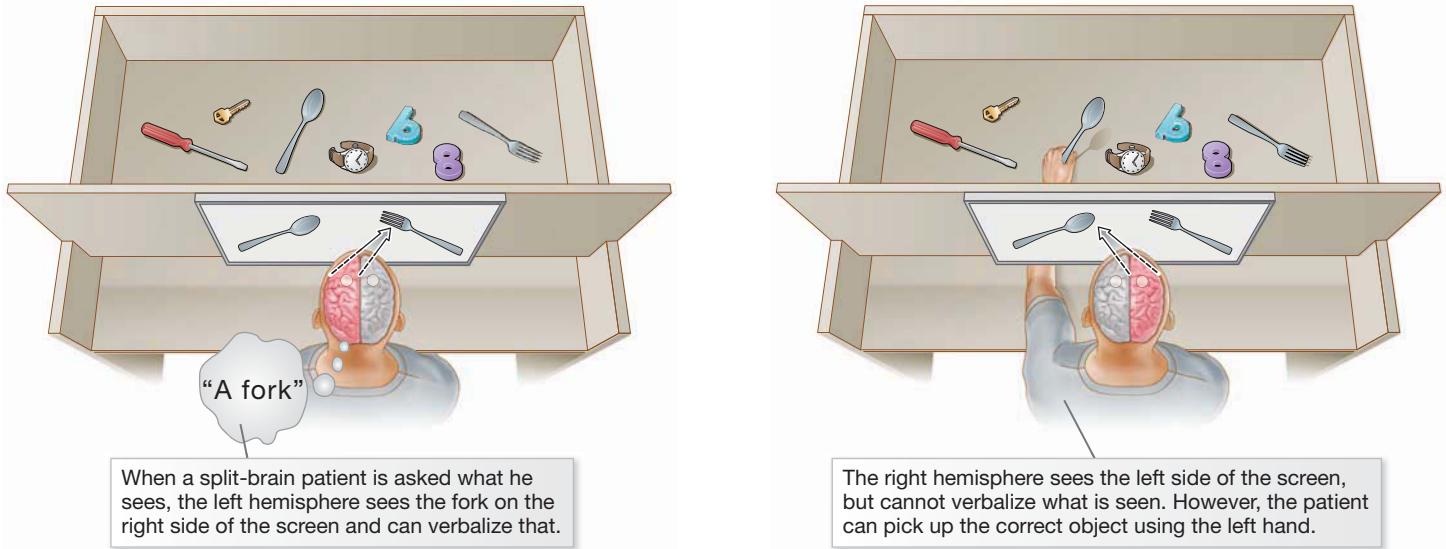


FIGURE 3.34 Split-Brain Experiment: The Left Hemisphere Versus the Right Hemisphere

Splitting the brain, then, produces two half brains. Each half has its own perceptions, thoughts, and consciousness (**FIGURE 3.34**).

Normally, the competencies of each hemisphere complement each other. The left brain is generally hopeless at spatial relationships, whereas the right hemisphere is much more proficient. In one experiment (Bogen & Gazzaniga, 1965), a split-brain participant is given a pile of blocks and a drawing of a simple arrangement in which to put them. For example, the participant is asked to produce a square. When using the left hand, controlled by the right hemisphere, the participant arranges the blocks effortlessly. However, when using the right hand, controlled by the left brain, the participant produces only an incompetent, meandering attempt. During this dismal performance, the right brain presumably grows frustrated, because it makes the left hand try to slip in and help! You will learn more about split-brain patients in Chapter 4, “Consciousness.”

Summing Up

What Are the Basic Brain Structures and Their Functions?

- Early researchers debated the relationship between human brain structures and brain functions. New imaging techniques have advanced our understanding of the brain.
- The spinal cord carries sensory information from the body to the brain and motor information from the brain to the body. It also produces reflexes.
- The brain stem serves survival functions, such as breathing, swallowing, and urination.
- At the back of the brain stem is the cerebellum. This structure is associated with coordinated movement, balance, and motor learning.
- Beneath the cerebral cortex are a number of structures that serve unique functions: The hypothalamus regulates bodily functions. The thalamus serves as a way station through which sensory information travels to the cortex. The hippocampus is involved in memory formation. The amygdala influences emotional states. The structures of the basal ganglia are involved in the planning and production of movement as well as in reward.
- The cerebral cortex is the outer surface of the brain and is divided into lobes. The occipital lobes are associated with vision. The parietal lobes are associated with touch and attention. The temporal lobes are associated with hearing, memory, facial perception, and object

perception. The frontal lobes, which contain the prefrontal cortex, are associated with movement, higher-level psychological processes, and personality.

- When the two hemispheres of the brain are surgically split, the left hemisphere displays different abilities than the right hemisphere.

Measuring Up

1. Match each of the following brain structures with its role or function. (You will need to remember these terms and facts to understand later discussions of learning, memory, emotions, mental illness, anxiety, and other aspects of mind and behavior.)

Brain structure	Role/function
a. brain stem	1. primary structure for memory
b. cerebellum	2. sensory relay station
c. basal ganglia	3. important for emotions
d. hypothalamus	4. divided into four lobes
e. thalamus	5. regulates vital functions such as body temperature
f. hippocampus	6. involved in reward
g. amygdala	7. regulates breathing and swallowing
h. cerebral cortex	8. "little brain," involved in movement

2. Match each lobe of the brain with its function.

Lobe	Function
a. frontal	1. hearing
b. occipital	2. thought
c. parietal	3. touch
d. temporal	4. vision

(2) a. 2; b. 4; c. 3; d. 1.

ANSWERS: (1) a. 7; b. 8; c. 6; d. 5; e. 2; f. 4; g. 3; h. 4.

Learning Objectives

- Differentiate between the subdivisions of the nervous system.
- Identify the primary structures of the endocrine system.
- Explain how the nervous system and the endocrine system communicate to control thought, feeling, and behavior.

3.3 How Does the Brain Communicate with the Body?

Recall that the peripheral nervous system (PNS) transmits a variety of information to the central nervous system (CNS). It also responds to messages from the CNS to perform specific behaviors or make bodily adjustments. In the production of psychological activity, however, both of these systems interact with a different mode of communication within the body, the endocrine system.

The Peripheral Nervous System Includes the Somatic and Autonomic Systems

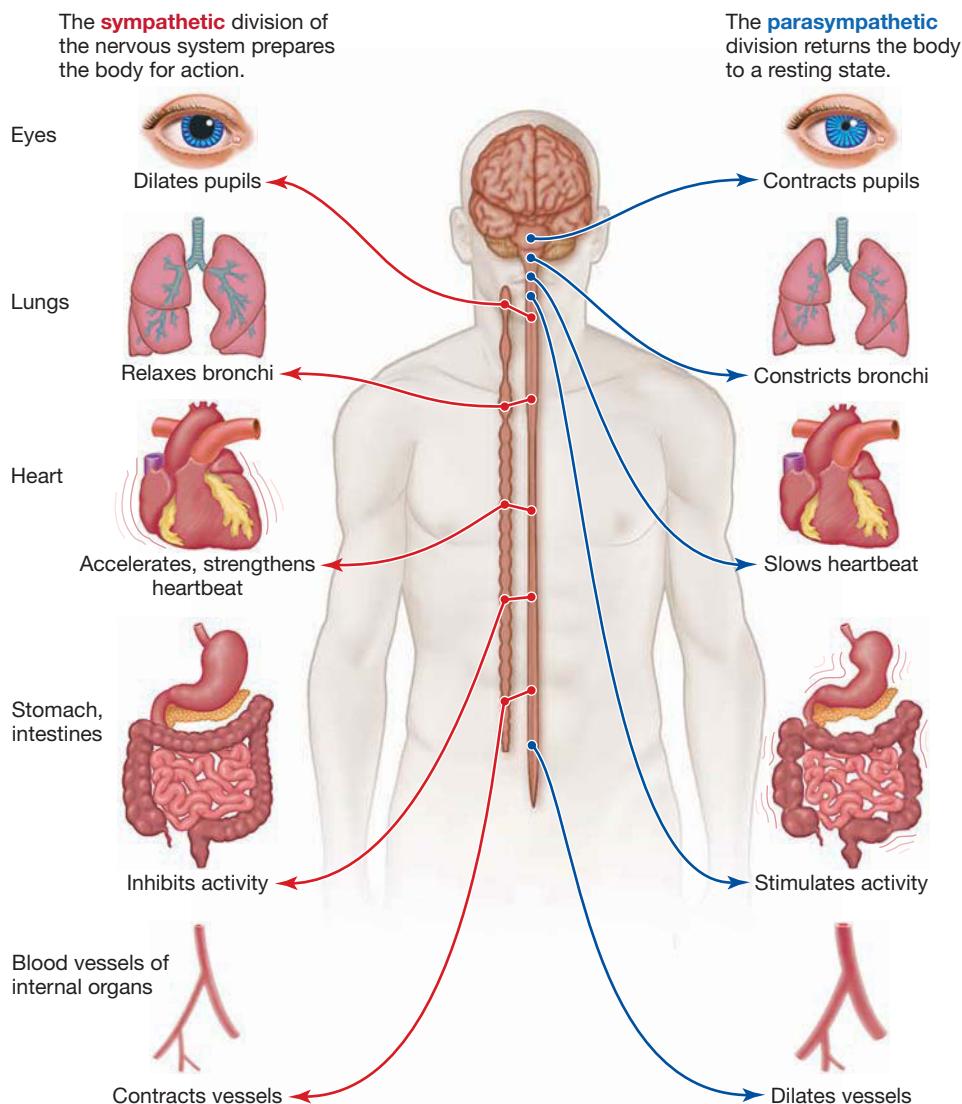
Recall that the PNS has two primary components: the somatic nervous system and the autonomic nervous system (see Figure 3.3). The **somatic nervous system (SNS)** transmits sensory signals to the CNS via nerves. Specialized receptors in the skin, muscles, and joints send sensory information to the spinal cord, which relays it to the brain. In addition, the CNS sends signals through the SNS to muscles, joints, and skin to initiate, modulate, or inhibit movement.

The second major component of the PNS, the **autonomic nervous system (ANS)**, regulates the body's internal environment by stimulating glands (such as sweat glands) and by maintaining internal organs (such as the heart). Nerves in the ANS also carry somatosensory signals from the glands and internal organs to the CNS.

These signals provide information about, for example, the fullness of your stomach or how anxious you feel.

SYMPATHETIC AND PARASYMPATHETIC DIVISIONS Two types of signals, sympathetic and parasympathetic, travel from the central nervous system to organs and glands, controlling their activity (**FIGURE 3.35**). To understand these signals, imagine you hear a fire alarm. In the second after you hear the alarm, signals go out to parts of your body telling them to prepare for action. As a result, blood flows to skeletal muscles; epinephrine is released, increasing your heart rate and blood sugar; your lungs take in more oxygen; your digestive system suspends activity as a way of conserving energy; your pupils dilate to maximize visual sensitivity; and you perspire to keep cool.

These preparatory actions are prompted by the autonomic nervous system's **sympathetic division**. Should there be a fire, you will be physically prepared to flee. If the alarm turns out to be false, your heart will return to its normal steady beat, your breathing will slow, you will resume digesting food, and you will stop perspiring. This return to a normal state will be prompted by the ANS's **parasympathetic division**. Most of your internal organs are controlled by inputs from sympathetic and parasympathetic systems. The more aroused you are, the greater the sympathetic system's dominance.



somatic nervous system (SNS)

A component of the peripheral nervous system; it transmits sensory signals and motor signals between the central nervous system and the skin, muscles, and joints.

autonomic nervous system (ANS)

A component of the peripheral nervous system; it transmits sensory signals and motor signals between the central nervous system and the body's glands and internal organs.

sympathetic division

A division of the autonomic nervous system; it prepares the body for action.

parasympathetic division

A division of the autonomic nervous system; it returns the body to its resting state.

endocrine system

A communication system that uses hormones to influence thoughts, behaviors, and actions.

It does not take a fire alarm to activate your sympathetic nervous system. For example, when you meet someone you find attractive, your heart beats quickly, you perspire, you might start breathing heavily, and your pupils widen. Such signs of sexual arousal provide nonverbal cues during social interaction. These signs occur because sexual arousal has activated the ANS's sympathetic division. The SNS is also activated by psychological states such as anxiety or unhappiness. Some people worry a great deal or do not cope well with stress. Their bodies are in a constant state of arousal. Important research in the 1930s and 1940s by Hans Selye demonstrated that chronic activation of the SNS is associated with medical problems that include heart disease and asthma. Selye's work is discussed further in Chapter 11, "Health and Well-Being."

The Endocrine System Communicates Through Hormones

Like the nervous system, the **endocrine system** is a communication network that influences thoughts, behaviors, and actions. Both systems work together to regulate psychological activity. For instance, from the nervous system the brain receives information about potential threats to the organism. The brain communicates with the endocrine system to prepare the organism to deal with those threats. (The threats could involve physical injury or be psychological, such as nervousness at having to talk in front of a group.) The main differences between the two systems are in their mode and speed of communication: Whereas the nervous system is fast and uses electrochemical signals, the endocrine system is slower and uses *hormones*.

Hormones are chemical substances released into the bloodstream by the ductless *endocrine glands*, such as the pancreas, thyroid, and testes or ovaries (**FIGURE 3.36**). Once released, hormones travel through the bloodstream until they reach their target tissues, where they bind to receptor sites and influence the tissues. Because they travel through the bloodstream, hormones can take from seconds to hours to exert

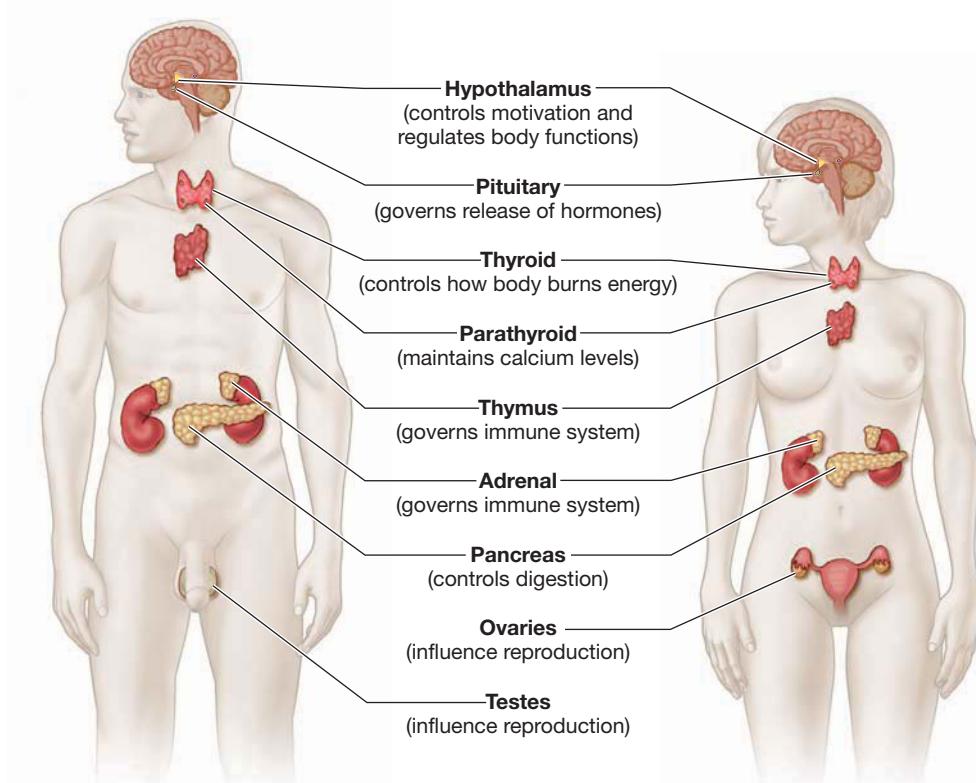


FIGURE 3.36
The Hypothalamus and the Major Endocrine Glands

their effects. Once hormones are in the bloodstream, their effects can last for a long time and affect multiple targets.

HORMONES' EFFECTS ON SEXUAL BEHAVIOR An example of hormonal influence is in sexual behavior. The main endocrine glands influencing sexual behavior are the **gonads**: the testes in males and the ovaries in females. Although many people talk about “male” and “female” hormones, the two major gonadal hormones are identical in males and females. What differs is the quantity: *Androgens* such as testosterone are more prevalent in males, whereas *estrogens* such as estradiol and progesterone are more prevalent in females. Gonadal hormones influence the development of secondary sex characteristics (e.g., breast development in females, growth of facial hair in males). Gonadal hormones also influence adult sexual behavior.

For males, successful sexual behavior depends on having at least a minimum amount of testosterone. Prior to puberty, surgical removal of the testes, or *castration*, diminishes the capacity for developing an erection and lowers sexual interest. Yet a man castrated after puberty will be able to perform sexually if he receives an injection of testosterone. Testosterone injections do not increase sexual behavior in healthy men, however, and this finding suggests that a healthy man needs only a minimum amount of testosterone to perform sexually (Sherwin, 1988).

In females, the influence of gonadal hormones is much more complex. Many nonhuman female animals experience a finite period, *estrus*, when the female is sexually receptive and fertile. During estrus, the female displays behaviors designed to attract the male. Surgical removal of the ovaries terminates estrus: No longer receptive, the female ends her sexual behavior. However, injections of estrogen reinstate estrus. Women’s sexual behavior may have more to do with androgens than estrogens (Morris, Udry, Khan-Dawood, & Dawood, 1987). According to pioneering work by Barbara Sherwin (1994, 2008), women with higher blood levels of testosterone report greater interest in sex, and testosterone injections increase women’s sexual interest after surgical removal of the uterus.

Women’s sexual activity is not particularly linked to the menstrual cycle (Breedlove, Rosenzweig, & Watson, 2007). However, when they are ovulating, heterosexual women find men who look and act masculine more attractive (Gangestad, Simpson, Cousins, Garver-Apgar, & Christensen, 2004), and they show greater activity in brain regions associated with reward while viewing attractive male faces (Rupp et al., 2009). In addition, women report having lower self-esteem when ovulating, and their greater motivation to find a mate during that time may increase their efforts to appear attractive (Hill & Durante, 2009). Indeed, one study found that when their fertility was highest, women showed up for a laboratory study wearing more-revealing clothing than they normally wore (Durante, Li, & Haselton, 2008). Multiple recent studies are now providing evidence that using hormonal contraceptives might significantly alter both female and male mate choice by removing the hormone-related mid-cycle change in preferences (for a review: Alvergne & Lummaa [2010]).

Actions of the Nervous System and Endocrine System Are Coordinated

All the communication systems described in this chapter link neurochemical and physiological processes to behaviors, thoughts, and feelings. These systems are fully



"You've been charged with driving under the influence of testosterone."

hormones

Chemical substances, released from endocrine glands, that travel through the bloodstream to targeted tissues; the tissues are subsequently influenced by the hormones.

gonads

The main endocrine glands involved in sexual behavior: in males, the testes; in females, the ovaries.

pituitary gland

A gland located at the base of the hypothalamus; it sends hormonal signals to other endocrine glands, controlling their release of hormones.

integrated and interact to facilitate survival. They use information from the organism's environment to direct adaptive behavioral responses. Ultimately, the endocrine system is under the central nervous system's control. The brain interprets external and internal stimuli, then sends signals to the endocrine system. The endocrine system responds by initiating various effects on the body and on behavior.

The endocrine system is primarily controlled by the hypothalamus (for the location of this structure, see Figure 3.36; for a more detailed look, see Figure 3.24) via signals to the **pituitary gland**, which is located at the base of the hypothalamus. Neural activation causes the hypothalamus to secrete a particular one of its many *releasing factors*. The particular releasing factor causes the pituitary to release a hormone specific to that factor, and the hormone then travels through the bloodstream to endocrine sites throughout the body. Once the hormone reaches the target sites, it touches off the release of other hormones, which subsequently affect bodily reactions or behavior. The pituitary is often referred to as the "master gland" of the body: By releasing hormones into the bloodstream, it controls all other glands and governs major processes such as development, ovulation, and lactation. This integration can be finely tuned.

Consider physical growth. *Growth hormone (GH)*, a hormone released from the pituitary gland, prompts bone, cartilage, and muscle tissue to grow or helps them regenerate after injury. Since the 1930s, many people have administered or self-administered GH to increase body size and strength. Many athletes have sought a competitive advantage by using GH. For example, in early 2013, the legendary cyclist Lance Armstrong admitted to using GH and other hormones, including testosterone, to gain a competitive advantage. In an interview with Oprah Winfrey, Armstrong claimed that because doping was so pervasive in the sport, it was impossible for any cyclist to win a major championship without doping (**FIGURE 3.37**).

The releasing factor for GH stimulates the eating of protein by making it especially enjoyable (Dickson & Vaccarino, 1994). The area of the hypothalamus that stimulates release of GH is also involved in sleep/wake cycles. Thus, the bursts of GH, the need for protein, and the consumption of protein are controlled by the body's internal clock. All these connections illustrate how the CNS, the PNS, and the endocrine system work together to ensure the organism's survival: These systems prompt the behaviors that provide the body with the substances it needs when it needs them.



FIGURE 3.37

Growth Hormone and Cycling

In January 2013, Lance Armstrong appeared on *The Oprah Winfrey Show* to admit using doping techniques to enhance his cycling performance.

Summing Up

How Does the Brain Communicate with the Body?

- The central nervous system—the brain and spinal cord—attends to the body and its environment, initiates actions, and directs the peripheral nervous system and endocrine system to respond appropriately.
- The peripheral nervous system is made up of the somatic nervous system and autonomic nervous system. The autonomic nervous system controls sympathetic and parasympathetic activity.
- The endocrine system consists of a number of endocrine glands, such as the pituitary and the adrenal glands. The central nervous system, peripheral nervous system, and endocrine system use chemicals to transmit their signals. Transmission in the nervous system occurs across synapses, whereas transmission in the endocrine system uses hormones that travel through the bloodstream.
- Gonadal hormones (estrogen, progesterone, and testosterone) are important in the development of secondary sex characteristics and in sexual behavior.

- The hypothalamus controls the endocrine system by directing the pituitary to release hormones that affect other endocrine glands.
- The various communication systems are integrated and promote behavior that is adaptive to the organism's environment.

Measuring Up

- Complete each statement by choosing one of the following terms: peripheral nervous system (PNS); somatic nervous system; autonomic nervous system (ANS); sympathetic division; parasympathetic division.
 - You are studying quietly in the library when a friend jumps out from behind a partition and scares you, making your heart race. Your _____ has been affected.
 - When you calm down and return to your former (not scared) state, your _____ is affected.
 - The _____ controls movement by carrying signals from the central nervous system to the muscles.
 - The _____ has two primary components: the somatic nervous system and the autonomic nervous system.
 - The _____ consists of two main divisions that regulate the body's internal environment.
- Which of the following statements are true? Choose as many as apply.
 - All (normal) people of both sexes secrete testosterone and estrogen.
 - Men have gonads, and women have ovaries.
 - The endocrine system acts more slowly than the nervous system.
 - Hormones are secreted from several places in the body.
 - The pituitary gland is called the master gland.
 - The central nervous system and the peripheral nervous system work together, whereas the endocrine system works independently.
 - Women's sexual responsiveness is related more to androgens (such as testosterone) than to estrogen.

(2) Choices a, c, d, e, and g are true.

ANSWERS: (1) a. sympathetic division; b. parasympathetic division; c. somatic nervous system (SNS); d. peripheral nervous system (PNS); e. autonomic nervous system (ANS).

3.4 How Does the Brain Change?

When Michelle Mack was a youngster, her parents realized that she was different from other children because even simple tasks could give her problems. They could not explain these differences. When Mack was 27 years old, they learned that she was missing the left hemisphere of her brain (**FIGURE 3.38**). Doctors suspected that Mack's condition was the result of a stroke she had experienced in the womb.

Without a left hemisphere, Mack should have shown severe deficits in skills processed in that half of the brain. For example, the left hemisphere controls language, and it controls motor actions for the right side of the body. Losing a hemisphere as an adult would result in devastating loss of function. But Mack's speech is only minimally affected, and she can move the right side of her body with some difficulty. Mack is able to lead a surprisingly independent life. She graduated from high school, has a job, pays her bills, and does chores. Where did her capabilities come from? Somehow, her right hemisphere developed language processing capabilities as well as functions that ordinarily occur across both hemispheres.

Michelle Mack's case shows that nurture can influence nature. Over time, Mack interacted with the world. Her experiences enabled her brain to reorganize itself. Her right hemisphere took over processing for the missing left hemisphere.

Learning Objectives

- Explain how environmental factors, including experiences, influence brain organization.
- Describe sex differences in brain structure and function.

(a)



(b)



FIGURE 3.38
Michelle Mack and a Case of Extreme Plasticity

(a) While in her mother's womb, Michelle Mack suffered a stroke that obliterated her left hemisphere (shown here, in a scan taken when she was an adult, as the black areas on the right). (b) Over time, Mack's right hemisphere took over the duties of the left hemisphere—language production and moving the right side of the body—to a surprising extent. Mack's case shows the plasticity of the brain.

plasticity

A property of the brain that allows it to change as a result of experience or injury.

In fact, despite the great precision and the specificity of its connections, the brain is extremely adaptable. Over the course of development, throughout a constant stream of experience, and after injury, the brain continually changes. This property is known as **plasticity**.

Experience Fine-Tunes Neural Connections

Connections form between brain structures when growing axons are directed by certain chemicals that tell them where to go and where not to go. The major connections are established by chemical messengers, but the detailed connections are governed by experience. If a cat's eyes are sewn shut at birth, depriving the animal of visual input, the visual cortex fails to develop properly. If the sutures are removed weeks later, the cat is permanently blind, even though its eyes function normally. Adult cats that are similarly deprived do not lose their sight (Wiesel & Hubel, 1963). Evidently, ongoing activity in the visual pathways is necessary in order to refine the visual cortex enough for it to be useful. In general, such plasticity has *critical periods*. During these times, particular experiences must occur for development to proceed normally.

To study the effects of experience on development, researchers reared rats in a number of different laboratory environments. For instance, one group was raised in deprived circumstances compared to that of normal laboratory rats, with minimal comfort and no opportunities for social interaction. Another group was raised in an enriched environment, with many companions, interesting things to look at, puzzles, obstacles, toys, running wheels, and even balance beams. The “luxury” items might simply have approximated rat life in the wild, but they enabled the luxury group to develop bigger, heavier brains than the deprived group (Rosenzweig, Bennett, & Diamond, 1972). Thus, it appears that experience is important for normal development and maybe even more so for superior development. Nowadays, as a result of these findings, most laboratory animals are kept in environments that provide enrichment (Simpson & Kelley, 2011). Some evidence suggests that the opportunity for physical exercise might have the most beneficial effects on brain development and learning (Mustroph et al., 2012).

Females' and Males' Brains Are Mostly Similar but May Have Revealing Differences

Everything a person experiences alters his or her brain, and females and males differ in their life experiences. They also differ in their hormonal makeups. The differences between females' and males' brains reveal the intertwined influences of biology and environment. In general, males have larger brains than females, but for both sexes the sizes of brain structures are highly variable (Giedd et al., 1997). In any case, larger brains are not necessarily better, because longer distances between brain regions can translate into slower communication. Both in the womb and after birth, hormonal differences between the sexes affect brain development (Lombardo et al., 2012). As a result, hormonal difference might influence the way males and females differ on some cognitive tasks, such as the ease with which they mentally rotate objects or recall parts of a story (Kimura, 1999). But the different ways that men and women are treated in society may also contribute to these differences on cognitive tasks (Miller & Halpern, 2014).

There is evidence that men and women may perform the same task by using different parts of the brain. For example, Richard Haier and colleagues (2005) found that females and males may solve some complex problems, such as items on IQ tests, differently. Females show greater use of language-related brain regions, whereas males show greater use of spatial-related brain regions, even when participants are matched for intelligence.

As discussed earlier in the chapter, to some extent the brain's two hemispheres are lateralized: Each hemisphere is dominant for different cognitive functions. A considerable body of evidence indicates that females' brains are more bilaterally organized for language. In other words, the brain areas important in processing language are more likely to be found in both halves of females' brains. In males' brains the equivalent language areas are more likely to be in only one hemisphere, usually the left (Phillips et al., 2001; **FIGURE 3.39**).

One source of data that supports this distinction between male and female brains is people's experiences following strokes. Even when patients are matched on the location and severity of the brain damage caused by a stroke, women are less impaired in language use than men are (Jiang, Sheikh, & Bullock, 2006). A possible reason for women having better outcomes is that, because language is represented in both halves of their brain, damage to half of the brain will have less effect on a woman's ability to process language than it would if most of the language areas were in the damaged half of the brain.

A related hypothesis, in accord with the idea that women's brains are more bilaterally organized, is that the halves of women's brains are connected by more neural fibers than men's are. Remember that the corpus callosum connects the brain's two halves (see Figure 3.20). Some researchers have found that a portion of the corpus callosum is larger in women (Gur & Gur, 2004). More recently, researchers have shown that many of the connections in the typical female brain run from side to side across the hemispheres, whereas in the typical male brain they run from back to front within each hemisphere (Ingalhalikar et al., 2014).

While differences between females' brains and males' brains may be revealing, in fact their brains are mostly similar. Ultimately, the interplay of biological and environmental effects on the brain is reflected in both the differences and the similarities between females' and males' brains.

The Brain Rewires Itself Throughout Life

Brain plasticity decreases with age. Even into very old age, however, the brain can grow new connections among neurons and even grow new neurons. The rewiring and growth within the brain represents the biological basis of learning.

CHANGE IN THE STRENGTH OF CONNECTIONS UNDERLIES LEARNING In every moment of life, we gain memories: experiences and knowledge that are acquired instantaneously and may be recalled later, as well as habits that form gradually. All these memories are reflected in the brain's physical changes.

Psychologists widely accept that changes in the brain are most likely not in its larger wiring or general arrangement. The changes are mainly in the strength of existing connections. One possibility is that when two neurons fire simultaneously, the synaptic connection between them strengthens. The strengthened synaptic connection makes these neurons more likely to fire together in the future. Conversely, *not* firing simultaneously tends to weaken the connection between two neurons. This theory can be summarized by the catchphrase *fire together, wire together*. First proposed in the 1940s, by the renowned psychologist Donald Hebb (1949), this idea is consistent with much experimental evidence and many theoretical models. It accounts for two phenomena: the "burning in" of an experience (a pattern of neural firing becomes more likely to recur, and its recurrence leads the mind to recall an event) and the ingraining of habits (repeating a behavior makes the person tend to perform that behavior automatically). More rarely, entirely new connections grow between neurons. This new growth is a major factor in recovery from brain injury.

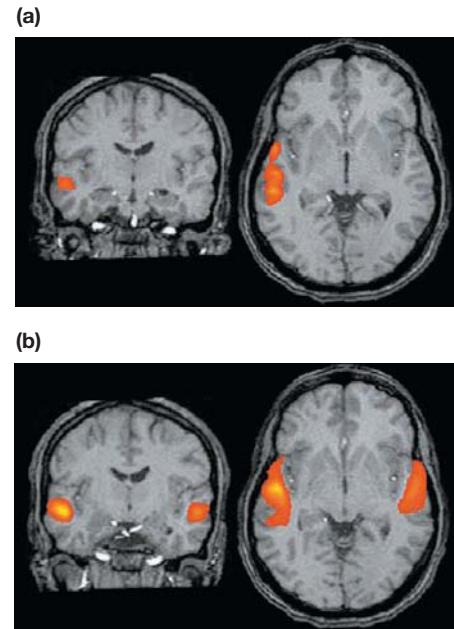


FIGURE 3.39
Males' Brains Versus Females' Brains

A considerable body of evidence indicates that female brains are more bilaterally organized for language than males' brains. For example, researchers studied men and women listening to someone reading aloud. As these fMRI images show, (a) the men listened with one side of their brains, whereas (b) the women tended to listen with both sides.

Until about 20 years ago, scientists believed that adult brains produced no new brain cells. There is now evidence that new neurons are produced in some brain regions (Eriksson et al., 1998). The production of new neurons is called *neurogenesis*. A fair amount of neurogenesis apparently occurs in the hippocampus. Recall from earlier in this chapter that the hippocampus is involved in the storage of new memories. These memories are eventually transferred to the cortex as the hippocampus is continuously overwritten. Perhaps, without disrupting memory, neurons in the hippocampus can be lost and replaced.

Elizabeth Gould and her colleagues have demonstrated that environmental conditions can play an important role in neurogenesis. For example, they have found that for rats, shrews, and marmosets, stressful experiences—such as being confronted by strange males in their home cages—interfere with neurogenesis during development and adulthood (Gould & Tanapat, 1999). When animals are housed together, they typically form dominance hierarchies that reflect social status. Dominant animals, those who possess the highest social status, show greater increases in new neurons than subordinate animals do (Kozorovitskiy & Gould, 2004). Thus, social environment can strongly affect brain plasticity, a dynamic process we are only beginning to understand. Neurogenesis may underlie neural plasticity. If so, further research might enable us, through neurogenesis, to reverse the brain's natural loss of neurons, thereby slowing age-based mental decline.

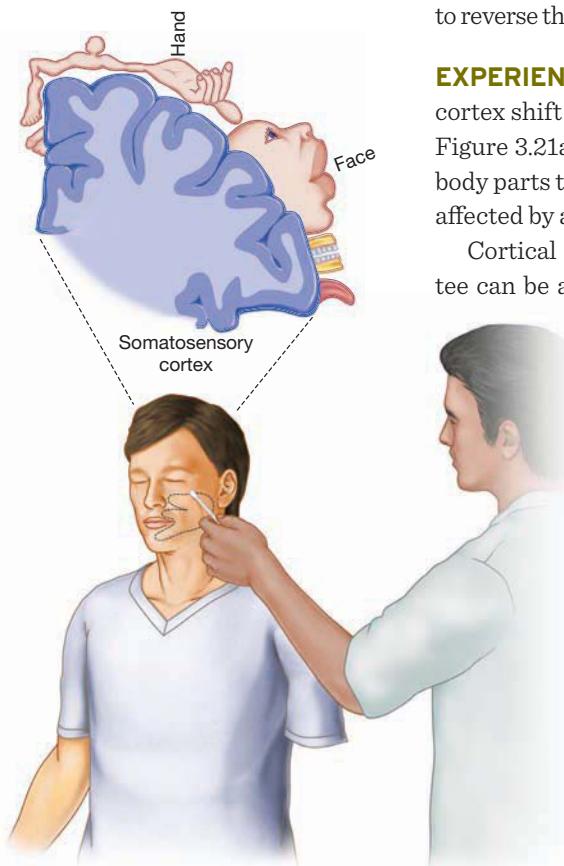


FIGURE 3.40
Cortical Remapping Following Amputation

The participant felt a cotton swab touching his cheek as if it were touching his missing hand.

EXPERIENCE CHANGES THE BRAIN The functions of portions of the cerebral cortex shift in response to their activity. Recall the somatosensory homunculus (see Figure 3.21a). As that representation makes clear, more cortical tissue is devoted to body parts that receive more sensation or are used more. Again, wiring in the brain is affected by amount of use.

Cortical reorganization can also have bizarre results. For example, an amputee can be afflicted with a *phantom limb*, the intense sensation that the amputated body part still exists. Some phantom limbs are experienced as moving normally, such as being used to gesture in conversation, whereas some are frozen in position. Moreover, a phantom limb is often accompanied by pain sensations, which may result from the misgrowth of the severed pain nerves at the stump. The cortex misinterprets the pain as coming from the place where those nerves originally came from. This phenomenon suggests that the brain has not reorganized in response to the injury and that the missing limb's cortical representation remains intact.

The neurologist V. S. Ramachandran has discovered that an amputee who has lost a hand may, when his or her eyes are closed, perceive a touch on the cheek as if it were on the missing hand (Ramachandran & Hirstein, 1998). Apparently, on the somatosensory homunculus the hand is represented next to the face. The unused part of the amputee's cortex (the part that would have responded to the now-missing limb) assumes to some degree the function of the closest group, representing the face. Somehow, the rest of the brain has not kept pace with the somatosensory area enough to figure out these neurons' new job, so the neurons formerly activated by a touch on the hand are activated by a touch on the amputee's face. The brain still codes the input as coming from the hand, and thus the amputee experiences a "phantom hand" (**FIGURE 3.40**).

The Brain Can Recover from Injury

Just as the brain reorganizes in response to amount of use, it also reorganizes in response to brain damage. Following an injury in the cortex, the surrounding gray

matter assumes the function of the damaged area, like a local business scrambling to pick up the customers of a newly closed competitor. This remapping seems to begin immediately, and it continues for years. Such plasticity involves all levels of the central nervous system, from the cortex down to the spinal cord.

Reorganization is much more prevalent in children than in adults, in accord with the sensitive periods of normal development. Young children afflicted with severe and uncontrollable epilepsy that has paralyzed one or more limbs sometimes undergo a *radical hemispherectomy*. This surgical procedure removes an entire cerebral hemisphere. Just as in the case of Michelle Mack, the remaining hemisphere eventually takes on most of the lost hemisphere's functions. The children regain almost complete use of their limbs. However, adults cannot undergo radical hemispherectomy. If the procedure were performed on adults, the lack of neural reorganization in their brains would lead to permanent paralysis and loss of function.

Summing Up

How Does the Brain Change?

- During development and across the life span, the circuitry of the brain is constantly reworked in response to experience.
- Males' brains and females' brains are mainly similar, but their differences may be revealing. Males' brains are larger, which does not necessarily mean better. Females' brains are organized more bilaterally for language. Men and women may perform the same cognitive task by using different parts of the brain.
- An understanding of the brain's organization and plasticity has enabled researchers to better understand conditions such as phantom limb syndrome. Neurogenesis, the creation of new neurons, may underlie neural plasticity.
- The brain can reorganize after a brain injury. However, children's brains demonstrate much greater reorganization after brain injury than adults' brains.

Measuring Up

1. Which of the following statements are examples of how environment can affect brain development or function? Place an X next to each example.
 - _____ a. The hippocampus may be larger than average in experienced taxi drivers.
 - _____ b. Laboratory rats raised in enriched environments developed heavier brains than laboratory rats raised in standard environments.
 - _____ c. Neurogenesis is more likely in socially dominant animals than in subordinate ones.
 - _____ d. Lack of visual stimulation from birth can result in a lack of development of the visual cortex, even if the eyes function normally.
2. Indicate whether the following statements, about the ways in which females' and males' brains differ, are true or false.
 - _____ a. Males' brains generally are larger than females' brains.
 - _____ b. Males' brains are more likely to be bilaterally organized.
 - _____ c. Researchers have found that sex differences in the brain are caused entirely by hormonal differences.
 - _____ d. Sex differences in the brain indicate that males and females have essentially different abilities.
 - _____ e. Females tend to use language-related areas for problem-solving, whereas males tend to use spatial-related areas.

(2) a. true; b. false; c. false; d. true; e. false.

brain development or function.

ANSWERS: (1) Choices a, b, c, and d are all examples of how environment can affect

Using Psychology in Your Life



Will My Learning Disability Prevent Me from Succeeding in College?

Have you been diagnosed with a learning disability? Do you suspect you might have one?

According to the National Center for Learning Disabilities (2009), a learning disability is a “neurological disorder that affects the brain’s ability to receive, process, store, and respond to information.” One of the most common learning disabilities is dyslexia, which involves difficulties in acquiring and processing language, leading to problems with reading, spelling, or writing (**FIGURE 3.41**). Someone who has difficulty spelling or writing might, alternatively, have the learning disability dysgraphia, a disorder of written expression.

Learning disabilities may become apparent in childhood or later in life. Individuals might excel academically in high school, but the new academic and organizational challenges of college might help reveal a learning disability.

If you have a learning disability or suspect you have one, the earlier you seek help, the sooner you will have access to the resources available on your campus that will help you learn. Contact the disability support office or someone at Student Affairs, and they will be able to direct you. If your learning disability is verified, disability support office staff will work with you to determine the types of accommodations necessary to enable you to get the most of your academic experience.

Given your particular strengths and weaknesses in processing information, some types of accommodations will be helpful, whereas others will not. Disability support office staff will let your professors know you are entitled to a specific type of accommodation, but they will not tell your professors about the nature of your learning disability. For example, a disability support office staff member might send a note to your professors that reads “[Your name will go here], a student in your introductory psychology course, has provided evidence of a condition that requires academic accommoda-



FIGURE 3.41

An Inspiring Example

The celebrity chef Jamie Oliver suffers from dyslexia. His disability has hardly kept him from achieving his career goals. Here, in June 2010, Oliver is announcing Home Cooking Skills, a new and inspirational program he has co-created to teach basic cooking skills to young people in England.

tion. As a result, please provide [him or her] with time and a half on exams and on in-class writing assignments.”

Of course, you can also speak directly with individual professors about your learning disability and the kinds of resources likely to help you. Linda Tessler, a psychologist who works with persons with learning disabilities, writes:

It must be clear that you are not asking for standards to be lowered. You are using tools to help you perform. To pass, you must perform the task that your classmates perform. You may, however, need to get there in a different way. Dyslexic students have to read the textbook just as nondyslexic students do. They may just do it differently through the use of books on tape. (Tessler, 1997, p. 2)

Will a learning disability prevent you from succeeding in college? Not if you can help it, and you can help it by advocating for yourself. Line up the resources you need to ensure that you are able to reap the rewards of college.

3.5 What Is the Genetic Basis of Psychological Science?

Jack Osbourne is experiencing the symptoms of MS because the neurons in his brain are becoming demyelinated. The affected neurons cannot carry the electrical signals that tell his muscles what to do. But why does he have this disease? Is it a genetic condition he inherited from his parents? Could environmental influences such as childhood nutrition be involved? Some researchers believe that people inherit a predisposition to respond to particular—as yet unknown—environmental triggers that produce MS. Whatever the cause of Jack Osbourne’s disorder, how he copes with the condition will depend partly on his psychological makeup.

So far, this chapter has presented the basic biological processes underlying psychological functions. The following section considers how genes and environment affect psychological functions. From the moment of conception, we receive the genes we will possess for the remainder of our lives, but to what extent do those genes determine our thoughts and behaviors? How do environmental influences, such as the families and cultures in which we are raised, alter how our brains develop and change?

Until the last few years, genetic research focused almost entirely on whether people possessed certain types of genes, such as genes for psychological disorders or for particular levels of intelligence. Although it is important to discover the effects of individual genes, this approach misses the critical role of environmental factors in shaping who we are. While the term *genetics* is typically used to describe how characteristics such as height, hair color, and eye color are passed along to offspring through inheritance, it also refers to the processes involved in turning genes “on” and “off.” Research has shown that environmental factors can affect **gene expression**. This term refers to whether a particular gene is turned on or off. Environmental factors may also influence how a gene, once turned on, influences our thoughts, feelings, and behavior.

Genetic predispositions are often important in determining the environments people select for themselves. So, once again, biology and environment mutually influence each other. All the while, biology and environment—in other words, one’s genes and every experience one ever has—fluence the development of one’s brain.

All of Human Development Has a Genetic Basis

Within nearly every cell in the body is the genome for making the entire organism. The *genome* is the master blueprint that provides detailed instructions for everything from how to grow a gallbladder to where the nose gets placed on a face. Whether a cell becomes part of a gallbladder or a nose is determined by which genes are turned on or off within that cell, and these actions are in turn determined by cues from both inside and outside the cell. The genome provides the options, and the environment determines which option is taken (Marcus, 2004).

Within each cell are **chromosomes**. These structures are made of *deoxyribonucleic acid (DNA)*, a substance that consists of two intertwined strands of molecules in a double helix shape. Segments of those strands are called **genes** (FIGURE 3.42).

In a typical human, nearly every cell contains 23 pairs of chromosomes. One member of each pair comes from the mother, the other from the father. In other words, each parent contributes half of a person’s DNA, half of his or her genes.

Each gene—a particular sequence of molecules along a DNA strand—specifies an exact instruction to manufacture a distinct *polypeptide*. One or more polypeptides

Learning Objectives

- Explain how genes are transmitted from parents to offspring.
- Discuss the goals and methods of behavioral genetics.
- Explain how environmental factors, including experience, influence genetic expression.

gene expression

Whether a particular gene is turned on or off.

chromosomes

Structures within the cell body that are made up of DNA, segments of which comprise individual genes.

genes

The units of heredity that help determine the characteristics of an organism.

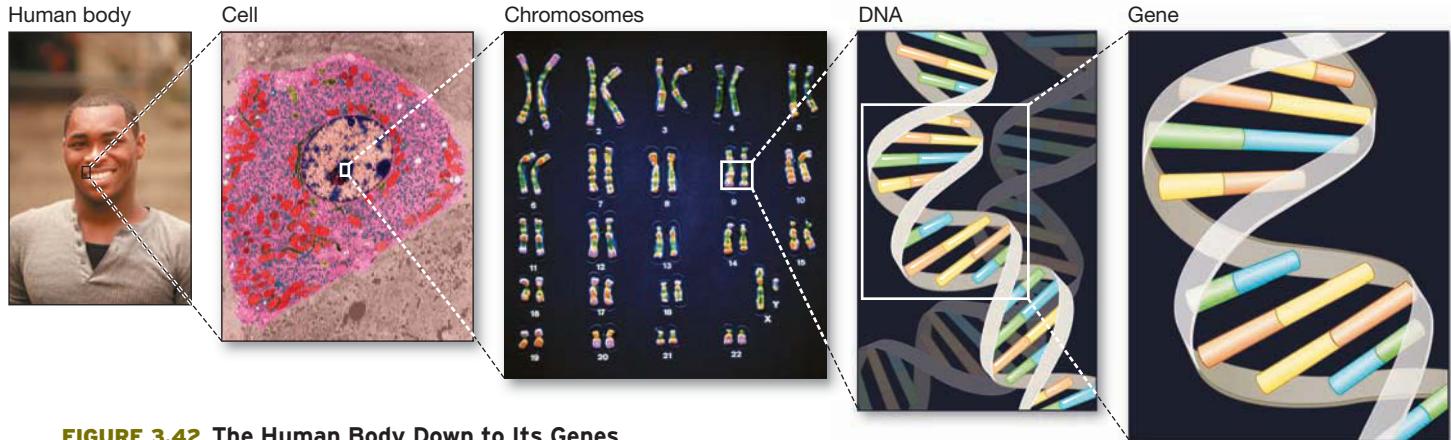


FIGURE 3.42 The Human Body Down to Its Genes

Each cell in the human body includes pairs of chromosomes, which consist of DNA strands. DNA has a double helix shape, and segments of it consist of individual genes.

make up a protein. Proteins are the basic chemicals that make up the structure of cells and direct their activities. There are thousands of different types of proteins, and each type carries out a specific task. The environment determines which proteins are produced and when they are produced.

For example, a certain species of butterfly becomes colorful or drab, depending on the season in which it is born (Brakefield & French, 1999). The environment causes a gene to be expressed during the butterfly's development that is sensitive to temperature or day length (**FIGURE 3.43**). Similarly, although each cell in the human body contains the same DNA, cells become specialized, depending on which of their genes are expressed. As noted earlier, gene expression determines the body's basic physical makeup, but it also determines specific developments throughout life. It is involved in all psychological activity. Gene expression allows us to sense, to learn, to fall in love, and so on.

In February 2001, two groups of scientists published separate articles that detailed the results of the first phase of the *Human Genome Project*, an international research effort. This achievement represents the coordinated work of hundreds of scientists around the world to map the entire structure of human genetic material. The first step of the Human Genome Project was to map the entire sequence of DNA. In other words, the researchers set out to identify the precise order of molecules that make up each of the thousands of genes on each of the 23 pairs of human chromosomes (**FIGURE 3.44**).

One of the most striking findings from the Human Genome Project is that people have fewer than 30,000 genes. That number means humans have only about twice as many genes as a fly (13,000) or a worm (18,000), not much more than the number in some plants (26,000), and fewer than the number estimated to be in an ear of corn (50,000). Why are we so complex if we have so few genes? The number of genes might be less important than subtleties in how those genes are expressed and regulated (Baltimore, 2001).

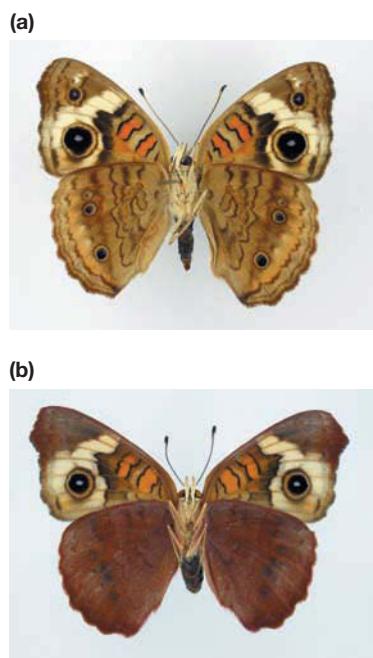


FIGURE 3.43
Gene Expression and Environment

The North American buckeye butterfly has seasonal forms that differ in the color patterns on their wings. (a) Generations that develop to adulthood in the summer—when temperatures are higher—take the “linea” form, with pale beige wings. (b) Generations that develop to adult in the autumn—when the days are shorter—take the “rosa” form, with dark reddish-brown wings.

Heredity Involves Passing Along Genes Through Reproduction

The first clues to the mechanisms responsible for heredity were discovered by the monk Gregor Mendel around 1866. The monastery where Mendel lived had a long history of studying plants. For studying inheritance, Mendel developed an



FIGURE 3.44
Human Genome Project

A map of human genes is presented by J. Craig Venter, president of the research company Celera Genomics, at a news conference in Washington on February 12, 2001. This map is one part of the international effort by hundreds of scientists to map the entire structure of human genetic material.

dominant gene

A gene that is expressed in the offspring whenever it is present.

recessive gene

A gene that is expressed only when it is matched with a similar gene from the other parent.

genotype

The genetic constitution of an organism, determined at the moment of conception.

phenotype

Observable physical characteristics, which result from both genetic and environmental influences.

(a)



(b)



FIGURE 3.45
Parent Plants Display Genetic Differences

Mendel studied pea plants. To observe the effects of cross-breeding, he started with (a) pea plants with purple flowers, and (b) pea plants with white flowers.

experimental technique, *selective breeding*, that strictly controlled which plants bred with which other plants.

In one simple study, Mendel selected pea plants that had either only purple flowers or only white flowers (**FIGURE 3.45**). He then cross-pollinated the two types to see which color of flowers the plants would produce. Mendel found that the first generation of pea offspring tended to be completely white or completely purple. If he had stopped there, he would never have discovered the basis of heredity. However, he then allowed each plant to self-pollinate into a second generation. This second generation revealed a different pattern: Of the hundreds of pea plants, about 75 percent had purple flowers and 25 percent had white flowers. This 3:1 ratio repeated itself in additional studies. It also held true for other characteristics, such as pod shape.

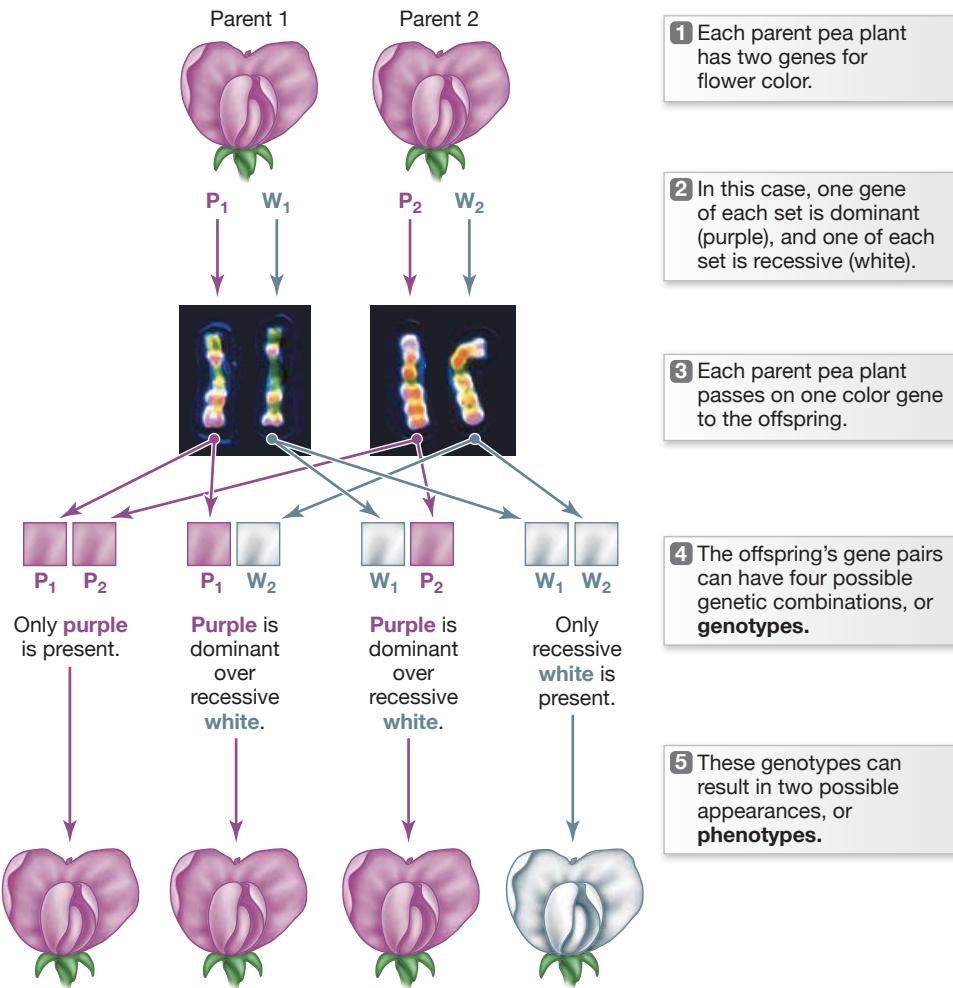
From this pattern, Mendel deduced that the plants contained separate units, now referred to as genes, that existed in different versions (e.g., white and purple). In determining an offspring's features, some of these versions would be dominant and others would be recessive. We now know that a **dominant gene** from either parent is expressed (becomes apparent or physically visible) whenever it is present. A **recessive gene** is expressed only when it is matched with a similar gene from the other parent. In pea plants, white flowers are recessive, so white flowers occur only when the gene for purple flowers is not present. All "white genes" and no purple ones was one of the four possible combinations of white and purple genes in Mendel's experiments.

GENOTYPE AND PHENOTYPE The existence of dominant and recessive genes means that not all genes are expressed. The **genotype** is an organism's genetic makeup. That genetic constitution is determined at the moment of conception and never changes. The **phenotype** is that organism's observable physical characteristics and is always changing.

Genetics, or nature, is one of the two influences on phenotype. So, for instance, in Mendel's experiments, two plants with purple flowers had the same phenotype but might have differed in genotype. Either plant might have had two (dominant) genes for purple. Alternatively, either plant might have had one (dominant) purple gene and

FIGURE 3.46
Genotypes and Phenotypes

Mendel's experiments with cross-breeding pea plants resulted in purple flowers 75 percent of the time and white flowers 25 percent of the time.



one (recessive) white gene (FIGURE 3.46). Environment, or nurture, is the second influence on phenotype. For instance, humans inherit their height and skin color. But good nutrition leads to increased size, and sunlight can change skin color.

POLYGENIC EFFECTS Mendel's flower experiments dealt with single-gene characteristics. Such traits appear to be determined by one gene each. When a population displays a range of variability for a certain characteristic, such as height or intelligence, the characteristic is *polygenic*. In other words, the trait is influenced by many genes (as well as by environment).

Consider human skin color. There are not just three or four separate skin colors. There is a spectrum of colors. The huge range of skin tones among Americans alone shows that human skin color is not inherited the same way as flower color was in Mendel's research. The rich variety of skin colors (phenotype) is not the end product of a single dominant/recessive gene pairing (genotype). Instead, the variety shows the effects of multiple genes.

Genotypic Variation Is Created by Sexual Reproduction

Although they have the same parents, siblings may differ from each other in many ways, such as eye color, height, and personality. These differences occur because each

person has a specific combination of genes. Most cells in the human body contain 23 pairs of chromosomes. These pairs include the sex chromosomes, which are denoted X and Y because of their shapes. Females have two X chromosomes. Males have one X chromosome and one Y (**FIGURE 3.47**).

After one sperm and one egg combine during fertilization, the resulting fertilized cell, known as a *zygote*, contains 23 pairs of chromosomes. Half of each pair of chromosomes comes from the mother, and the other half comes from the father. From any two parents, 8 million different combinations of the 23 chromosomes are possible. The net outcome is that a unique genotype is created at conception, accounting for the *genetic variation* of the human species.

The zygote grows through *cell division*. This process has two stages: First the chromosomes duplicate. Then the cell divides into two new cells with an identical chromosome structure. Cell division is the basis of the life cycle and is responsible for growth and development.

GENETIC MUTATIONS: ADVANTAGEOUS, DISADVANTAGEOUS, OR BOTH?

Errors sometimes occur during cell division, leading to *mutations*, or alterations in the DNA. Most mutations are benign and have little influence on the organism. Occasionally, a genetic mutation produces a selective advantage or disadvantage in terms of survival or reproduction. That is, mutations can be adaptive or maladaptive. The evolutionary significance of such a change in adaptiveness is complex. If a mutation produces an ability or behavior that proves advantageous to the organism, that mutation may spread through the population. The mutation may spread because those who carry the gene are more likely to survive and reproduce.

Consider *industrial melanism*. This phenomenon accounts for the fact that in areas of the world with heavy soot or smog, moths and butterflies tend to be darker in color. What has created this dark coloration? Before industrialization, landscapes (trees, buildings, etc.) were lighter in color. Predators were more likely to spot darker insects against pale backgrounds, so any mutation that led to darker coloring in insects was disadvantageous and was eliminated quickly through natural selection. But with industrialization, pollution darkened the landscapes. Darker coloring in insects therefore became advantageous and more adaptive because the darker insects were harder to see against the darker backgrounds (**FIGURE 3.48**).

What about genetic mutations that are disadvantageous adaptively, such as by leading to disease? Genes that lead to diseases that do not develop until well beyond reproductive age do not have a reproductive disadvantage and are not removed from the population. The dominance or recessiveness of a gene also helps determine if it remains in the gene pool.

For instance, *sickle-cell disease* is a genetic disorder that alters the bloodstream's processing of oxygen. It can lead to pain, organ and bone damage, and anemia. The disease occurs mainly in African Americans: Approximately 8 percent of African Americans are estimated to have the (recessive) gene for it (Centers for Disease Control and Prevention, 2011b). Because the sickle-cell gene is recessive, only those African Americans who receive it from both parents will develop the disease. Those who receive a recessive gene from only one parent have what is called *sickle-cell trait*. They may exhibit symptoms under certain conditions (such as during exercise), but they will have a generally healthy phenotype in spite of a genotype that includes the trait (**FIGURE 3.49**).

Recessive genes do not interfere with most people's health. For this reason, the recessive genes for diseases such as sickle-cell anemia can survive in the gene pool. This particular gene also has some benefit in that it increases resistance to malaria, a parasitic disease prevalent in certain parts of Africa. People with only one sickle-cell

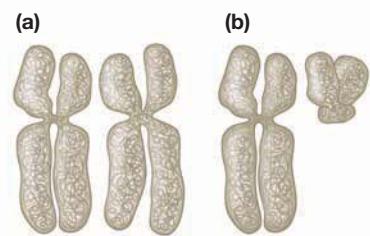


FIGURE 3.47
Sex Chromosomes

(a) In females, the 23rd pair of chromosomes consists of two X chromosomes. (b) In males, the 23rd pair consists of one X and one Y chromosome. The Y chromosome is much smaller than the X chromosome.



FIGURE 3.48
Industrial Melanism

These moths illustrate industrial melanism. As shown here, it is easier to spot light-colored insects against dark backgrounds. Because predators have an easier time catching insects they can spot, darker moths and darker butterflies are better able to survive in more-polluted areas. As a result, the lighter moths and lighter butterflies in those areas tend to die off, leaving more of the moths and butterflies with the selective advantage of darkness.

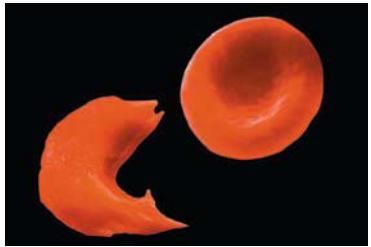


FIGURE 3.49
Sickle-Cell Disease

Sickle-cell disease occurs when people receive recessive genes for the trait from both parents. It causes red blood cells to assume the distinctive "sickle" shape seen here in the left cell. Sickle-cell disease is most common among African Americans.

gene enjoy this resistance without suffering from sickle-cell disease. In contrast to recessive gene disorders like this one, most dominant gene disorders are lethal for most of their carriers and therefore do not last in the gene pool.

Genes Affect Behavior

What determines the kind of person you are? What factors make you more or less bold, intelligent, or able to read a map? Your abilities and your psychological traits are influenced by the interaction of your genes and the environment in which you were raised or to which you are now exposed. The study of how genes and environment interact to influence psychological activity is known as *behavioral genetics*. Behavioral genetics has provided important information about the extent to which biology influences mind, brain, and behavior.

Any research suggesting that abilities to perform certain behaviors are biologically based is controversial. Most people do not want to be told that what they can achieve is limited or promoted by something beyond their control, such as their genes. It is easy to accept that genes control physical characteristics such as sex, race, eye color, and predisposition to diseases such as cancer and alcoholism. But can genes determine whether people will get divorced, how happy they are, or what careers they choose?

Increasingly, science indicates that genes lay the groundwork for many human traits. From this perspective, people are born essentially like undeveloped photographs: The image is already captured, but the way it eventually appears can vary based on the development process. Psychologists study the ways in which characteristics are influenced by nature, nurture, and their combination. In other words, who we are is determined by how our genes are expressed in distinct environments.

BEHAVIORAL GENETICS METHODS Most of us, at one time or another, have marveled at how different siblings can be, even those raised around the same time and in the same household. The differences are to be expected, because most siblings do not share identical genes or identical life experiences. Within the household and outside it, environments differ subtly and not so subtly. Siblings have different birth orders. Their mother may have consumed different foods and other substances during her pregnancies. They may have different friends and teachers. Their parents may treat them differently. Their parents are at different points in their own lives.

It is difficult to know what causes the similarities and differences between siblings, who always share some genes and often share much of their environments. Therefore, behavioral geneticists use two methods to assess the degree to which traits are inherited: twin studies and adoption studies.

Twin studies compare similarities between different types of twins to determine the genetic basis of specific traits. **Monozygotic twins**, or *identical twins*, result from one zygote (fertilized egg) dividing in two. Each new zygote, and therefore each twin, has the same chromosomes and the same genes on each chromosome (**FIGURE 3.50A**). However, monozygotic twins' DNA might not be as identical as long thought, due to subtle differences in how the mother's and father's genes are combined (Bruder et al., 2008). **Dizygotic twins**, sometimes called *fraternal* or *nonidentical twins*, result when two separately fertilized eggs develop in the mother's womb simultaneously. The resulting twins are no more similar genetically than any other pair of siblings (**FIGURE 3.50B**). To the extent that monozygotic twins are more similar than dizygotic twins, the increased similarity is considered most likely due to genetic influence.

Adoption studies compare the similarities between biological relatives and adoptive relatives. Nonbiological adopted siblings may share similar home environments,

monozygotic twins

Also called *identical twins*; twin siblings that result from one zygote splitting in two and therefore share the same genes.

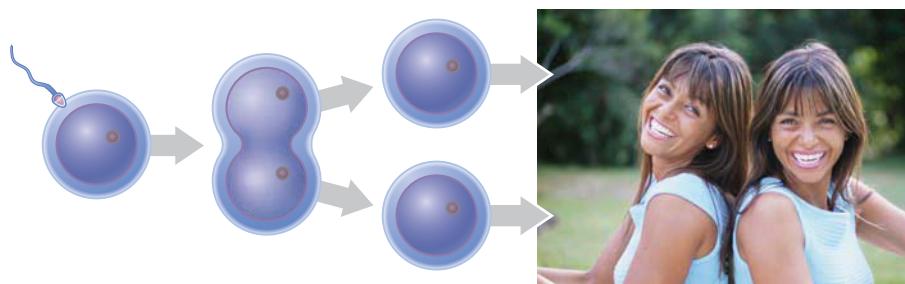
dizygotic twins

Also called *fraternal twins*; twin siblings that result from two separately fertilized eggs and therefore are no more similar genetically than nontwin siblings.

(a) Monozygotic (identical) twins

One sperm fertilizes one egg...

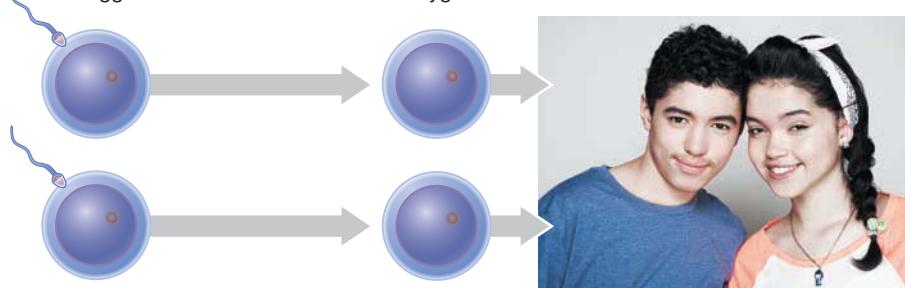
and the zygote splits in two.



(b) Dizygotic (fraternal) twins

Two sperm fertilize two eggs...

which become two zygotes.



but they will have different genes. Therefore, the assumption is that similarities among nonbiological adopted siblings have more to do with environment than with genes.

How much influence would you say your home life has had on you? It turns out that growing up in the same home has relatively little influence on many traits, including personality traits. Indeed, after genetic similarity is controlled for, even biological siblings raised in the same home are no more similar than two strangers plucked at random off the street. (This point is examined in greater detail in Chapter 9, "Human Development," and Chapter 13, "Personality.")

One way to conduct a behavioral genetic study is to compare monozygotic twins who have been *raised together* with ones who were *raised apart*. Thomas Bouchard and his colleagues at the University of Minnesota identified more than 100 pairs of identical and nonidentical twins, some raised together and some raised apart (1990). The researchers examined a variety of these twins' characteristics, including intelligence, personality, well-being, achievement, alienation, and aggression. The general finding from the Minnesota Twin Project was that identical twins, whether they were raised together or not, were likely to be similar (FIGURE 3.51).

Some critics have argued that most of the adopted twins in the Minnesota study were raised in relatively similar environments. This similarity came about, in part, because adoption agencies try to match the child to the adoptive home. However, this argument does not explain the identical twins Oskar Stohr and Jack Yufe, who were born in Trinidad in 1933 (Bouchard, Lykken, McGue, Segal, & Tellegen, 1990). Oskar was raised Catholic in Germany and eventually joined the Nazi Party. Jack was raised Jewish in Trinidad and lived for a while in Israel. Few twins have more-different backgrounds. Yet when they met, at an interview for the study, they were wearing similar clothes, exhibited similar mannerisms, and shared odd habits, such as flushing the toilet before using it, dipping toast in coffee, storing rubber bands on their wrists, and enjoying startling people by sneezing loudly in elevators.

FIGURE 3.50

The Two Kinds of Twins

(a) Monozygotic (identical) twins result when one fertilized egg splits in two. **(b)** Dizygotic (fraternal) twins result when two separate eggs are fertilized at the same time.



FIGURE 3.51

Identical Twins Raised Apart Are Also Similar

Identical twins Gerald Levey and Mark Newman, participants in Dr. Bouchard's study, were separated at birth. Reunited at age 31, they discovered they were both firefighters and had similar personality traits.

Some critics feel that nothing more than coincidence is at work in these case studies. They argue that if a researcher randomly selected any two people of the same age, many surprising similarities would exist in those people and their lives, just by coincidence, even if the people and their lives differed in most other ways. But twins and other relatives share similarities beyond coincidental attributes and behavior quirks. For instance, intelligence and personality traits such as shyness tend to run in families because of strong genetic components.

Moreover, there is some evidence that twins raised apart may be more similar than twins raised together. This phenomenon might occur if parents encouraged individuality in twins raised together by emphasizing different strengths and interests as a way of helping each twin develop as an individual. In effect, the parents would actively create a different environment for each twin.

UNDERSTANDING HERITABILITY *Heredity* is the transmission of characteristics from parents to offspring by means of genes. A term that is often confused with *heredity* but means something different is **heritability**. This term refers to the proportion of the variation in some specific trait in a population, not in an individual, that is due to genetics. That is, the trait cannot be due to environment or random chance.

Consider a specific trait, height, in a particular population, American women. The heritability for a trait depends on the *variation*: the measure of the overall difference among a group of people for that particular trait. To know the heritability of height, we need to know how much individual American women vary in that trait. Once we know the typical amount of variation within the population, we can see whether people who are related—sisters or a mother and daughter—show less variation than women chosen at random.

Say that within the population of American women, height has a heritability of .60. This figure means that 60 percent of the variation in height among American women is genetic. It does not mean that any individual necessarily gets 60 percent of her height from genetics and 40 percent from environment. Heritability estimates aid in identifying the causes of differences between individuals in a population.

For researchers to perform a heritability analysis, there must be variation in the population. For instance, almost everyone has two legs. There is very little variability in the population. More people lose legs through accidents than are born without them. Thus, the heritability value for having two legs is nearly zero, despite the obvious fact that the human genome includes instructions for growing two legs. The key lesson here is: Estimates of heritability are concerned only with the extent that people differ in terms of their genetic makeup within the group. So, the next time you hear that some trait or other is heritable, you need to appreciate that this refers to the distribution of that trait within a group, not to particular persons in that group.

Social and Environmental Contexts Influence Genetic Expression

In a longitudinal study of criminality, Avshalom Caspi and his colleagues (2002) followed a group of more than 1,000 New Zealanders from their births in 1972–73 until adulthood. The group was made up of all the babies that were born in the town of Dunedin over the course of a year. Every few years, the researchers collected enormous amounts of information about the participants and their lives. When the participants were 26 years old, the investigators examined which factors predicted who became a violent criminal.

heritability

A statistical estimate of the extent to which variation in a trait within a population is due to genetics.

Prior research had demonstrated that children who are mistreated by their parents are more likely to become violent offenders. But not all mistreated children become violent, and these researchers wanted to know why not. They hypothesized that the enzyme monoamine oxidase (MAO) is important in determining susceptibility to the effects of mistreatment, because low levels of MAO have been implicated in aggressive behaviors (this connection is discussed further in Chapter 12, “Social Psychology”).

The gene that controls MAO is called MAOA and comes in two forms. One form of the MAOA gene leads to higher levels of MAO, and the other form leads to lower levels. Caspi and colleagues found that boys with the low-MAOA gene appeared to be especially susceptible to the effects of early-childhood mistreatment. Those boys were also much more likely to be convicted of a violent crime than those with the high-MAOA gene. Only 1 in 8 boys was mistreated *and* had the low-MAOA gene. That minority, however, were responsible for nearly half of the violent crimes committed by the group (see “Scientific Thinking: Caspi’s Study of the Influence of Environment and Genes,” on p. 124).

The New Zealand study is a good example of how nature and nurture together affect behavior—in this case, unfortunately, violent behavior. Nature and nurture are inextricably entwined.

EPIGENETICS An exciting new field of genetic study is *epigenetics* (Berger, Kouzarides, Shiekhattar, & Shilatifard, 2009; Holliday, 1987). This term literally means “on top of genetics.” Here, environment is seen as layered over genetics. Epigenetics researchers are looking at the processes by which the environment affects genetic expression. They have found that various environmental exposures do not alter DNA, but they *do* alter DNA expression. That alteration makes it more or less likely that a gene will be expressed. For example, living under stress or consuming a poor diet makes some genes more active and some less active.

According to recent research, these changes in how DNA is expressed can be passed along to future generations (Daxinger & Whitelaw, 2012). The process is somewhat like giving a child a broken toy and saying, “Here is the toy, but it doesn’t work very well.” The child may then give that toy to his or her own child. The biological mechanisms are too complex to consider here. A simple way to think about epigenetic processes is that a parent’s experiences create tags on DNA that tell it when to express, and these tags are passed along with the DNA. They may then be passed along to future generations.

The potential implications of epigenetics for understanding health problems and health benefits are enormous. It is possible that smoking cigarettes or drinking alcohol, like chronic stress or bad nutrition, can create epigenetic tags (Pembrey et al., 2006). Further research will reveal how individuals’ life circumstances might change how their genes operate and how such processes may affect future generations (Grossniklaus, Kelly, Ferguson-Smith, Pembrey, & Lindquist, 2013).

Genetic Expression Can Be Modified

Researchers can employ various gene manipulation techniques to enhance or reduce the expression of a particular gene or even to insert a gene from one animal species into the embryo of another. The researchers can then compare the genetically modified animal with an unmodified one to test theories about the affected gene’s function (**FIGURE 3.52**). Such techniques have dramatically increased our understanding of how gene expression influences thought, feeling, and behavior.

For instance, some of the transgenic mice discussed in Chapter 2 are called *knockouts*. Within these research mice, particular genes have been “knocked out,” or rendered inactive by being removed from the genome or disrupted within the genome. If a gene is important for a specific function, knocking out that gene should interfere



FIGURE 3.52
Genetic Modifications

The two white mice and three brown mice in this photo are genetically normal. The sixth mouse is hairless because it has been genetically modified. Specifically, this mouse has received two *nu* genes, which cause the “nude” mutation. These genes also affect the immune system, so the mouse is a good laboratory subject for studies related to immune function.

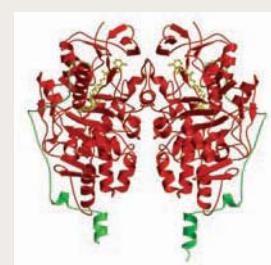
Scientific Thinking

Caspi's Study of the Influence of Environment and Genes

HYPOTHESIS: The MAOA gene regulates enzyme monoamine oxidase (MAO) and may be important in determining susceptibility to the effects of maltreatment, because low levels of MAO have been implicated in aggressive behaviors.

RESEARCH METHOD:

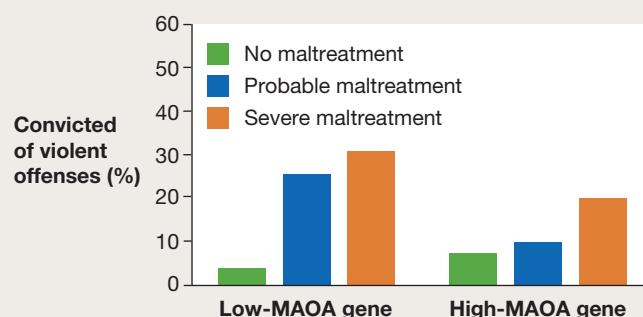
- 1 A group of more than 1,000 New Zealanders were followed from birth to adulthood.
- 2 Researchers measured which children were mistreated by their parents (**nurture**).
- 3 Researchers measured the presence of the MAOA gene, which comes in two forms. One form leads to higher levels of MAO, and the other form leads to lower levels (**nature**).



- 4 Researchers measured the tendency toward criminal behavior.



RESULTS: Those who had the MAOA gene for low MAO activity were much more likely than others to have been convicted of violent crimes if they had been maltreated as children. The effects of maltreatment had less influence on those with the high-MAOA gene.



CONCLUSION: Nature and nurture can work together to affect human behavior.

SOURCE: Caspi, A., McClay, J., Moffit, T. E., Mill, J., Martin, J., Craig, I. W., et al. (2002). Role of genotype in the cycle of violence in maltreated children. *Science*, 29, 851–854.

with the function. This experimental technique has revolutionized genetics, and in recognition the 2007 Nobel Prize was awarded to the three scientists who developed it: Mario Capecchi, Oliver Smithies, and Sir Martin Evans.

One remarkable finding from genetic manipulation is that changing even a single gene can dramatically change behavior. Through various gene manipulations, researchers have created anxious mice, hyperactive mice, mice that cannot learn or remember, mice that groom themselves to the point of baldness, mice that fail to take care of their offspring, and even mice that progressively increase alcohol intake when stressed (Marcus, 2004; Ridley, 2003).

In one study, a gene from the highly social prairie vole was inserted into the developing embryos of normally antisocial mice. The resulting transgenic mice exhibited social behavior more typical of prairie voles than of mice (Insel & Young, 2001). Another study found that knocking out specific genes led mice to forget other mice they had previously encountered. These “knockouts” also failed to investigate new mice placed in their cages, though normal mice would do so readily. In essence, knocking out one gene led to multiple impairments in social recognition (Choleris et al., 2003).

These findings do not indicate that mice have a specific gene for being social. It indicates that—in mice and in humans—changing one gene’s expression leads to the expression or nonexpression of a series of other genes. This effect ultimately influences even complex behaviors. In other words, genes seldom work in isolation to influence mind and behavior. Rather, complex interaction among thousands of genes gives rise to the complexity of human experience.

OPTOGENETICS One problem with most studies of brain function is that they use correlational methods. Recall from Chapter 2 that correlational techniques do not allow us to show causality. For example, fMRI studies show which areas of the brain are most active while a person performs a task. These findings do not mean there is a causal relationship between the brain activity and the task.

To address this limitation, scientists have recently pioneered *optogenetics*. This research technique provides precise control over when a neuron fires. That control enables researchers to better understand the causal relationship between neural firing and behavior. Optogenetics combines the use of light (optics) with gene alterations (Boyden et al., 2005; **FIGURE 3.53**). The genes are altered to change a particular subpopulation of neurons in the brain. Specifically, the membrane ion channels are changed within the neurons (recall that ion channels allow ions to enter the neuron and trigger action potentials). The changes to the membrane ion channels make these specific neurons sensitive to different types of light (e.g., red, green, blue). By inserting fiber optics into that region of the brain and shining a particular type of light, researchers are able to trigger action potentials in the neurons of interest (Williams & Deisseroth, 2013). Using similar techniques, researchers can modify neurons so that firing is inhibited when light is presented (Berndt, Lee, Ramakrishnan, & Deisseroth, 2014).

These techniques allow researchers to show that activating or deactivating specific neurons causes changes in brain activity or behavior. For instance, turning on one set of neurons led animals to act more anxiously (Tye et al., 2011). Turning off another set of neurons reduced cocaine use in animals addicted to that drug (Stefanik et al., 2013).

However, shining a light in a particular brain region will not be used to change human behavior. Rather, the technique allows researchers to better understand the causal relationships between brain activity and behavior. The development of optogenetics is an excellent example of how cutting-edge methods allow researchers to ask increasingly direct questions about biology and behavior.

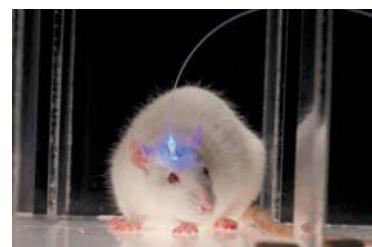


FIGURE 3.53
Optogenetics

This mouse is showing optogenetic display.

Summing Up

What Is the Genetic Basis of Psychological Science?

- Human behavior is influenced by genes.
- People inherit physical attributes and personality traits from their parents.
- The Human Genome Project has mapped the basic sequence of DNA, providing information that will help scientists increase their understanding of individual differences in people's characteristics and develop treatments for genetically based disorders.
- In addition to studying the heritability of traits, researchers study how and when genes are expressed. Genetic expression is affected by environment, including experience.
- Epigenetics is the study of how environment can alter genetic expression.
- Scientific techniques, including the study of transgenic mice and optogenetics, help scientists learn more about how genes and brain activity control behavior.

Measuring Up

1. What is the difference between genotype and phenotype?

- a. Genotype refers to an organism's genetic makeup. Phenotype refers to observable characteristics that result from genetic and environmental influences.
- b. Genotype refers to monozygotic twins' (nearly) identical genetic makeup. Phenotype refers to dizygotic twins' genetic makeup.
- c. Genotypes can be modified by experiences. Phenotypes can be modified only if the underlying genes are knocked out.
- d. Genotypes direct the experiences organisms seek for themselves. Phenotypes cannot affect environmental events.

2. What is the relation between optogenetics and gene manipulation studies?

- a. Gene manipulations and optogenetics alter membrane ion channels so that different neurotransmitters bind with receptors.
- b. Gene manipulations and optogenetics alter membrane ion channels so that optogenetics can trigger neural firing.
- c. Gene manipulations lead to epigenetic changes, but optogenetics does not.
- d. Optogenetic tags are passed to future generations, but gene manipulations are not.

(2) b. Gene manipulations alter membrane ion channels so that optogenetics can trigger neural firing.

Characteristics that result from genetic and environmental influences.

ANSWERS: (1) a. Genotype refers to an organism's genetic makeup. Phenotype refers to observable

Your Chapter Review

Chapter Summary

3.1 How Does the Nervous System Operate?

- **The Nervous System Has Two Basic Divisions:** Nerve cells, or neurons, are the basic units of the human nervous system. Neurons are linked as neural networks, and neural networks are linked together. The entire nervous system is divided into two basic units: the central nervous system (the brain and the spinal cord) and the peripheral nervous system (all the other nerve cells in the rest of the body).
- **Neurons Are Specialized for Communication:** Neurons receive and send electrical and chemical messages. All neurons have the same basic structure, but neurons vary by function and by location in the nervous system.
- **The Resting Membrane Potential Is Negatively Charged:** A neuron at rest is polarized. That is, it has a greater negative electrical charge inside than outside. The passage of negative and positive ions inside and outside the membrane is regulated by ion channels, such as those located at the nodes of Ranvier.
- **Action Potentials Cause Neural Communication:** Changes in a neuron's electrical charge are the basis of an action potential, or neural firing. Firing is the means of communication within networks of neurons.
- **Neurotransmitters Bind to Receptors Across the Synapse:** Neurons do not touch. They release chemicals (neurotransmitters) into the synapse, a small gap between the neurons. Neurotransmitters bind with the receptors of postsynaptic neurons, thus changing the charge in those neurons. Neurotransmitters' effects are halted by reuptake of the neurotransmitters into the presynaptic neurons, by enzyme deactivation, or by autoreception.
- **Neurotransmitters Influence Mental Activity and Behavior:** Neurotransmitters have been identified that influence aspects of the mind and behavior in humans. For example, neurotransmitters influence emotions, motor skills, sleep, dreaming, learning and memory, arousal, pain control, and pain perception. Drugs and toxins can enhance or inhibit the activity of neurotransmitters by affecting their synthesis, their release, and the termination of their action in the synapse.

3.2 What Are the Basic Brain Structures and Their Functions?

- **Scientists Can Now Watch the Working Brain:** Electrophysiology (often using an electroencephalograph, or EEG) measures the brain's electrical activity. Brain imaging is done using positron emission tomography (PET), magnetic resonance imaging (MRI), and functional magnetic resonance imaging (fMRI). Transcranial

magnetic stimulation (TMS) disrupts normal brain activity, allowing researchers to infer the brain processing involved in particular thoughts, feelings, and behaviors.

- **The Brain Stem Houses the Basic Programs of Survival:** The top of the spinal cord forms the brain stem, which is involved in basic functions such as breathing and swallowing. The brain stem includes the medulla, which controls heart rate, breathing, and other autonomic functions. The brain stem also includes the pons and the reticular formation, a network of neurons that influences general alertness and sleep.
- **The Cerebellum Is Essential for Movement:** The cerebellum ("little brain") is the bulging structure connected to the back of the brain stem. This structure is essential for movement and controls balance.
- **Subcortical Structures Control Emotions and Appetitive Behaviors:** The subcortical structures play a key part in psychological processes because they control vital functions (the hypothalamus), relay of sensory information (the thalamus), memories (the hippocampus), emotions (the amygdala), and the planning and production of movement (the basal ganglia).
- **The Cerebral Cortex Underlies Complex Mental Activity:** The lobes of the cortex play specific roles in vision (occipital), touch (parietal), hearing and speech comprehension (temporal), and movement, rational activity, social behavior, and personality (frontal).
- **Splitting the Brain Splits the Mind:** The hemispheres can be split from each other to reveal their primary functions.

3.3 How Does the Brain Communicate with the Body?

- **The Peripheral Nervous System Includes the Somatic and Autonomic Systems:** The somatic system transmits sensory signals and motor signals between the central nervous system and the skin, muscles, and joints. The autonomic system regulates the body's internal environment through the sympathetic division, which responds to alarm, and the parasympathetic division, which returns the body to its resting state.
- **The Endocrine System Communicates Through Hormones:** Endocrine glands produce and release chemical substances. These substances travel to body tissues through the bloodstream and influence a variety of processes, including the stress response and sexual behavior.
- **Actions of the Nervous System and Endocrine System Are Coordinated:** The endocrine system is largely controlled through the actions of the hypothalamus and the pituitary gland. The hypothalamus controls the release of hormones from the pituitary gland. The pituitary controls the release of hormones from other endocrine glands in the body.

3.4 How Does the Brain Change?

- **Experience Fine-Tunes Neural Connections:** Chemical signals influence cell growth and cell function. Experiences, particularly during critical periods, influence cell development and neural connections.
- **Females' and Males' Brains Are Mostly Similar but May Have Revealing Differences:** Females' and males' brains are more similar than different. They are different, however: Males' brains are larger than females' (on average), though larger does not necessarily mean better. Females' brains are organized more bilaterally for language. Men and women may perform the same cognitive task by using different parts of the brain.
- **The Brain Rewires Itself Throughout Life:** Although brain plasticity decreases with age, the brain retains the ability to rewire itself throughout life. This ability is the biological basis of learning. Anomalies in sensation and in perception, such as phantom limb syndrome, are attributed to the cross-wiring of connections in the brain.
- **The Brain Can Recover from Injury:** The brain can reorganize its functions in response to brain damage. However, this capacity decreases with age.

3.5 What Is the Genetic Basis of Psychological Science?

- **All of Human Development Has a Genetic Basis:** Human behavior is influenced by genes. Through genes, people inherit both physical attributes and personality traits from their parents.

Chromosomes are made of genes, and the Human Genome Project has mapped the genes that make up humans' 23 chromosomal pairs.

- **Heredity Involves Passing Along Genes Through Reproduction:** Genes may be dominant or recessive. An organism's genetic constitution is referred to as its genotype. The organism's observable characteristics are referred to as its phenotype. Many characteristics are polygenic.
- **Genotypic Variation Is Created by Sexual Reproduction:** An offspring receives half of its chromosomes from its mother and half of its chromosomes from its father. Because so many combinations of the 23 pairs of chromosomes are possible, there is tremendous genetic variation in the human species. Mutations resulting from errors in cell division also give rise to genetic variation.
- **Genes Affect Behavior:** Behavioral geneticists examine how genes and environment interact to influence psychological activity and behavior. Twin studies and research on adoptees provide insight into heritability.
- **Social and Environmental Contexts Influence Genetic Expression:** Genes and environmental contexts interact in ways that influence observable characteristics. Epigenetics studies how genes may change due to experience.
- **Genetic Expression Can Be Modified:** Genetic manipulation has been achieved in mammals such as mice. Animal studies using gene knockouts, which allow genes to be turned on and off, are valuable tools for understanding genetic influences on behavior and on health. In optogenetics, researchers modify genes to trigger action potentials in neurons.

Key Terms

- | | | |
|--|---|--|
| acetylcholine (ACh), p. 85 | frontal lobes, p. 98 | parasympathetic division, p. 105 |
| action potential, p. 81 | functional magnetic resonance imaging (fMRI), p. 92 | parietal lobes, p. 96 |
| all-or-none principle, p. 82 | GABA, p. 87 | peripheral nervous system (PNS), p. 77 |
| amygdala, p. 95 | gene expression, p. 115 | phenotype, p. 117 |
| autonomic nervous system (ANS), p. 104 | genes, p. 115 | pituitary gland, p. 108 |
| axon, p. 78 | genotype, p. 117 | plasticity, p. 110 |
| basal ganglia, p. 95 | glutamate, p. 87 | positron emission tomography (PET), p. 91 |
| brain stem, p. 93 | gonads, p. 107 | prefrontal cortex, p. 98 |
| Broca's area, p. 90 | heritability, p. 122 | receptors, p. 83 |
| cell body, p. 78 | hippocampus, p. 94 | recessive gene, p. 117 |
| central nervous system (CNS), p. 77 | hormones, p. 106 | resting membrane potential, p. 79 |
| cerebellum, p. 93 | hypothalamus, p. 94 | reuptake, p. 84 |
| cerebral cortex, p. 96 | interneurons, p. 78 | sensory neurons, p. 77 |
| chromosomes, p. 115 | magnetic resonance imaging (MRI), p. 91 | serotonin, p. 86 |
| corpus callosum, p. 96 | monozygotic twins, p. 120 | somatic nervous system (SNS), p. 104 |
| dendrites, p. 78 | motor neurons, p. 78 | split brain, p. 100 |
| dizygotic twins, p. 120 | myelin sheath, p. 82 | sympathetic division, p. 105 |
| dominant gene, p. 117 | neurons, p. 76 | synapse, p. 79 |
| dopamine, p. 87 | neurotransmitters, p. 83 | temporal lobes, p. 98 |
| electroencephalograph (EEG), p. 91 | nodes of Ranvier, p. 82 | terminal buttons, p. 79 |
| endocrine system, p. 106 | norepinephrine, p. 86 | thalamus, p. 94 |
| endorphins, p. 88 | occipital lobes, p. 96 | transcranial magnetic stimulation (TMS), p. 92 |

Practice Test

1. Which label accurately describes neurons that detect information from the physical world and pass that information along to the brain?
 - a. motor neuron
 - b. sensory neuron
 - c. interneuron
 - d. glia
2. Parkinson's disease is associated with the loss of neurons that produce which of the following neurotransmitters?
 - a. acetylccholine
 - b. norepinephrine
 - c. dopamine
 - d. serotonin
3. Drugs can produce the following actions on neurotransmitter activity. Label each example as either an agonist or antagonist effect.
 - a. mimic the neurotransmitter and activate the postsynaptic receptor
 - b. block the reuptake of neurotransmitter
 - c. decrease neurotransmitter release
 - d. clear neurotransmitter from the synapse
4. Which of the following statements about behavioral genetics is false?
 - a. Heritability refers to traits passed from parent to offspring.
 - b. Similarities among nonbiological adopted siblings are inferred to reflect environmental influences.
 - c. Identical twins raised apart are often more similar than identical twins raised together.
 - d. Greater similarities between monozygotic twins compared to dizygotic twins are inferred to reflect genetic influences.
5. In what order are incoming signals processed by a neuron? Place a 1, 2, 3, or 4 in front of each of the following parts of a neuron.
 soma
 terminal buttons
 dendrites
 axon
6. Which statement about the resting membrane potential is false?
 - a. The inside of the neuron is negatively charged relative to the outside.
 - b. The cell membrane allows more sodium than potassium ions to cross easily.
 - c. Action of the sodium-potassium pump results in more potassium inside the neuron.
 - d. The polarization of charge creates the electrical energy that powers the action potential.
7. Which of the following techniques can provide information about whether a particular brain region is necessary for a task?
 - a. electroencephalograph (EEG)
 - b. functional magnetic resonance imaging (fMRI)
 - c. positron emission tomography (PET)
 - d. transcranial magnetic stimulation (TMS)
8. Which statement about split-brain patients is true?
 - a. They have had surgery to therapeutically remove one hemisphere of the brain.
 - b. The left hemisphere can perceive stimuli, but the right hemisphere cannot.
 - c. The left hemisphere can verbally report its perception. The right hemisphere cannot articulate what it saw but can act on its perception.
 - d. The left hemisphere is analytical, and the right hemisphere is creative.

The answer key for the Practice Tests can be found at the back of the book.