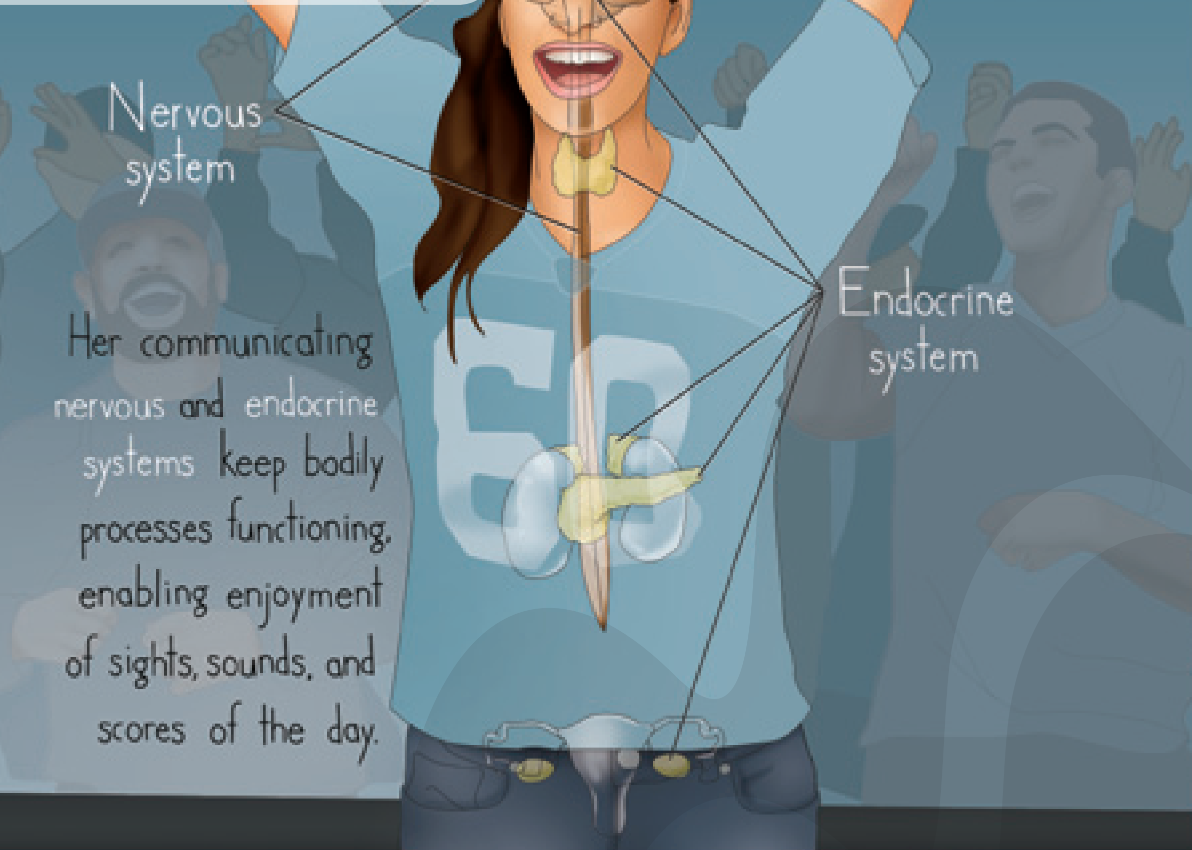
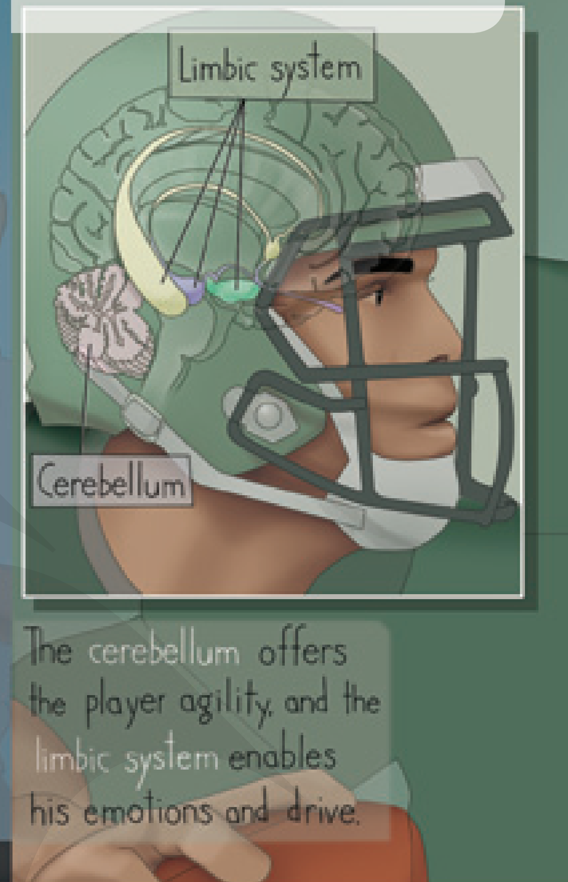
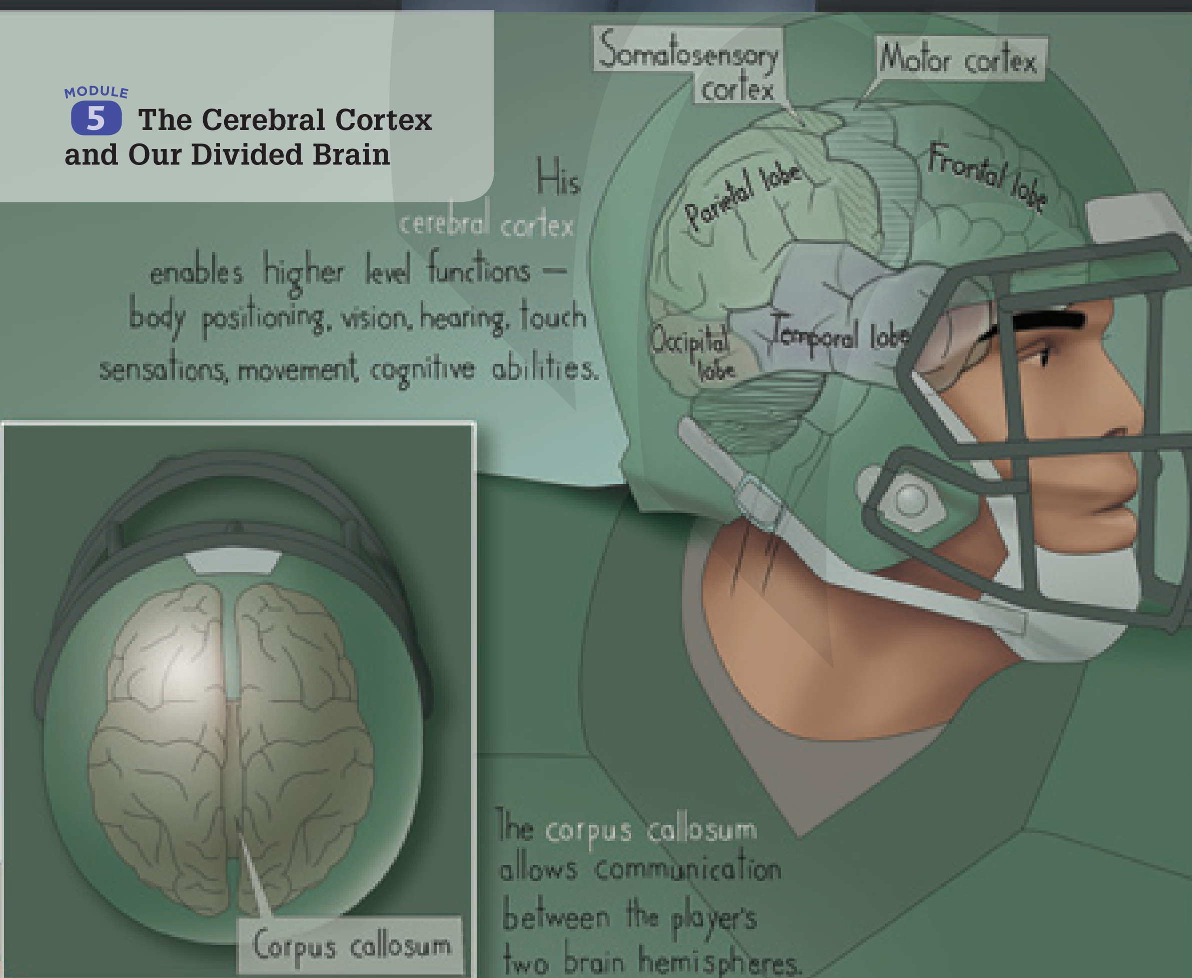
MODULE 3 Neural and Hormonal Systems



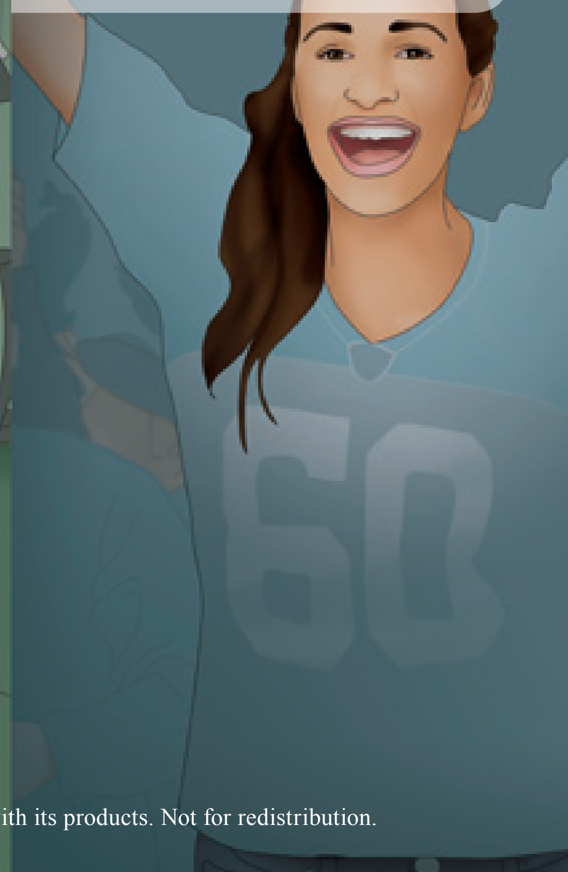
MODULE 4 Tools of Discovery and Older Brain Structures

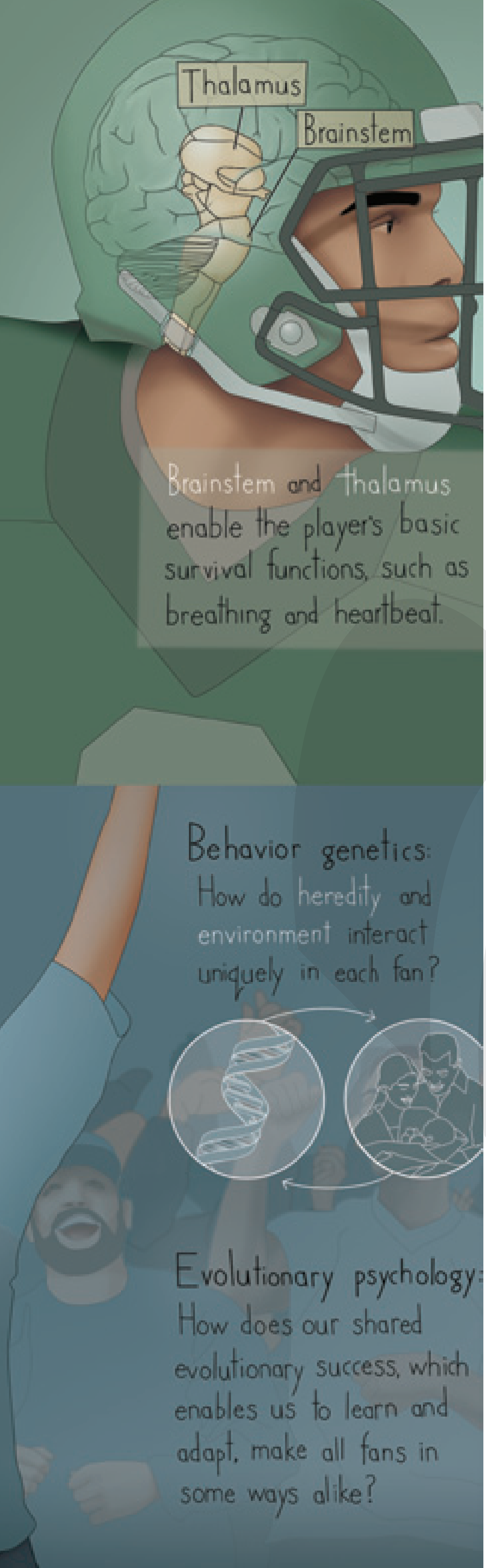


MODULE 5 The Cerebral Cortex and Our Divided Brain



MODULE 6 Genetics, Evolutionary Psychology, and Behavior





The Biology of Behavior

IN 2000, a Virginia teacher began collecting sex magazines, visiting child pornography websites, and then making subtle advances on his young stepdaughter. When his wife called the police, he was arrested and later convicted of child molestation. Though put into a sexual addiction rehabilitation program, he still felt overwhelmed by his sexual urges. The day before being sentenced to prison, he went to his local emergency room complaining of a headache and thoughts of suicide. He was also distraught over his uncontrollable impulses, which led him to proposition nurses.

A brain scan located the problem—in his mind's biology. Behind his right temple there was an egg-sized brain tumor. After surgeons removed the tumor, his lewd impulses faded and he returned home to his wife and stepdaughter. All was well until a year later, when the tumor partially grew back, and with it the sexual urges. A second tumor removal again lessened the urges (Burns & Swerdlow, 2003).

This case illustrates what you likely believe: that you reside in your head. If surgeons transplanted all your organs below your neck, and even your skin and limbs, you would *(Yes?)* still be you. An acquaintance of mine [DM's] received a new heart from a woman who, in a rare operation, had received a matched heart-lung transplant. When the two chanced to meet in their hospital ward, she introduced herself: "I think you have my heart." But only her heart. Her self, she assumed, still resided in her head. We rightly presume that our brain enables our mind.

Indeed, no principle is more central to today's psychology than this: *Everything psychological is simultaneously biological*. Throughout this book, you will find examples of this interplay.

In Modules 3 through 5, we start small and build from the bottom up—from nerve cells up to the brain. In Module 6, we consider how our genetic histories predispose our shared human nature, and, in combination with our environments, our individual differences.

MODULE 3 Neural and Hormonal Systems

3-1 Why are psychologists concerned with human biology?

Your every idea, every mood, every urge is a biological happening. You love, laugh, and cry with your body. Without your body—your genes, your brain, your appearance—you would, indeed, be nobody. **Biological psychologists** study the links between our biology and behavior. We find it convenient and intuitive to talk separately of biological and psychological influences on behavior (Forstmann & Burgmer, 2015). But we need to remember that to think, feel, or act without a body would be like running without legs.

Neural Communication

For scientists, it is a happy fact of nature that the information systems of humans and other animals operate similarly—so much so that you could not distinguish between small samples of brain tissue from a human and a monkey. This similarity allows researchers to study relatively simple animals to discover how our neural systems operate. Cars differ, but all have engines, accelerators, steering wheels, and brakes. A space alien could study any one of them and grasp the operating principles. Likewise, animals differ, yet their nervous systems operate similarly. Though the human brain is more complex than a rat's, both follow the same principles.

Neurons

3-2 What are neurons, and how do they transmit information?

Our body's neural information system is complexity built from simplicity. Its building blocks are **neurons,** or nerve cells. Throughout life, new neurons are born and unused neurons wither away (Shors, 2014). To fathom our thoughts and actions, our memories and moods, we must first understand how neurons work and communicate.

Neurons differ, but all are variations on the same theme (**FIGURE 3.1**). Each consists of a *cell body* and its branching fibers. The often bushy **dendrite** fibers receive information and conduct it toward the cell body. From there, the cell's single lengthy **axon** fiber passes the message through its terminal branches to other neurons or to muscles or glands. (See **FIGURE 3.2**.) Dendrites listen. Axons speak.

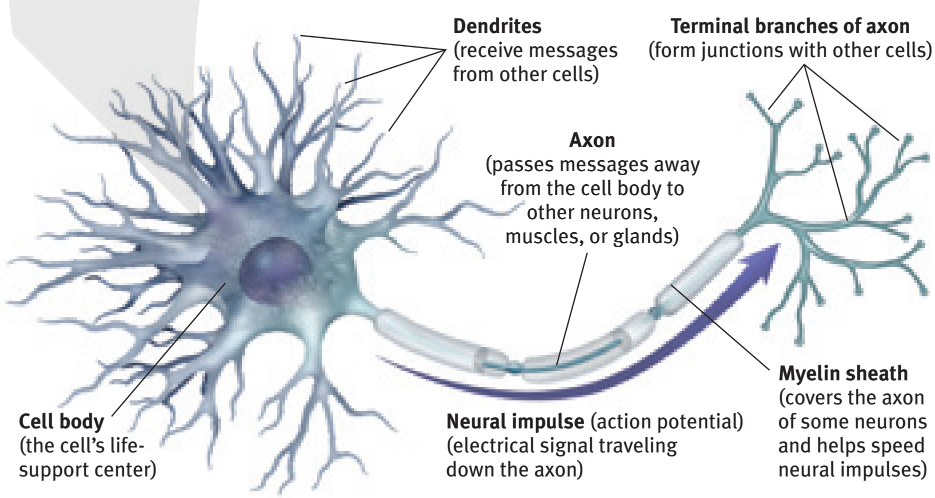
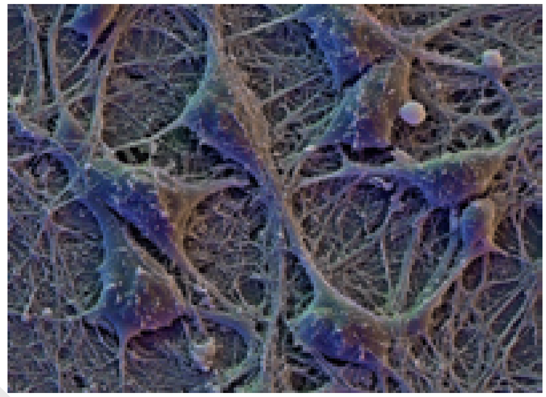


FIGURE 3.1 A motor neuron

Unlike the short dendrites, axons may be very long, projecting several feet through the body. A human neuron carrying orders to a leg muscle, for example, has a cell body and axon roughly on the scale of a basketball attached to a 4-mile-long rope. Much as home electrical wire is insulated, some axons are encased in a **myelin sheath,** a layer of fatty tissue that insulates them and speeds their impulses. As myelin is laid down up to about age 25, neural efficiency, judgment, and self-control grow (Fields, 2008). If the myelin sheath degenerates, *multiple sclerosis* results: Communication to muscles slows, with eventual loss of muscle control.

Supporting our billions of nerve cells are spidery **glial cells** ("glue cells"). Neurons are like queen bees; on their own they cannot feed or sheathe themselves. Glial cells are worker bees. They provide nutrients and insulating myelin, guide neural connections, and clean up after neurons send messages to one another. Glia also play a role in learning and thinking. By "chatting" with neurons they participate in information transmission and memory (Fields, 2011, 2013; Miller, 2005).

In more complex animal brains, the proportion of glia to neurons increases. A postmortem analysis of Albert Einstein's brain did not find more or larger-than-usual neurons, but it did reveal a much greater concentration of glial cells than found in an average Albert's head (Fields, 2004).



David Scharf/Science Source

FIGURE 3.2

Neurons communicating When we learn about neurons, we often see them one at a time to learn their parts. But our billions of neurons exist in a vast and dense interconnected web. One neuron's terminal branches send messages to neighboring dendrites. Read on to learn more about this complex and fascinating electrochemical communication process.

The Neural Impulse

Neurons transmit messages when stimulated by signals from our senses or when triggered by chemical signals from neighboring neurons. A neuron sends a message by firing an impulse, called the **action potential**—a brief electrical charge that travels down its axon.

Depending on the type of fiber, a neural impulse travels at speeds ranging from a sluggish 2 miles per hour to more than 200 miles per hour. But even its top speed is 3 million times slower than that of electricity through a wire. We measure brain activity in milliseconds (thousandths of a second) and computer activity in nanoseconds (billionths of a second). Thus, unlike the nearly instantaneous reactions of a computer, your reaction to a sudden event, such as a child darting in front of your car, may take a quarter-second or more. Your brain is vastly more complex than a computer but slower at executing simple responses. And if you were an elephant—whose round-trip message travel time from a yank on the tail to the brain and back to the tail is 100 times longer than that of a tiny shrew—your reflexes would be slower yet (More et al., 2010).

Like batteries, neurons generate electricity from chemical events. In the neuron's chemistry-to-electricity process, *ions* (electrically charged atoms) are exchanged. The fluid outside an axon's membrane has mostly positively charged sodium ions. A resting axon's fluid interior (which includes both large, negatively charged protein ions and smaller, positively charged potassium ions) has a mostly negative charge. Like a tightly guarded facility, the axon's surface is selective about what it allows through its doors. We say the axon's surface is *selectively permeable*. This positive-outside/negative-inside state is called the *resting potential* (measured at about –70 mV [millivolts]; see **FIGURE 3.3** on the next page).

When a neuron fires, the first section of the axon opens its gates, rather like a sewer cover flipping open, and positively charged sodium ions (attracted to the negative interior) flood in through the now-open channels (Figure 3.3 on the next page). The loss of the inside/outside charge difference, called *depolarization,* causes the next section of axon channels to open, and then the next, like a line of falling dominos. This temporary inflow of positive ions is the neural impulse—the action potential (measured at about +40 mV). Each neuron is itself a miniature decision-making device performing complex calculations as it receives signals from hundreds, even thousands, of other neurons. The mind boggles when

biological psychology the scientific study of the links between biological (genetic, neural, hormonal) and psychological processes. (Some biological psychologists call themselves *behavioral neuroscientists, neuropsychologists, behavior geneticists, physiological psychologists,* or *biopsychologists*.)

neuron a nerve cell; the basic building block of the nervous system.

dendrites a neuron's often bushy, branching extensions that receive messages and conduct impulses toward the cell body.

axon the neuron extension that passes messages through its branches to other neurons or to muscles or glands.

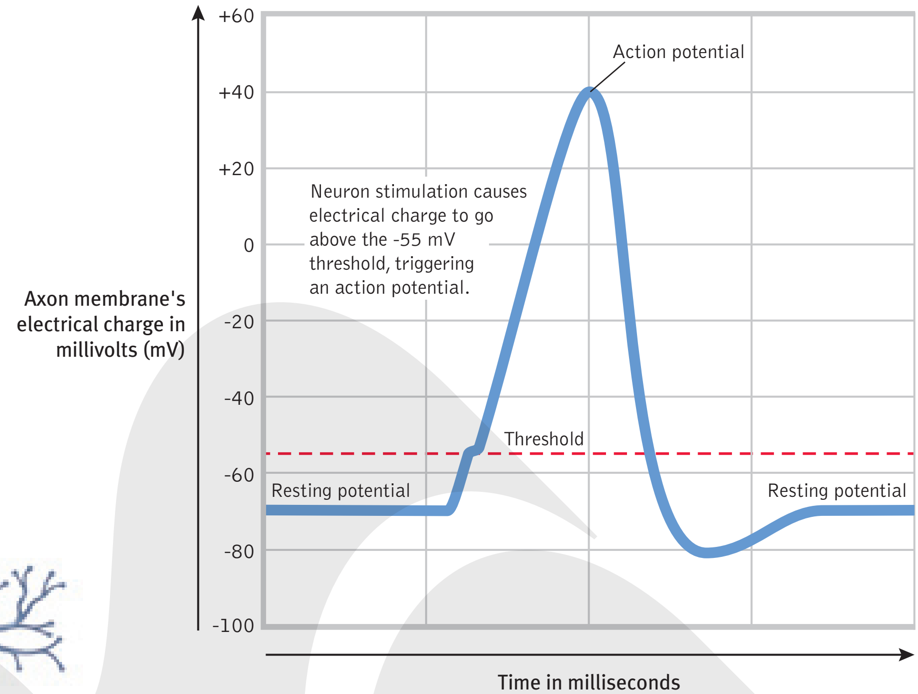
myelin [MY-uh-lin] sheath a fatty tissue layer segmentally encasing the axons of some neurons; enables vastly greater transmission speed as neural impulses hop from one node to the next.

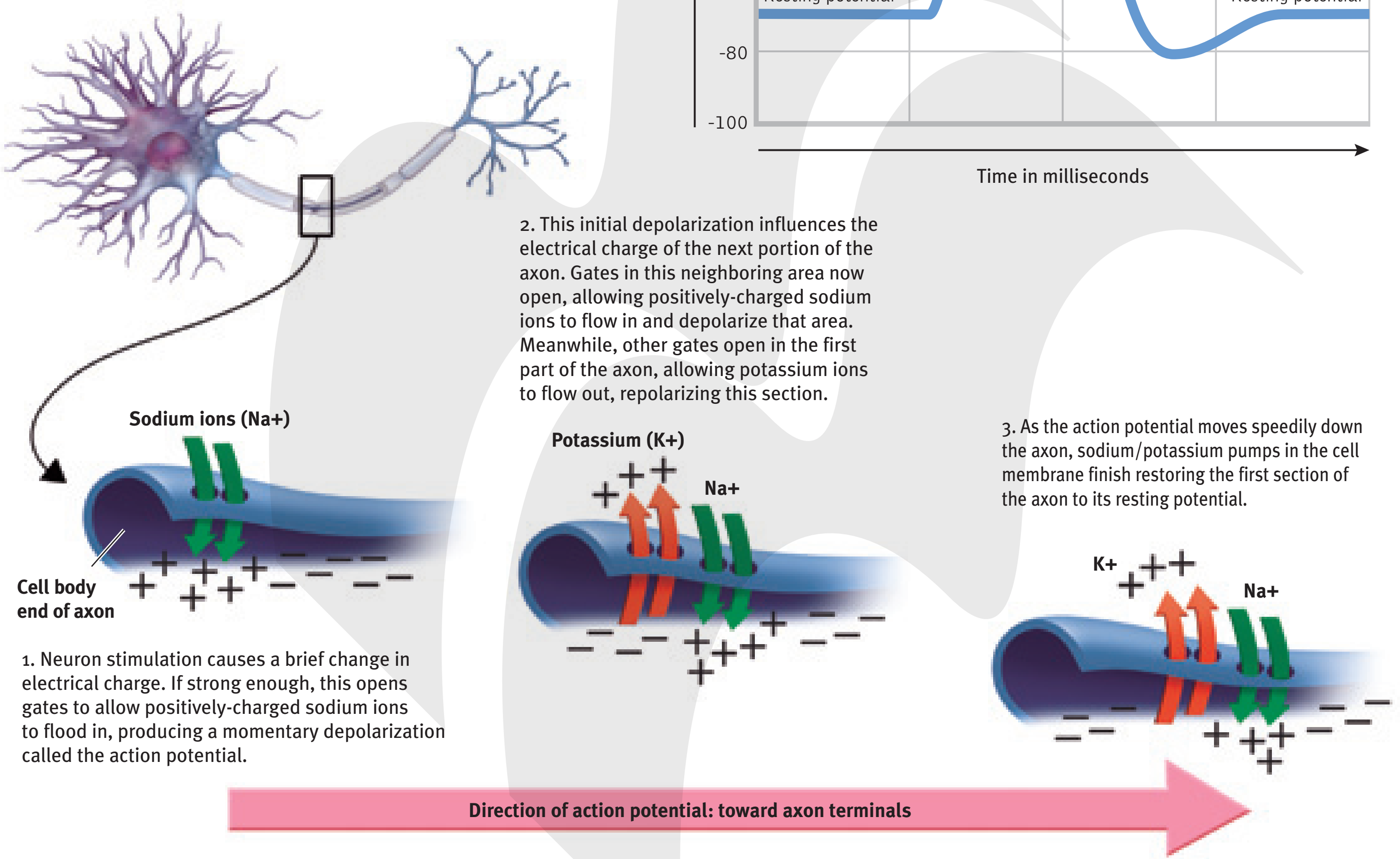
glial cells (glia) cells in the nervous system that support, nourish, and protect neurons; they may also play a role in learning, thinking, and memory.

action potential a neural impulse; a brief electrical charge that travels down an axon.

FIGURE 3.3

Action potential Bodily sensations and actions—detecting a hug or kicking a soccer ball—happen when our neurons are stimulated enough that their membrane's electrical charge reaches a threshold (–55 mV in this example—see graph at right). This prompts each of those neurons to "fire" an impulse—an action potential—which travels down its axon (see numbered drawings below) and transmits a message to other neurons, muscles, or glands.





imagining this electrochemical process repeating up to 100 or even 1000 times a second. But this is just the first of many astonishments.

Most neural signals are *excitatory,* somewhat like pushing a neuron's accelerator. Some are *inhibitory,* more like pushing its brake. If excitatory signals exceed the inhibitory signals by a minimum intensity, or **threshold** (about –55 mV; see Figure 3.3), the combined signals trigger an action potential. (Think of it this way: If the excitatory party animals outvote the inhibitory party poopers, the party's on.) The action potential then travels down the axon, which branches into junctions with hundreds or thousands of other neurons or with the body's muscles and glands.

"What one neuron tells another neuron is simply how much it is excited."

Francis Crick,
The Astonishing Hypothesis, 1994

Neurons need tiny breaks between action potentials. During a resting pause called the **refractory period,** subsequent action potentials cannot occur until the axon returns to its resting state. Then the neuron can fire again.

Increasing the level of stimulation above the threshold will not increase the neural impulse's intensity. The neuron's reaction is an **all-or-none response:** Like guns, neurons either fire or they don't. How, then, do we detect the intensity of a stimulus? How do we distinguish a gentle touch from a big hug? A strong stimulus can trigger *more* neurons to fire, and to fire more often. But it does not affect the action potential's strength or speed. Squeezing a trigger harder won't make a bullet go faster.

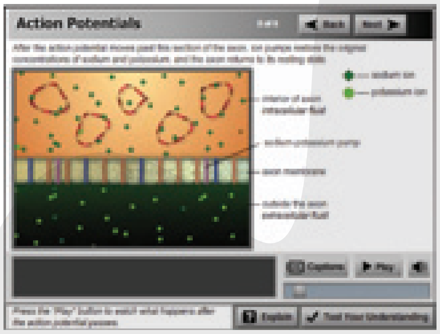
threshold the level of stimulation required to trigger a neural impulse.

refractory period a brief resting pause that occurs after a neuron has fired; subsequent action potentials cannot occur until the axon returns to its resting state.

all-or-none response a neuron's reaction of either firing (with a full-strength response) or not firing.

synapse [SIN-aps] the junction between the axon tip of the sending neuron and the dendrite or cell body of the receiving neuron. The tiny gap at this junction is called the *synaptic gap* or *synaptic cleft*.

LaunchPad For an animated explanation of this process, visit LaunchPad's *Concept Practice: Action Potentials.*



RETRIEVE IT

- When a neuron fires an action potential, the information travels through the axon, the dendrites, and the cell body, but not in that order. Place these three structures in the correct order.

ANSWER: dendrites, cell body, axon

- How does our nervous system allow us to experience the difference between a slap and a tap on the back?

ANSWER: Stronger stimuli (the slap) cause more neurons to fire and to fire more frequently than happens with weaker stimuli (the tap).

How Neurons Communicate

3-3 How do nerve cells communicate with other nerve cells?

Neurons interweave so intricately that even with a microscope you would have trouble seeing where one neuron ends and another begins. Scientists once believed that the axon of one cell fused with the dendrites of another in an uninterrupted fabric. Then British physiologist Sir Charles Sherrington (1857–1952) noticed that neural impulses were taking an unexpectedly long time to travel a neural pathway. Inferring that there must be a brief interruption in the transmission, Sherrington called the meeting point between neurons a **synapse.**

We now know that the axon terminal of one neuron is in fact separated from the receiving neuron by a *synaptic gap (or synaptic cleft)* less than a millionth of an inch wide. Spanish anatomist Santiago Ramón y Cajal (1852–1934) marveled at these near-unions of neurons, calling them "protoplasmic kisses." "Like elegant ladies air-kissing so as not to muss their makeup, dendrites and axons don't quite touch," noted poet Diane Ackerman (2004, p. 37). How do the neurons execute this protoplasmic kiss, sending information across the tiny synaptic gap? The answer is one of the important scientific discoveries of our age.

"All information processing in the brain involves neurons 'talking to' each other at synapses."

Neuroscientist Solomon H. Snyder (1984)

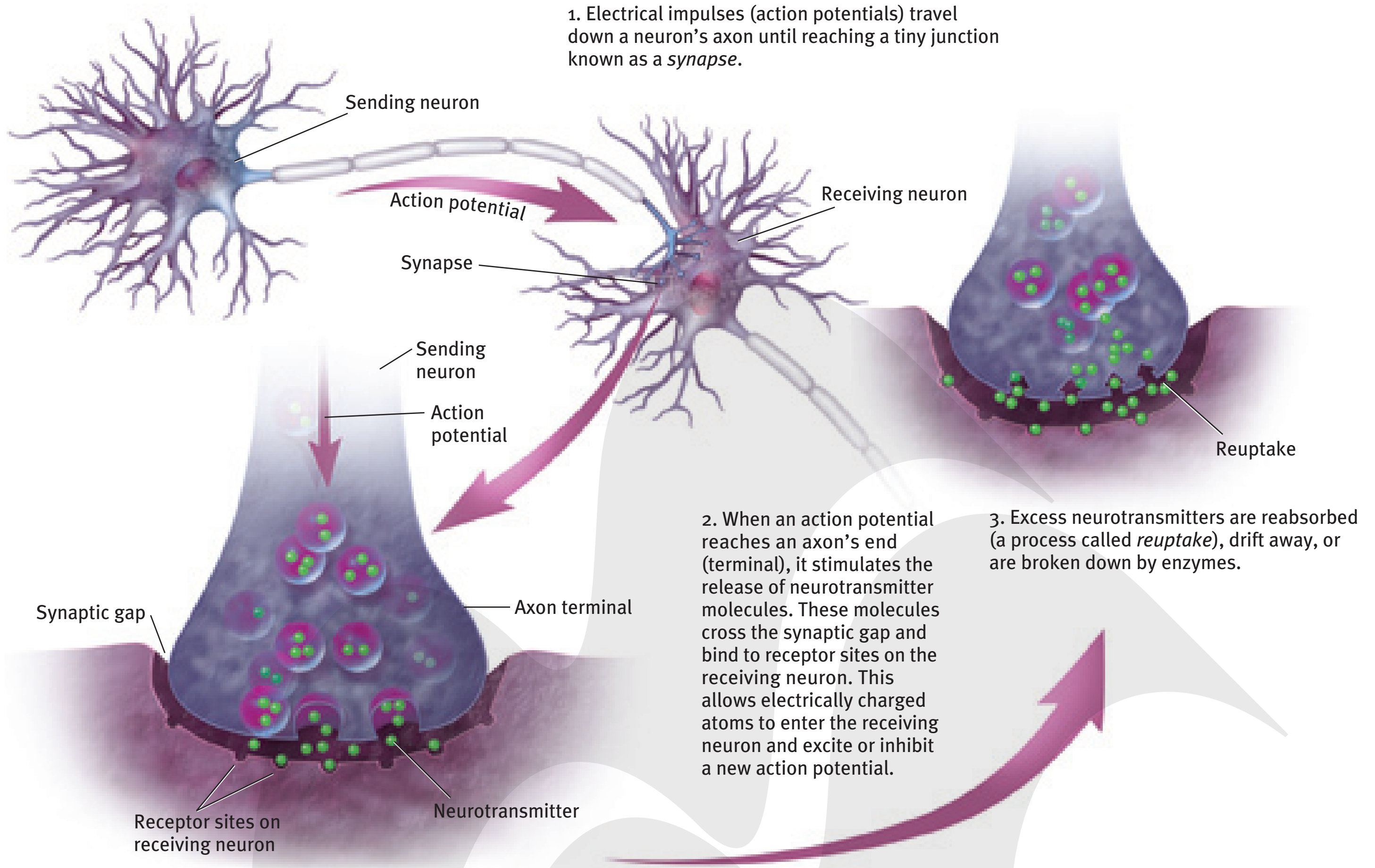


FIGURE 3.4
How neurons communicate

When an action potential reaches the knob-like terminals at an axon's end, it triggers the release of chemical messengers, called **neurotransmitters** (**FIGURE 3.4**). Within 1/10,000th of a second, the neurotransmitter molecules cross the synaptic gap and bind to receptor sites on the receiving neuron—as precisely as a key fits a lock. For an instant, the neurotransmitter unlocks tiny channels at the receiving site, and electrically charged atoms flow in, exciting or inhibiting the receiving neuron's readiness to fire. The excess neurotransmitters then drift away, are broken down by enzymes, or are reabsorbed by the sending neuron—a process called **reuptake.**

RETRIEVE IT

- What happens in the *synaptic gap?*

ANSWER: Neurons send neurotransmitters (chemical messengers) across this tiny space between one neuron's terminal branch and the next neuron's dendrite or cell body.

- What is *reuptake?* What two other things can happen to excess neurotransmitters after a neuron reacts?

ANSWER: Reuptake occurs when excess neurotransmitters are reabsorbed by the sending neuron. They can also drift away or be broken down by enzymes.

neurotransmitters chemical messengers that cross the synaptic gaps between neurons. When released by the sending neuron, neurotransmitters travel across the synapse and bind to receptor sites on the receiving neuron, thereby influencing whether that neuron will generate a neural impulse.

reuptake a neurotransmitter's reabsorption by the sending neuron.

endorphins [en-DOR-fins] "morphine within"—natural, opiate-like neurotransmitters linked to pain control and to pleasure.

How Neurotransmitters Influence Us

3-4 How do neurotransmitters influence behavior, and how do drugs and other chemicals affect neurotransmission?

In their quest to understand neural communication, researchers have discovered several dozen neurotransmitters and almost as many new questions: Are certain neurotransmitters found only in specific places? How do neurotransmitters affect our moods, memories, and mental abilities? Can we boost or diminish these effects through drugs or diet?

Other modules explore neurotransmitter influences on hunger and thinking, depression and euphoria, addictions and therapy. For now, let's glimpse how neurotransmitters influence our motions and emotions. Particular neurotransmitters affect specific behaviors and emotions (**TABLE 3.1**).

One of the best-understood neurotransmitters, *acetylcholine (ACh)*, plays a role in learning and memory. In addition, it is the messenger at every junction between motor neurons (which carry information from the brain and spinal cord to the body's tissues) and skeletal muscles. When ACh is released to our muscle cell receptors, the muscle contracts. If ACh transmission is blocked, as happens during some kinds of anesthesia and with some poisons, the muscles cannot contract and we are paralyzed.

Candace Pert and Solomon Snyder (1973) made an exciting discovery about neurotransmitters when they attached a radioactive tracer to morphine, showing where it was taken up in an animal's brain. The morphine, an opiate drug that elevates mood and eases pain, bound to receptors in areas linked with mood and pain sensations. But why would the brain have these "opiate receptors"? Why would it have a chemical lock, unless it also had a natural key to open it?

Researchers soon confirmed that the brain does indeed produce its own naturally occurring opiates. Our body releases several types of neurotransmitter molecules similar to morphine in response to pain and vigorous exercise. These **endorphins** (short for *endo*genous [produced within] m*orphine*) help explain good feelings such as the "runner's high" (Boecker et al., 2008), the painkilling effects of acupuncture, and the indifference to pain in some severely injured people. But once again, new knowledge led to new questions.

"When it comes to the brain, if you want to see the action, follow the neurotransmitters."

Neuroscientist Floyd Bloom (1993)

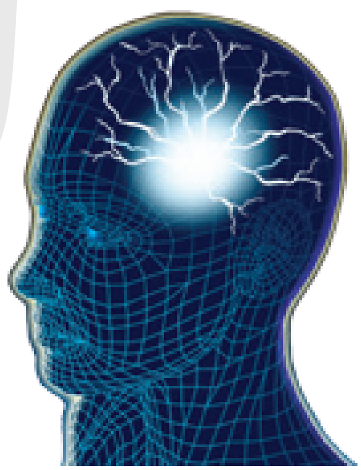
Physician Lewis Thomas, on the endorphins: "There it is, a biologically universal act of mercy. I cannot explain it, except to say that I would have put it in had I been around at the very beginning, sitting as a member of a planning committee."

The Youngest Science, *1983*

TABLE 3.1

Some Neurotransmitters and Their Functions

Neurotransmitter	Function	Examples of Malfunctions
Acetylcholine (ACh)	Enables muscle action, learning, and memory	With Alzheimer's disease, ACh-producing neurons deteriorate.
Dopamine	Influences movement, learning, attention, and emotion	Oversupply linked to schizophrenia. Undersupply linked to tremors and decreased mobility in Parkinson's disease.
Serotonin	Affects mood, hunger, sleep, and arousal	Undersupply linked to depression. Some drugs that raise serotonin levels are used to treat depression.
Norepinephrine	Helps control alertness and arousal	Undersupply can depress mood.
GABA (gamma-aminobutyric acid)	A major inhibitory neurotransmitter	Undersupply linked to seizures, tremors, and insomnia.
Glutamate	A major excitatory neurotransmitter; involved in memory	Oversupply can overstimulate brain, producing migraines or seizures (which is why some people avoid MSG, monosodium glutamate, in food).
Endorphins	Neurotransmitters that influence the perception of pain or pleasure	Oversupply with opiate drugs can suppress the body's natural endorphin supply.



LiquidLibrary/Getty Images

HOW DRUGS AND OTHER CHEMICALS ALTER NEUROTRANSMISSION If indeed the endorphins lessen pain and boost mood, why not flood the brain with artificial opiates, thereby intensifying the brain's own "feel-good" chemistry? But there is a problem: When flooded with opiate drugs such as heroin and morphine, the brain, to maintain its chemical balance, may stop producing its own natural

agonist a molecule that increases a neurotransmitter's action.

antagonist a molecule that inhibits or blocks a neurotransmitter's action.

nervous system the body's speedy, electrochemical communication network, consisting of all the nerve cells of the peripheral and central nervous systems.

central nervous system (CNS) the brain and spinal cord.

peripheral nervous system (PNS) the sensory and motor neurons that connect the central nervous system (CNS) to the rest of the body.

nerves bundled axons that form neural cables connecting the central nervous system with muscles, glands, and sense organs.

sensory (afferent) neurons neurons that carry incoming information from the sensory receptors to the brain and spinal cord.

LaunchPad For an illustrated review of neural communication, visit LaunchPad's *PsychSim 6: Neural Messages*.

opiates. When the drug is withdrawn, the brain may then be deprived of any form of opiate, causing intense discomfort. For suppressing the body's own neurotransmitter production, nature charges a price.

Drugs and other chemicals affect brain chemistry, often by either exciting or inhibiting neurons' firing. **Agonist** molecules increase a neurotransmitter's action. Agonists may increase the production or release of neurotransmitters, or block reuptake in the synapse. Other agonists may be similar enough to a neurotransmitter to bind to its receptor and mimic its excitatory or inhibitory effects. Some opiate drugs are agonists and produce a temporary "high" by amplifying normal sensations of arousal or pleasure.

Antagonists decrease a neurotransmitter's action by blocking production or release. Botulin, a poison that can form in improperly canned food, causes paralysis by blocking ACh release. (Small injections of botulin—Botox—smooth wrinkles by paralyzing the underlying facial muscles.) These antagonists are enough like the natural neurotransmitter to occupy its receptor site and block its effect, but are not similar enough to stimulate the receptor (rather like foreign coins that fit into, but won't operate, a candy machine). Curare, a poison some South American Indians have applied to hunting-dart tips, occupies and blocks ACh receptor sites on muscles, producing paralysis in their prey.

RETRIEVE IT

- Serotonin, dopamine, and endorphins are all chemical messengers called ________________.

ANSWER: neurotransmitters

- Curare poisoning paralyzes its victims by blocking ACh receptors involved in muscle movements. Morphine mimics endorphin actions. Which is an agonist, and which is an antagonist?

ANSWER: Morphine is an agonist; curare is an antagonist.

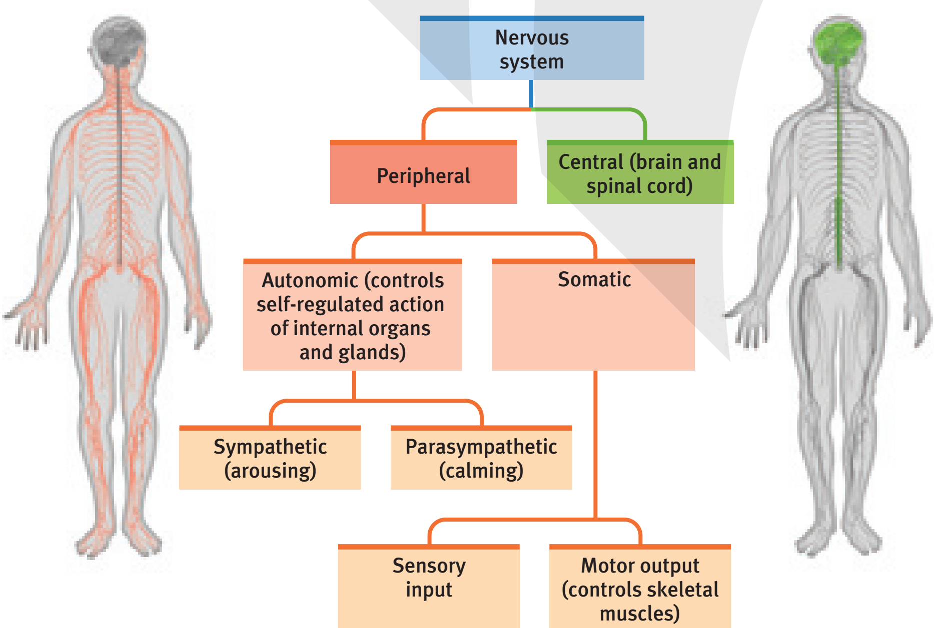
The Nervous System

3-5 What are the functions of the nervous system's main divisions, and what are the three main types of neurons?

All those neurons communicating with neurotransmitters make up our body's **nervous system** (**FIGURE 3.5**). This communication network allows us to take in information from the world and the body's tissues, to make decisions, and to send back information and orders to the body's tissues. A quick overview: The brain and spinal cord form the **central nervous system (CNS),** the body's decision maker. The **peripheral nervous system (PNS)** is responsible for gathering information and for transmitting CNS decisions to other body parts. **Nerves,** electrical cables formed of bundles of axons, link the CNS with the body's sensory receptors, muscles, and glands. The optic nerve, for example, bundles a million axons into a single cable carrying the messages each eye sends to the brain (Mason & Kandel, 1991).

Information travels in the nervous system through three types of neurons. **Sensory neurons** carry messages from the body's tissues and sensory receptors inward (thus, they are *afferent*) to

FIGURE 3.5
The functional divisions of the human nervous system



the brain and spinal cord for processing. **Motor neurons** (which are *efferent*) carry instructions from the central nervous system out to the body's muscles and glands. Between the sensory input and motor output, information is processed via the **interneurons.** Our complexity resides mostly in these interneurons. Our nervous system has a few million sensory neurons, a few million motor neurons, and billions and billions of interneurons.

The Peripheral Nervous System

Our peripheral nervous system has two components—somatic and autonomic. Our **somatic nervous system** enables voluntary control of our skeletal muscles. As you reach the end of this page, your somatic nervous system will report to your brain the current state of your skeletal muscles and carry instructions back, triggering a response from your hand so you can read on.

Our **autonomic nervous system (ANS)** controls our glands and our internal organ muscles. The ANS influences functions such as glandular activity, heartbeat, and digestion. (*Autonomic* means "self-regulating.") Like an automatic pilot, this system may be consciously overridden, but usually it operates on its own (autonomously).

The autonomic nervous system serves two important functions (**FIGURE 3.6**). The **sympathetic nervous system** arouses and expends energy. If something alarms or challenges you (such as a longed-for job interview), your sympathetic

motor (efferent) neurons neurons that carry outgoing information from the brain and spinal cord to the muscles and glands.

interneurons neurons within the brain and spinal cord; communicate internally and process information between the sensory inputs and motor outputs.

somatic nervous system the division of the peripheral nervous system that controls the body's skeletal muscles. Also called the *skeletal nervous system*.

autonomic [aw-tuh-NAHM-ik] nervous system (ANS) the part of the peripheral nervous system that controls the glands and the muscles of the internal organs (such as the heart). Its sympathetic division arouses; its parasympathetic division calms.

sympathetic nervous system the division of the autonomic nervous system that arouses the body, mobilizing its energy.

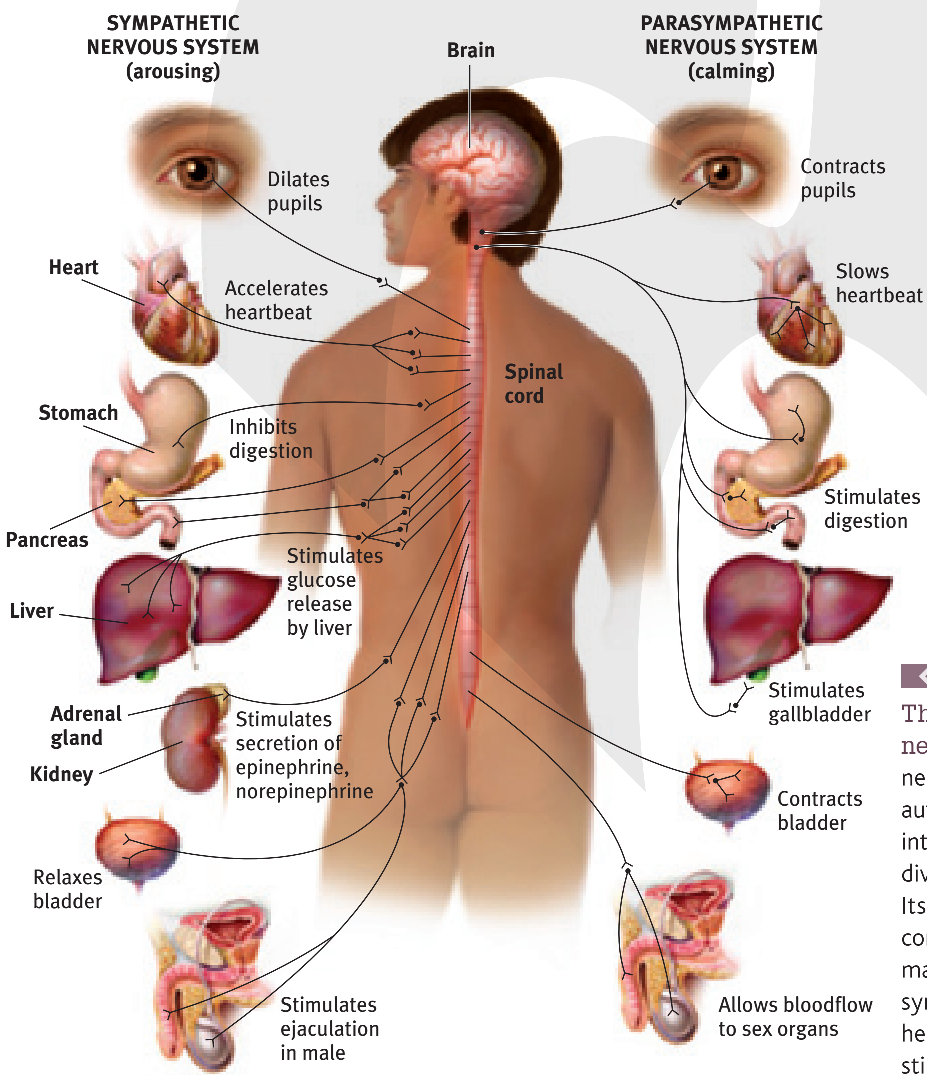


FIGURE 3.6
The dual functions of the autonomic nervous system The autonomic nervous system controls the more autonomous (or self-regulating) internal functions. Its sympathetic division arouses and expends energy. Its parasympathetic division calms and conserves energy, allowing routine maintenance activity. For example, sympathetic stimulation accelerates heartbeat, whereas parasympathetic stimulation slows it.

parasympathetic nervous system the division of the autonomic nervous system that calms the body, conserving its energy.

reflex a simple, automatic response to a sensory stimulus, such as the knee-jerk response.

endocrine [EN-duh-krin] system the body's "slow" chemical communication system; a set of glands that secrete hormones into the bloodstream.

hormones chemical messengers that are manufactured by the endocrine glands, travel through the bloodstream, and affect other tissues.

nervous system will accelerate your heartbeat, raise your blood pressure, slow your digestion, raise your blood sugar, and cool you with perspiration, making you alert and ready for action. When the stress subsides (the interview is over), your **parasympathetic nervous system** will produce the opposite effects, conserving energy as it calms you. The sympathetic and parasympathetic nervous systems work together to keep us in a steady internal state called *homeostasis*.

I [DM] recently experienced my ANS in action. Before sending me into an MRI machine for a shoulder scan, the technician asked if I had issues with claustrophobia. "No, I'm fine," I assured her, with perhaps a hint of macho swagger. Moments later, as I found myself on my back, stuck deep inside a coffin-sized box and unable to move, my sympathetic nervous system had a different idea. Claustrophobia overtook me. My heart began pounding, and I felt a desperate urge to escape. Just as I was about to cry out for release, I felt my calming parasympathetic nervous system kick in. My heart rate slowed and my body relaxed, though my arousal surged again before the 20-minute confinement ended. "You did well!" the technician said, unaware of my ANS roller-coaster ride.

RETRIEVE IT

- Match the type of neuron to its description.

Type	Description
1. Motor neurons	a. carry incoming messages from sensory receptors to the CNS.
2. Sensory neurons	b. communicate within the CNS and process information between incoming and outgoing messages.
3. Interneurons	c. carry outgoing messages from the CNS to muscles and glands.

ANSWERS: 1. c, 2. a, 3. b

- What bodily changes does your ANS direct before and after you give an important speech?

ANSWER: Responding to this challenge, your ANS *sympathetic* division will arouse you. It accelerates your heartbeat, raises your blood pressure and blood sugar, slows your digestion, and cools you with perspiration. After you give the speech, your ANS *parasympathetic* division will reverse these effects.

The Central Nervous System

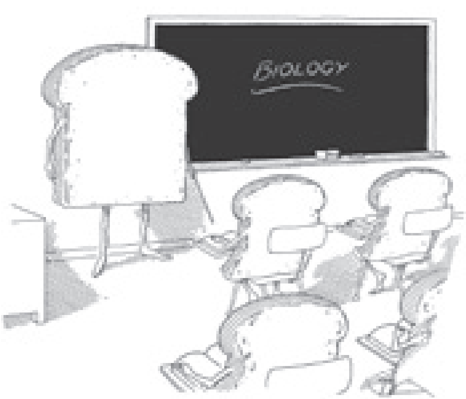
From neurons "talking" to other neurons arises the complexity of the central nervous system's brain and spinal cord.

It is the brain that enables our humanity—our thinking, feeling, and acting. Tens of billions of neurons, each communicating with thousands of other neurons, yield an ever-changing wiring diagram. By one estimate—projecting from neuron counts in small brain samples—our brains have some 86 billion neurons (Azevedo et al. 2009; Herculano-Houzel, 2012).

The brain's neurons cluster into work groups called *neural networks*. To understand why, Stephen Kosslyn and Olivier Koenig (1992, p. 12) have invited us to "think about why cities exist; why don't people distribute themselves more evenly across the countryside?" Like people networking with people, neurons network with nearby neurons with which they can have short, fast connections.

The other part of the CNS, the *spinal cord,* is a two-way information highway connecting the peripheral nervous system and the brain. Ascending neural fibers send up sensory information, and descending fibers send back motor-control information. The neural pathways governing our **reflexes,** our automatic responses to stimuli, illustrate the spinal cord's work. A simple spinal reflex pathway is composed of a single sensory neuron and a single motor neuron. These often communicate through an interneuron. The knee-jerk response, for example, involves one such simple pathway. A headless warm body could do it.

Another neural circuit enables the pain reflex (**FIGURE 3.7**). When your finger touches a flame, neural activity (excited by the heat) travels via sensory neurons



© Tom Swick/Cartoonstock.com

"The body is made up of millions and millions of crumbs."

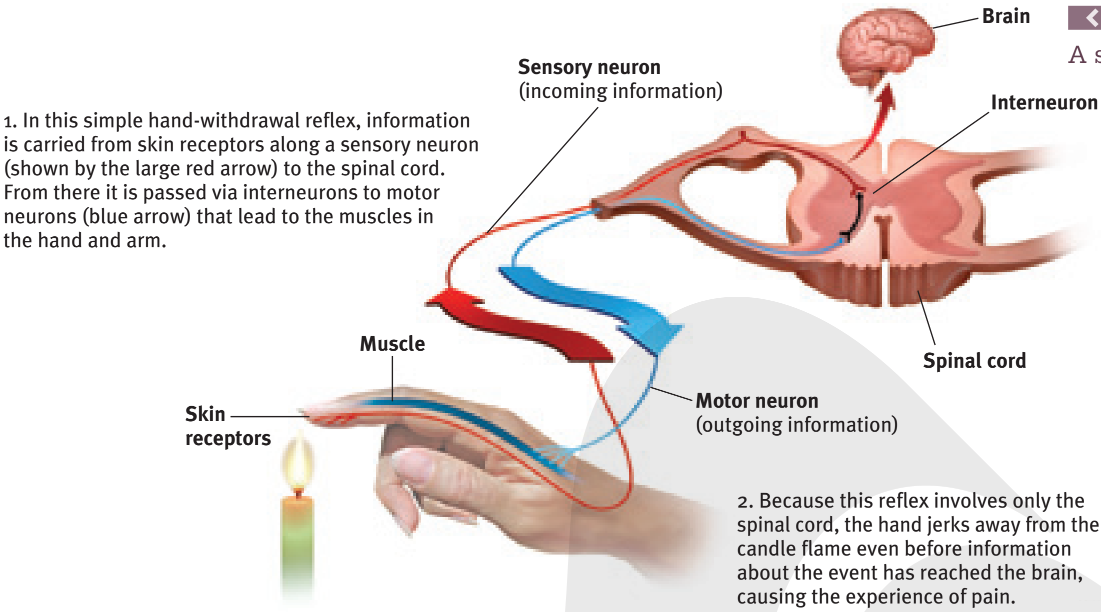


FIGURE 3.7
A simple reflex

to interneurons in your spinal cord. These interneurons respond by activating motor neurons leading to the muscles in your arm. Because the simple pain-reflex pathway runs through the spinal cord and right back out, your hand jerks away from the candle's flame *before* your brain receives and responds to the information that causes you to feel pain. That's why it feels as if your hand jerks away not by your choice, but on its own.

Information travels to and from the brain by way of the spinal cord. Were the top of your spinal cord severed, you would not feel pain from your paralyzed body below. Nor would you feel pleasure. With your brain literally out of touch with your body, you would lose all sensation and voluntary movement in body regions with sensory and motor connections to the spinal cord below its point of injury. You would exhibit the knee-jerk response without feeling the tap. Men paralyzed below the waist may be capable of an erection (a simple reflex) if their genitals are stimulated (Goldstein, 2000). Women similarly paralyzed may respond with vaginal lubrication. But, depending on where and how completely the spinal cord is severed, they may be genitally unresponsive to erotic images and have no genital feeling (Kennedy & Over, 1990; Sipski & Alexander, 1999). To produce bodily pain or pleasure, the sensory information must reach the brain.

"If the nervous system be cut off between the brain and other parts, the experiences of those other parts are nonexistent for the mind. The eye is blind, the ear deaf, the hand insensible and motionless."

William James, Principles of Psychology, *1890*

The Endocrine System

3-6 How does the endocrine system transmit information and interact with the nervous system?

So far, we have focused on the body's speedy electrochemical information system. Interconnected with your nervous system is a second communication system, the **endocrine system** (**FIGURE 3.8** on the next page). The endocrine system's glands secrete another form of chemical messengers, **hormones,** which travel through the bloodstream and affect other tissues, including the brain. When hormones act on the brain, they influence our interest in sex, food, and aggression.

Some hormones are chemically identical to neurotransmitters (the chemical messengers that diffuse across a synapse and excite or inhibit an adjacent neuron). The endocrine system and nervous system are therefore close relatives: Both produce molecules that act on receptors elsewhere. Like many relatives,

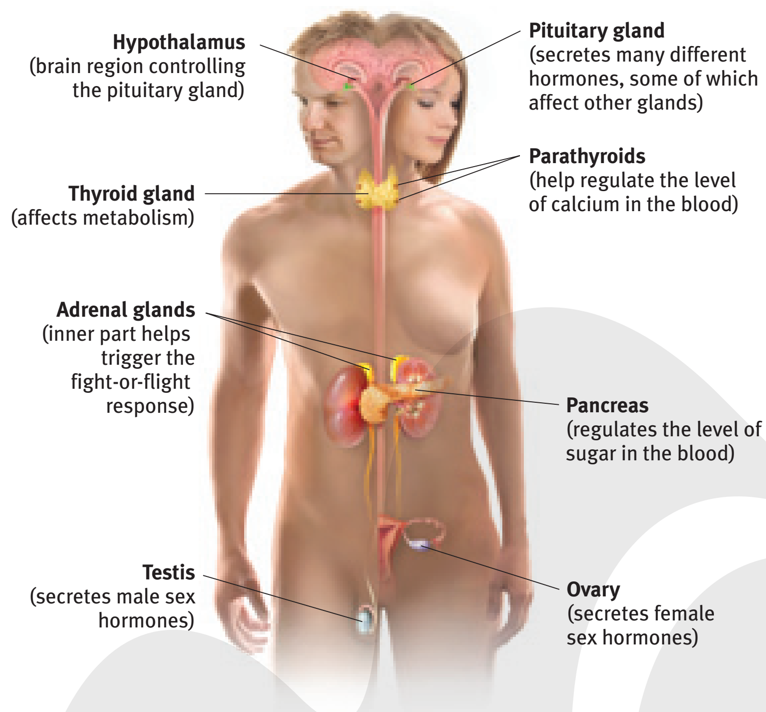


FIGURE 3.8 The endocrine system

they also differ. The speedy nervous system zips messages from eyes to brain to hand in a fraction of a second. Endocrine messages trudge along in the bloodstream, taking several seconds or more to travel from the gland to the target tissue. If the nervous system transmits information with text-message speed, the endocrine system delivers an old-fashioned letter.

Endocrine messages tend to outlast the effects of neural messages. That helps explain why upset feelings may linger beyond our awareness of what upset us. When this happens, it takes time for us to "simmer down."

In a moment of danger, for example, the ANS orders the **adrenal glands** on top of the kidneys to release *epinephrine* and *norepinephrine* (also called *adrenaline* and *noradrenaline*). These hormones increase heart rate, blood pressure, and blood sugar, providing a surge of energy. When the emergency passes, the hormones—and the feelings—linger a while.

The most influential endocrine gland is the **pituitary gland,** a pea-sized structure located in the core of the brain, where it is controlled by an adjacent brain area, the *hypothalamus*. Among the hormones released by the pituitary is a growth hormone that stimulates physical development. Another is *oxytocin,* which enables contractions associated with birthing, milk flow during nursing, and orgasm. Oxytocin also promotes pair bonding, group cohesion, and social trust (De Dreu et al., 2010; Zak, 2012). During a laboratory game, those given a nasal squirt of oxytocin rather than a placebo were more likely to trust strangers with their money and with confidential information (Kosfeld et al., 2005; Mikolajczak et al., 2010).

Pituitary secretions also direct other endocrine glands to release their hormones. The pituitary, then, is a master gland (whose own master is the hypothalamus). For example, under the brain's influence, the pituitary triggers your sex glands to release sex hormones. These in turn influence your brain and behavior (Goetz et al., 2014).

This feedback system (brain → pituitary → other glands → hormones → body and brain) reveals the intimate connection of the nervous and endocrine systems. The nervous system directs endocrine secretions, which then affect the nervous system. Conducting and coordinating this whole electrochemical orchestra is that maestro we call the brain.

adrenal [ah-DREEN-el] glands a pair of endocrine glands that sit just above the kidneys and secrete hormones (epinephrine and norepinephrine) that help arouse the body in times of stress.

pituitary gland the endocrine system's most influential gland. Under the influence of the hypothalamus, the pituitary regulates growth and controls other endocrine glands.

RETRIEVE IT

- Why is the pituitary gland called the "master gland"?

ANSWER: Responding to signals from the hypothalamus, the pituitary releases hormones that trigger other endocrine glands to secrete hormones, which in turn influence brain and behavior.

- How are the nervous and endocrine systems alike, and how do they differ?

ANSWER: Both of these communication systems produce chemical molecules that act on the body's receptors to influence our behavior and emotions. The endocrine system, which secretes hormones into the bloodstream, delivers its messages much more slowly than the speedy nervous system, and the effects of the endocrine system's messages tend to linger much longer than those of the nervous system.

Learning Objectives

Test Yourself by taking a moment to answer each of these Learning Objective Questions (repeated here from within the module). Then turn to Appendix D, Complete Module Reviews, to check your answers. Research suggests that trying to answer these questions on your own will improve your long-term memory of the concepts (McDaniel et al., 2009).

3-1 Why are psychologists concerned with human biology?

3-2 What are neurons, and how do they transmit information?

3-3 How do nerve cells communicate with other nerve cells?

3-4 How do neurotransmitters influence behavior, and how do drugs and other chemicals affect neurotransmission?

3-5 What are the functions of the nervous system's main divisions, and what are the three main types of neurons?

3-6 How does the endocrine system transmit information and interact with the nervous system?

Terms and Concepts to Remember

Test yourself on these terms by trying to write down the definition in your own words before flipping back to the referenced page to check your answers.

biological psychology, p. 36
neuron, p. 36
dendrites, p. 36
axon, p. 36
myelin [MY-uh-lin] sheath, p. 37
glial cells (glia), p. 37
action potential, p. 37
threshold, p. 38
refractory period, p. 39
all-or-none response, p. 39
synapse [SIN-aps], p. 39
neurotransmitters, p. 40
reuptake, p. 40
endorphins [en-DOR-fins], p. 41
agonist, p. 42
antagonist, p. 42
nervous system, p. 42
central nervous system (CNS), p. 42
peripheral nervous system (PNS), p. 42
nerves, p. 42
sensory (afferent) neurons, p. 42
motor (efferent) neurons, p. 43
interneurons, p. 43
somatic nervous system, p. 43
autonomic [aw-tuh-NAHM-ik] nervous system (ANS), p. 43
sympathetic nervous system, p. 43
parasympathetic nervous system, p. 44
reflex, p. 44
endocrine [EN-duh-krin] system, p. 45
hormones, p. 45
adrenal [ah-DREEN-el] glands, p. 46
pituitary gland, p. 46

Experience the Testing Effect

Test yourself repeatedly throughout your studies. This will not only help you figure out what you know and don't know; the testing itself will help you learn and remember the information more effectively thanks to the *testing effect*.

1. The neuron fiber that passes messages through its branches to other neurons or to muscles and glands is the ______________.

2. The tiny space between the axon of one neuron and the dendrite or cell body of another is called the
   a. axon terminal.
   b. branching fiber.
   c. synaptic gap.
   d. threshold.

3. Regarding a neuron's response to stimulation, the intensity of the stimulus determines
   a. whether or not an impulse is generated.
   b. how fast an impulse is transmitted.
   c. how intense an impulse will be.
   d. whether reuptake will occur.

4. In a sending neuron, when an action potential reaches an axon terminal, the impulse triggers the release of chemical messengers called ______________.

5. Endorphins are released in the brain in response to
   a. morphine or heroin.
   b. pain or vigorous exercise.
   c. the all-or-none response.
   d. all of the above.

6. The autonomic nervous system controls internal functions, such as heart rate and glandular activity. The word *autonomic* means
   a. calming.
   b. voluntary.
   c. self-regulating.
   d. arousing.

7. The sympathetic nervous system arouses us for action and the parasympathetic nervous system calms us down. Together, the two systems make up the ______________ nervous system.

8. The neurons of the spinal cord are part of the ______________ nervous system.

9. The most influential endocrine gland, known as the master gland, is the
   a. pituitary.
   b. hypothalamus.
   c. thyroid.
   d. pancreas.

10. The ______________ ______________ secrete(s) epinephrine and norepinephrine, helping to arouse the body during times of stress.

Find answers to these questions in Appendix E, in the back of the book.

Use LearningCurve to create your personalized study plan, which will direct you to the resources that will help you most in LaunchPad.

"You're certainly a lot less fun since the operation."

"I am a brain, Watson. The rest of me is a mere appendix."

Sherlock Holmes, in Arthur Conan Doyle's "The Adventure of the Mazarin Stone"

MODULE 4 Tools of Discovery and Older Brain Structures

The mind seeking to understand the brain—that is among the ultimate scientific challenges. And so it will always be. To paraphrase cosmologist John Barrow, a brain simple enough to be fully understood is too simple to produce a mind able to understand it.

When you think *about* your brain, you're thinking *with* your brain—by firing across millions of synapses and releasing billions of neurotransmitter molecules. Indeed, say neuroscientists, *the mind is what the brain does*.

The Tools of Discovery: Having Our Head Examined

4-1 How do neuroscientists study the brain's connections to behavior and mind?

A century ago, scientists had no tools high powered yet gentle enough to explore the living human brain. Early case studies helped localize some brain functions. Damage to one side of the brain often caused numbness or paralysis on the opposite side, suggesting that the body's right side is wired to the brain's left side, and vice versa. Damage to the back of the brain disrupted vision, and damage to the left-front part of the brain produced speech difficulties. Gradually, these early explorers were mapping the brain.

Robert Ludlow/UCL Institute of Neurology/Wellcome Images

A living human brain exposed Today's neuroscience tools enable us to "look under the hood" and glimpse the brain at work, enabling the mind.

Now, within a lifetime, a new generation of neural mapmakers is charting the known universe's most amazing organ. Whether in the interests of science or medicine, they can selectively **lesion** (destroy) tiny clusters of normal or defective brain cells, leaving the surrounding tissue unharmed. Today's scientists can snoop on the messages of individual neurons, using modern microelectrodes with tips small enough to detect the electrical pulse in a single neuron. For example, they can now detect exactly where the information goes in a cat's brain when someone strokes its whisker. They can also stimulate various brain parts and note the effect, eavesdrop on the chatter of billions of neurons, and see color representations of the brain's energy-consuming activity. These techniques for peering into the thinking, feeling brain are doing for psychology what the microscope did for biology and the telescope did for astronomy.

Right now, your mental activity is emitting telltale electrical, metabolic, and magnetic signals that would enable neuroscientists to observe your brain at work. Electrical activity in your brain's billions of neurons sweeps in regular waves across its surface. An **electroencephalogram (EEG)** is an amplified readout of such waves (**FIGURE 4.1**). Researchers record the brain waves through a shower-cap-like hat that is filled with electrodes covered with a conductive gel.

"You must look into people, as well as at them," advised Lord Chesterfield in a 1746 letter to his son. Unlike EEGs, newer neuroimaging techniques give us that Superman-like ability to see inside the living brain. One such tool, the **PET (positron emission tomography) scan** (**FIGURE 4.2**), depicts brain activity by

lesion [LEE-zhuhn] tissue destruction. A brain lesion is a naturally or experimentally caused destruction of brain tissue.

electroencephalogram (EEG) an amplified recording of the waves of electrical activity sweeping across the brain's surface. These waves are measured by electrodes placed on the scalp.

PET (positron emission tomography) scan a visual display of brain activity that detects where a radioactive form of glucose goes while the brain performs a given task.

AJPhoto/Science Source

FIGURE 4.1

Brain hacking An electroencephalograph provides amplified tracings of waves of electrical activity in the brain.

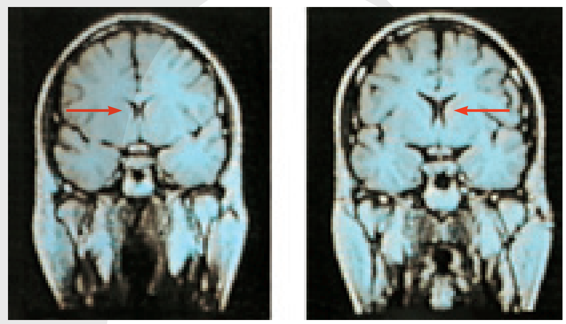
Mark Harmel/The Image Bank/Getty Images

FIGURE 4.2

The PET scan To obtain a PET scan, researchers inject volunteers with a low and harmless dose of a short-lived radioactive sugar. Detectors around the person's head pick up the release of gamma rays from the sugar, which has concentrated in active brain areas. A computer then processes and translates these signals into a map of the brain at work.

showing each brain area's consumption of its chemical fuel, the sugar glucose. Active neurons are glucose hogs. Our brain, though only about 2 percent of our body weight, consumes 20 percent of our calorie intake. After a person receives temporarily radioactive glucose, the PET scan can track the gamma rays released by this "food for thought" as a task is performed. Rather like weather radar showing rain activity, PET-scan "hot spots" show the most active brain areas as the person does mathematical calculations, looks at images of faces, or daydreams.

In **MRI (magnetic resonance imaging)** brain scans, the person's head is put in a strong magnetic field, which aligns the spinning atoms of brain molecules. Then, a radio-wave pulse momentarily disorients the atoms. When the atoms return to their normal spin, they emit signals that provide a detailed picture of soft tissues, including the brain. MRI scans have revealed a larger-than-average neural area in the left hemisphere of musicians who display perfect pitch (Schlaug et al., 1995). They have also revealed enlarged *ventricles*—fluid-filled brain areas (marked by the red arrows in **FIGURE 4.3**)—in some patients who have schizophrenia, a disabling psychological disorder.



From Daniel Weinberger, M.D., CBDB, NIMH

FIGURE 4.3

MRI scan of a healthy individual (left) and a person with schizophrenia (right) Note the enlarged ventricle, the fluid-filled brain region at the tip of the arrow in the image on the right.

A special application of MRI—**fMRI (functional MRI)**—can reveal the brain's functioning as well as its structure. Where the brain is especially active, blood goes. By comparing successive MRI scans, researchers can watch as specific brain areas activate, showing increased oxygen-laden bloodflow. As a person looks at a scene, for example, the fMRI machine detects blood rushing to the back of the brain, which processes visual information (see Figure 5.3). When the brain is unoccupied, blood continues to flow via a web of brain regions called the *default network* (Mason et al., 2007).

Such snapshots of the brain's activity provide new insights into how the brain divides its labor. A mountain of recent fMRI studies suggests which brain areas are most active when people feel pain or rejection, listen to angry voices, think about scary things, feel happy, or become sexually excited. The technology enables a very crude sort of mind reading. One neuroscience team scanned 129 people's brains as they did eight different mental tasks (such as reading, gambling, or rhyming). Later, they were able, with 80 percent accuracy, to predict which of these mental activities their participants had been doing (Poldrack et al., 2009).

MRI (magnetic resonance imaging) a technique that uses magnetic fields and radio waves to produce computer-generated images of soft tissue. MRI scans show brain anatomy.

fMRI (functional MRI) a technique for revealing bloodflow and, therefore, brain activity by comparing successive MRI scans. fMRI scans show brain function as well as structure.

You've seen the pictures—of colorful brains with accompanying headlines, such as "your brain on music." Hot brains make hot news (Fine, 2010). But "neuro-skeptics" caution against overblown claims (Satel & Lilienfeld, 2013; Vul et al., 2009a,b). Neuromarketing, neuropolitics, and neurotheology are often neuro-hype. Imaging techniques illuminate brain structure and activity, and sometimes help us test different theories of behavior (Mather et al., 2013). But given that all human experience is brain-based, it's no surprise that different brain areas become active when one listens to a lecture or lusts for a lover.

Nevertheless, to learn about the neurosciences now is like studying world geography when Magellan explored the seas. The $40 million Human Connectome Project (2013; Gorman, 2014), for example, seeks "neural pathways [that] will reveal much about what makes us uniquely human and what makes every person different from all others." It harnesses the power of *diffusion spectrum imaging*, a type of MRI technology that maps long-distance brain fiber connections (Jarbo & Verstynen, 2015). Today's whole-brain mapping effort has been likened to last century's Apollo program, which landed humans on the Moon. This truly is the golden age of brain science.

RETRIEVE IT

- Match the scanning technique with the correct description.

Technique:	Description:
1. fMRI scan	a. tracks radioactive glucose to reveal brain activity.
2. PET scan	b. tracks successive images of brain tissue to show brain function.
3. MRI scan	c. uses magnetic fields and radio waves to show brain anatomy.

ANSWERS: 1. b, 2. a, 3. c

Older Brain Structures

4-2 What structures make up the brainstem, and what are the functions of the brainstem, thalamus, reticular formation, and cerebellum?

Stefan Klein/imagebroker/Alamy

An animal's capacities come from its brain structures. In primitive animals, such as sharks, a not-so-complex brain primarily regulates basic survival functions: breathing, resting, and feeding. In lower mammals, such as rodents, a more complex brain enables emotion and greater memory. In advanced mammals, such as humans, a brain that processes more information enables increased foresight as well.

This increasing complexity arises from new brain systems built on top of the old, much as Earth's landscape covers the old with the new. Digging down, one discovers the fossil remnants of the past—brainstem components performing for us much as they did for our distant ancestors. Let's start with the brain's base and work up to the newer systems.

LaunchPad For an introductory 12.5-minute overview of the brain, visit LaunchPad's *Video: The Central Nervous System—Spotlight on the Brain.*

The Brainstem

The brain's oldest and innermost region is the **brainstem.** It begins where the spinal cord swells slightly after entering the skull. This slight swelling is the **medulla** (**FIGURE 4.4**). Here lie the controls for your heartbeat and breathing. As brain-damaged patients in a vegetative state illustrate, we need no higher brain or conscious mind to orchestrate our heart's pumping and lungs' breathing. The brainstem handles those tasks. Just above the medulla sits the *pons,* which helps coordinate movements and control sleep.

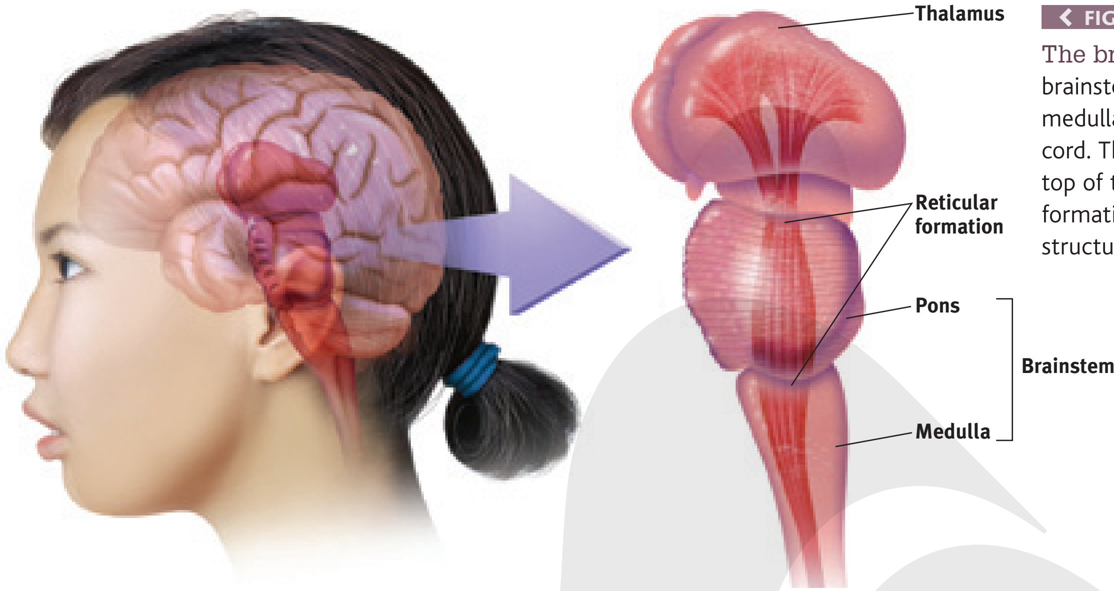


FIGURE 4.4

The brainstem and thalamus The brainstem, including the pons and medulla, is an extension of the spinal cord. The thalamus is attached to the top of the brainstem. The reticular formation passes through both structures.

If a cat's brainstem is severed from the rest of the brain above it, the animal will still breathe and live—and even run, climb, and groom (Klemm, 1990). But cut off from the brain's higher regions, it won't *purposefully* run or climb to get food.

The brainstem is a crossover point, where most nerves to and from each side of the brain connect with the body's opposite side (**FIGURE 4.5**). This peculiar cross-wiring is but one of the brain's many surprises.

RETRIEVE IT

- Nerves from the left side of the brain are mostly linked to the ____________ side of the body, and vice versa.

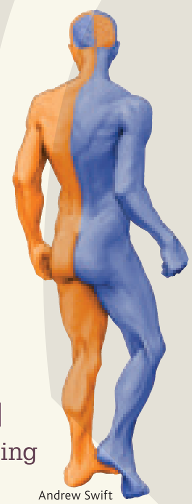


FIGURE 4.5

The body's wiring

Andrew Swift

ANSWER: right

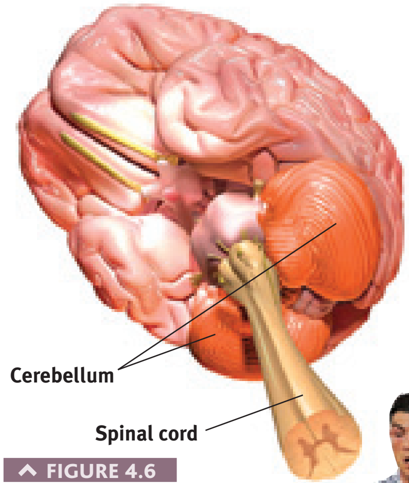
The Thalamus

Sitting atop the brainstem is the **thalamus,** a pair of egg-shaped structures that act as the brain's sensory control center (Figure 4.4). The thalamus receives information from all the senses except smell, and routes that information to higher brain regions that deal with seeing, hearing, tasting, and touching. The thalamus also receives some of the higher brain's replies, which it then directs to the medulla and to the cerebellum. Think of the thalamus as being to sensory information what London is to England's trains: a hub through which traffic passes en route to various destinations.

brainstem the oldest part and central core of the brain, beginning where the spinal cord swells as it enters the skull; the brainstem is responsible for automatic survival functions.

medulla [muh-DUL-uh] the base of the brainstem; controls heartbeat and breathing.

thalamus [THAL-uh-muss] the brain's sensory control center, located on top of the brainstem; it directs messages to the sensory receiving areas in the cortex and transmits replies to the cerebellum and medulla.



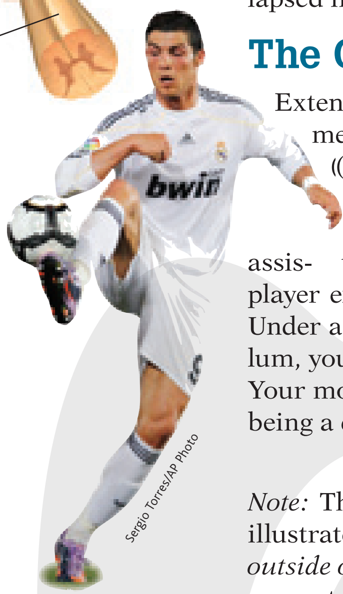


FIGURE 4.6

The brain's organ of agility Hanging at the back of the brain, the cerebellum coordinates our voluntary movements.

The Reticular Formation

Inside the brainstem, between your ears, lies the **reticular** ("netlike") **formation,** a neuron network extending from the spinal cord right up through the thalamus. As the spinal cord's sensory input flows up to the thalamus, some of it travels through the reticular formation, which filters incoming stimuli, relays important information to other brain areas, and controls arousal.

In 1949, Giuseppe Moruzzi and Horace Magoun discovered that electrically stimulating a sleeping cat's reticular formation almost instantly produced an awake, alert animal. When Magoun *severed* a cat's reticular formation without damaging nearby sensory pathways, the effect was equally dramatic: The cat lapsed into a coma from which it never awakened.

The Cerebellum

Extending from the rear of the brainstem is the baseball-sized **cerebellum,** meaning "little brain," which is what its two wrinkled halves resemble (**FIGURE 4.6**). The cerebellum enables nonverbal learning and skill memory. It also helps us judge time, modulate our emotions, and discriminate sounds and textures (Bower & Parsons, 2003). And (with assistance from the pons) it coordinates voluntary movement. When a soccer player executes a perfect bicycle kick, give the player's cerebellum some credit. Under alcohol's influence, coordination suffers. And if you injured your cerebellum, you would have difficulty walking, keeping your balance, or shaking hands. Your movements would be jerky and exaggerated. Gone would be any dreams of being a dancer or guitarist.

* * *

Note: These older brain functions all occur without any conscious effort. This illustrates another of our recurring themes: *Our brain processes most information outside of our awareness.* We are aware of the *results* of our brain's labor—say, our current visual experience—but not *how* we construct the visual image. Likewise, whether we are asleep or awake, our brainstem manages its life-sustaining functions, freeing our newer brain regions to think, talk, dream, or savor a memory.

RETRIEVE IT [✖]

- In what brain region would damage be most likely to (1) disrupt your ability to skip rope? (2) disrupt your ability to hear and taste? (3) perhaps leave you in a coma? (4) cut off the very breath and heartbeat of life?

ANSWERS: 1. cerebellum, 2. thalamus, 3. reticular formation, 4. medulla

The Limbic System

4-3 What are the limbic system's structures and functions?

We've considered the brain's oldest parts, but we've not yet reached its newest and highest regions, the *cerebral hemispheres* (the two halves of the brain). Between the oldest and newest brain areas lies the **limbic system** (*limbus* means "border"). This system contains the *amygdala,* the *hypothalamus,* and the *hippocampus* (**FIGURE 4.7**).

THE AMYGDALA Research has linked the **amygdala,** two lima-bean-sized neural clusters, to aggression and fear. In 1939, psychologist Heinrich Klüver and neurosurgeon Paul Bucy surgically removed a rhesus monkey's amygdala, turning the normally ill-tempered animal into the most mellow of creatures. So, too, with human patients. Those with amygdala lesions often display reduced arousal to fear- and anger-arousing stimuli (Berntson et al., 2011). One such woman, patient S. M., has been called "the woman with no fear," even of being threatened with a gun (Feinstein et al., 2013).

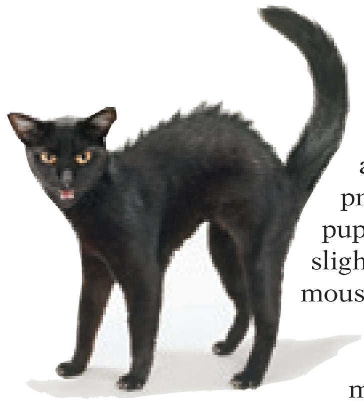
reticular formation a nerve network that travels through the brainstem into the thalamus and plays an important role in controlling arousal.

cerebellum [sehr-uh-BELL-um] the "little brain" at the rear of the brainstem; functions include processing sensory input, coordinating movement output and balance, and enabling nonverbal learning and memory.

limbic system neural system (including the *amygdala, hypothalamus,* and *hippocampus*) located below the cerebral hemispheres; associated with emotions and drives.

amygdala [uh-MIG-duh-la] two lima-bean-sized neural clusters in the limbic system; linked to emotion.

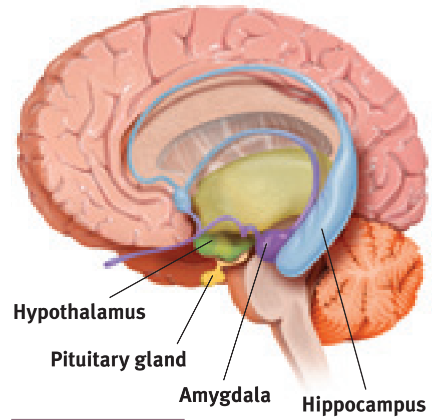
hypothalamus [hi-po-THAL-uh-muss] a neural structure lying below *(hypo)* the thalamus; it directs several maintenance activities (eating, drinking, body temperature), helps govern the endocrine system via the pituitary gland, and is linked to emotion and reward.



GK Hart/Vikki Hart/Gettyimages

What then might happen if we electrically stimulated the amygdala of a normally placid domestic animal, such as a cat? Do so in one spot and the cat prepares to attack, hissing with its back arched, its pupils dilated, its hair on end. Move the electrode only slightly within the amygdala, cage the cat with a small mouse, and now it cowers in terror.

These and other experiments have confirmed the amygdala's role in fear and rage. One study found math anxiety associated with hyperactivity in the right amygdala (Young et al., 2012). Other studies link criminal behavior with amygdala dysfunction (Boccardi et al., 2011; Ermer et al., 2012). But we must be careful. The brain is not neatly organized into structures that correspond to our behavior categories. When we feel or act in aggressive or fearful ways, there is neural activity in many areas of our brain—not just the amygdala. If you destroy a car's dead battery, you can't start the engine. Yet the battery is merely one link in an integrated system.



^ FIGURE 4.7

The limbic system This neural system sits between the brain's older parts and its cerebral hemispheres. The limbic system's hypothalamus controls the nearby pituitary gland.

RETRIEVE IT [✖]

- Electrical stimulation of a cat's amygdala provokes angry reactions. Which *autonomic nervous system* division is activated by such stimulation?

ANSWER: The sympathetic nervous system

THE HYPOTHALAMUS Just below *(hypo)* the thalamus is the **hypothalamus** (**FIGURE 4.8**), an important link in the command chain governing bodily maintenance. Some neural clusters in the hypothalamus influence hunger; others regulate thirst, body temperature, and sexual behavior. Together, they help maintain a steady *(homeostatic)* internal state.

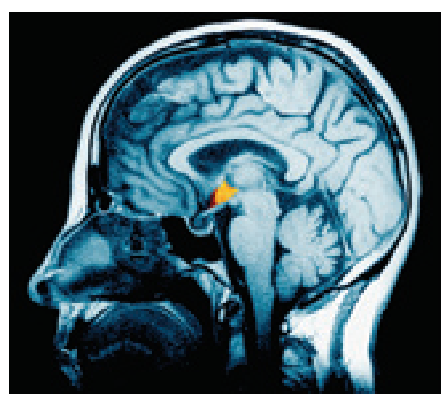
As the hypothalamus monitors the state of your body, it tunes into your blood chemistry and any incoming orders from other brain parts. For example, picking up signals from your brain's cerebral cortex that you are thinking about sex, your hypothalamus will secrete hormones. These hormones will in turn trigger the adjacent "master gland" of the endocrine system, your pituitary (see Figure 4.7), to influence your sex glands to release their hormones. These will intensify the thoughts of sex in your cerebral cortex. (Once again, we see the interplay between the nervous and endocrine systems: The brain influences the endocrine system, which in turn influences the brain.)

A remarkable discovery about the hypothalamus illustrates how progress in science often occurs—when curious, open-minded investigators make an unexpected observation. Two young McGill University neuropsychologists, James Olds and Peter Milner (1954), were trying to implant an electrode in a rat's reticular formation when they made a magnificent mistake: They placed the electrode incorrectly (Olds, 1975). Curiously, as if seeking more stimulation, the rat kept returning to the location where it had been stimulated by this misplaced electrode. On discovering that they had actually placed the device in a region of the hypothalamus, Olds and Milner realized they had stumbled upon a brain center that provides pleasurable rewards (Olds, 1975).

Later experiments located other "pleasure centers" (Olds, 1958). (What the rats actually experience only they know, and they aren't telling. Rather than attribute human feelings to rats, today's scientists refer to *reward centers,* not "pleasure centers.") Just how rewarding are these reward centers? Enough to cause rats to self-stimulate these brain regions more than 1000 times per hour. In other species, including dolphins and monkeys, researchers later discovered other limbic system reward centers, such as the *nucleus accumbens* in front of the hypothalamus. Animal research has also revealed both a general dopamine-related reward system and specific centers associated with the

⌄ FIGURE 4.8

The hypothalamus This small but important structure, colored yellow/orange in this MRI-scan photograph, helps keep the body's internal environment in a steady state.



ISM/Phototake

hippocampus a neural center located in the limbic system; helps process explicit memories for storage.

"If you were designing a robot vehicle to walk into the future and survive, . . . you'd wire it up so that behavior that ensured the survival of the self or the species—like sex and eating—would be naturally reinforcing."

Candace Pert (1986)

pleasures of eating, drinking, and sex. Animals, it seems, come equipped with built-in systems that reward activities essential to survival.

Do humans have limbic centers for pleasure? To calm violent patients, one neurosurgeon implanted electrodes in such areas. Stimulated patients reported mild pleasure; unlike Olds' rats, however, they were not driven to a frenzy (Deutsch, 1972; Hooper & Teresi, 1986). Moreover, newer research reveals that stimulating the brain's "hedonic hotspots" (its reward circuits) produces more *desire* than pure enjoyment (Kringelbach & Berridge, 2012).

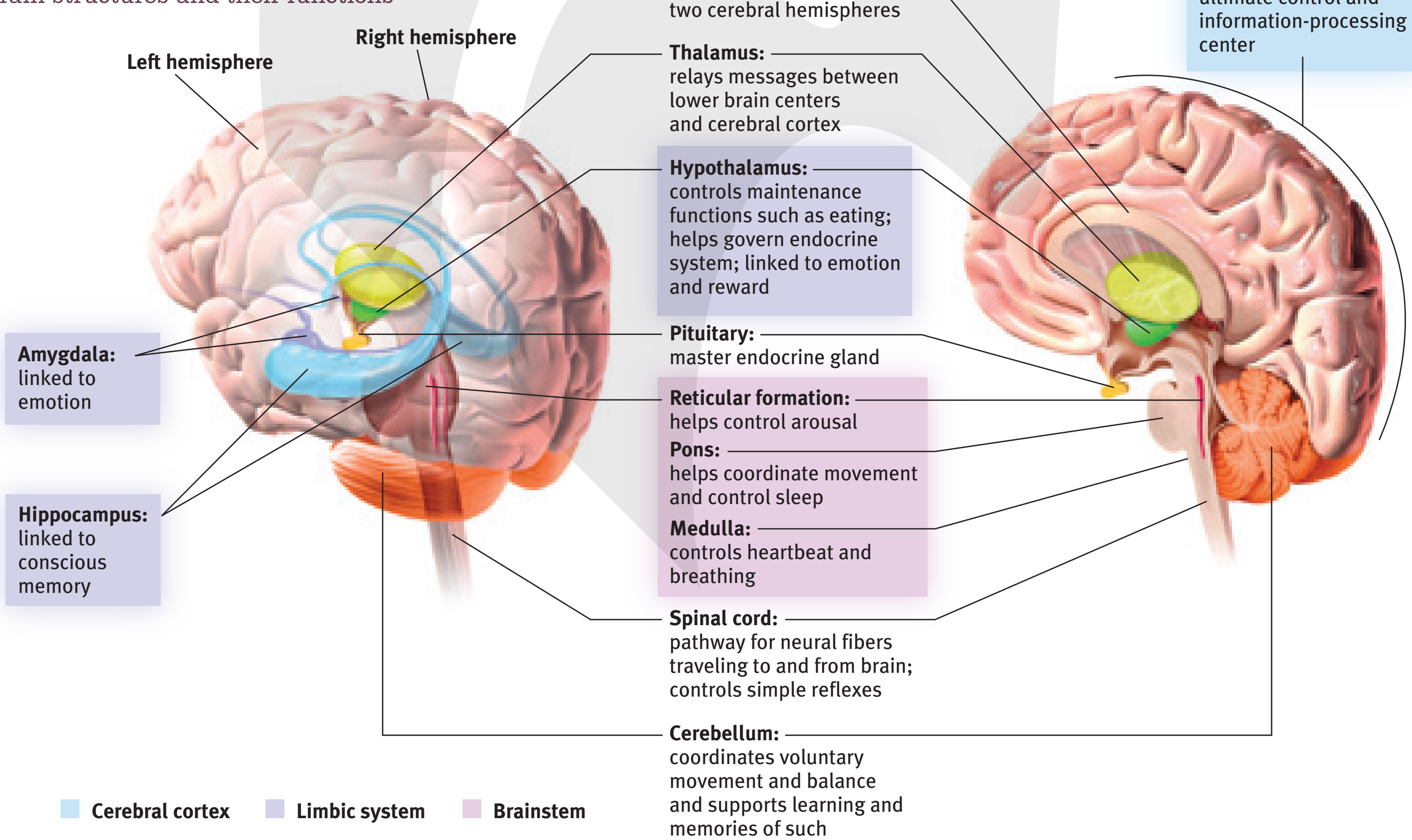
Some researchers believe that substance use disorders may stem from malfunctions in natural brain systems for pleasure and well-being (Balodis & Potenza, 2015). People genetically predisposed to this *reward deficiency syndrome* may crave whatever provides that missing pleasure or relieves negative feelings (Blum et al., 1996).

THE HIPPOCAMPUS The **hippocampus** processes conscious, explicit memories and decreases in size and function as we grow older. Animals or humans who lose their hippocampus to surgery or injury lose their ability to form new memories of facts and events. Those who survive a hippocampal brain tumor in childhood struggle to remember new information in adulthood (Jayakar et al., 2015). Other modules discuss how hippocampus size and function decrease as we grow older, and how our two-track mind uses the hippocampus to process our memories.

* * *

FIGURE 4.9 locates the brain areas we've discussed, as well as the *cerebral cortex*.

FIGURE 4.9
Brain structures and their functions



RETRIEVE IT [✖]

- What are the three key structures of the limbic system, and what functions do they serve?

ANSWER: (1) The *amygdala* is involved in aggression and fear responses. (2) The *hypothalamus* is involved in bodily maintenance, pleasurable rewards, and control of the hormonal systems. (3) The *hippocampus* processes conscious memory.

LaunchPad To review and assess your understanding, visit LaunchPad's *Concept Practice: The Limbic System.*

MODULE 4 REVIEW Tools of Discovery and Older Brain Structures

Learning Objectives

Test Yourself by taking a moment to answer each of these Learning Objective Questions (repeated here from within the module). Then turn to Appendix D, Complete Module Reviews, to check your answers. Research suggests that trying to answer these questions on your own will improve your long-term memory of the concepts (McDaniel et al., 2009).

4-1 How do neuroscientists study the brain's connections to behavior and mind?

4-2 What structures make up the brainstem, and what are the functions of the brainstem, thalamus, reticular formation, and cerebellum?

4-3 What are the limbic system's structures and functions?

Terms and Concepts to Remember

Test yourself on these terms by trying to write down the definition in your own words before flipping back to the referenced page to check your answers.

lesion [LEE-zhuhn], p. 48
electroencephalogram (EEG), p. 48
PET (positron emission tomography) scan, p. 48
MRI (magnetic resonance imaging), p. 49
fMRI (functional MRI), p. 49
brainstem, p. 50
medulla [muh-DUL-uh], p. 50
thalamus [THAL-uh-muss], p. 51
reticular formation, p. 52
cerebellum [sehr-uh-BELL-um], p. 52
limbic system, p. 52
amygdala [uh-MIG-duh-la], p. 52
hypothalamus [hi-po-THAL-uh-muss], p. 53
hippocampus, p. 54

Experience the Testing Effect

Test yourself repeatedly throughout your studies. This will not only help you figure out what you know and don't know; the testing itself will help you learn and remember the information more effectively thanks to the *testing effect*.

1. The part of the brainstem that controls heartbeat and breathing is the
   a. cerebellum.
   b. medulla.
   c. cortex.
   d. thalamus.

2. The thalamus functions as a
   a. memory bank.
   b. balance center.
   c. breathing regulator.
   d. sensory control center.

3. The lower brain structure that governs arousal is the
   a. spinal cord.
   b. cerebellum.
   c. reticular formation.
   d. medulla.

4. The part of the brain that coordinates voluntary movement and enables nonverbal learning and memory is the ______________.

5. Two parts of the limbic system are the amygdala and the
   a. cerebral hemispheres.
   b. hippocampus.
   c. thalamus.
   d. pituitary.

6. A cat's ferocious response to electrical brain stimulation would lead you to suppose the electrode had touched the ______________.

7. The neural structure that most directly regulates eating, drinking, and body temperature is the
   a. endocrine system.
   b. hypothalamus.
   c. hippocampus.
   d. amygdala.

8. The initial reward center discovered by Olds and Milner was located in the ______________.

Find answers to these questions in Appendix E, in the back of the book.

Use LearningCurve to create your personalized study plan, which will direct you to the resources that will help you most in LaunchPad.

cerebral [seh-REE-bruhl] cortex the intricate fabric of interconnected neural cells covering the cerebral hemispheres; the body's ultimate control and information-processing center.

frontal lobes portion of the cerebral cortex lying just behind the forehead; involved in speaking and muscle movements and in making plans and judgments.

parietal [puh-RYE-uh-tuhl] lobes portion of the cerebral cortex lying at the top of the head and toward the rear; receives sensory input for touch and body position.

occipital [ahk-SIP-uh-tuhl] lobes portion of the cerebral cortex lying at the back of the head; includes areas that receive information from the visual fields.

temporal lobes portion of the cerebral cortex lying roughly above the ears; includes the auditory areas, each receiving information primarily from the opposite ear.

The people who first dissected and labeled the brain used the language of scholars—Latin and Greek. Their words are actually attempts at graphic description: For example, *cortex* means "bark," *cerebellum* is "little brain," and *thalamus* is "inner chamber."

MODULE 5 The Cerebral Cortex and Our Divided Brain

The Cerebral Cortex

5-1 What are the functions of the various cerebral cortex regions?

Older brain networks sustain basic life functions and enable memory, emotions, and basic drives. Newer neural networks within the *cerebrum*—the two cerebral hemispheres contributing 85 percent of the brain's weight—form specialized work teams that enable our perceiving, thinking, and speaking. Like other structures above the brainstem (including the thalamus, hippocampus, and amygdala), the cerebral hemispheres come as a pair. Covering those hemispheres, like bark on a tree, is the **cerebral cortex,** a thin surface layer of interconnected neural cells. It is your brain's thinking crown, your body's ultimate control and information-processing center.

As we move up the ladder of animal life, the cerebral cortex expands, tight genetic controls relax, and the organism's adaptability increases. Frogs and other small-cortex amphibians operate extensively on preprogrammed genetic instructions. The larger cortex of mammals offers increased capacities for learning and thinking, enabling them to be more adaptable. What makes us distinctively human mostly arises from the complex functions of our cerebral cortex.

RETRIEVE IT

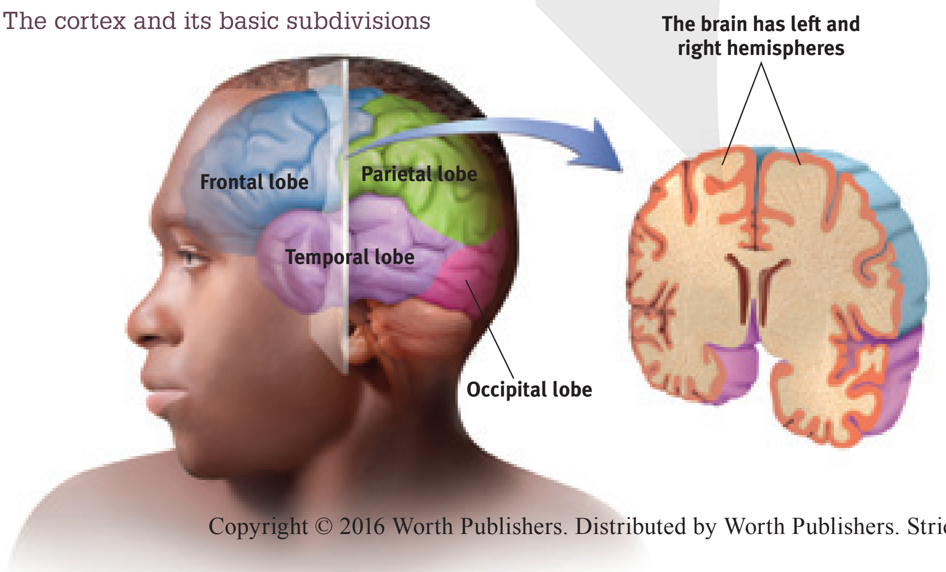
- Which area of the human brain is most similar to that of less complex animals? Which part of the human brain distinguishes us most from less complex animals?

ANSWERS: The brainstem; the cerebral cortex

Structure of the Cortex

If you opened a human skull, exposing the brain, you would see a wrinkled organ, shaped somewhat like an oversized walnut. Without these wrinkles, a flattened cerebral cortex would require triple the area—roughly that of a large pizza. The brain's left and right hemispheres are filled mainly with axons connecting the cortex to the brain's other regions. The cerebral cortex—that thin surface layer—contains some 20 to 23 billion of the brain's nerve cells and 300 trillion synaptic connections (de Courten-Myers, 2005). Being human takes a lot of nerve.

FIGURE 5.1
The cortex and its basic subdivisions



Each hemisphere's cortex is subdivided into four *lobes,* separated by prominent *fissures,* or folds (**FIGURE 5.1**). Starting at the front of your brain and moving over the top, there are the **frontal lobes** (behind your forehead), the **parietal lobes** (at the top and to the rear), and the **occipital lobes** (at the back of your head). Reversing direction and moving forward, just above your ears, you find the **temporal lobes.** Each of the four lobes carries out many functions, and many functions require the interplay of several lobes.

Functions of the Cortex

More than a century ago, surgeons found damaged cortical areas during autopsies of people who had been partially paralyzed or speechless. This rather crude evidence did not prove that specific parts of the cortex control complex functions like movement or speech. After all, if the entire cortex controlled speech and movement, damage to almost any area might produce the same effect. A TV with its power cord cut would go dead, but we would be fooling ourselves if we thought we had "localized" the picture in the cord.

MOTOR FUNCTIONS Scientists had better luck in localizing simpler brain functions. For example, in 1870, German physicians Gustav Fritsch and Eduard Hitzig made an important discovery: Mild electrical stimulation to parts of an animal's cortex made parts of its body move. The effects were selective: Stimulation caused movement only when applied to an arch-shaped region at the back of the frontal lobe, running roughly ear-to-ear across the top of the brain. Moreover, stimulating parts of this region in the left or right hemisphere caused movements of specific body parts on the *opposite* side of the body. Fritsch and Hitzig had discovered what is now called the **motor cortex.**

motor cortex an area at the rear of the frontal lobes that controls voluntary movements.

MAPPING THE MOTOR CORTEX Lucky for brain surgeons and their patients, the brain has no sensory receptors. Knowing this, in the 1930s, Otfrid Foerster and Wilder Penfield were able to map the motor cortex in hundreds of wide-awake patients by stimulating different cortical areas and observing the body's responses. They discovered that body areas requiring precise control, such as the fingers and mouth, occupy the greatest amount of cortical space (**FIGURE 5.2**). In one of his many demonstrations of motor behavior mechanics, Spanish neuroscientist José Delgado stimulated a spot on a patient's left motor cortex, triggering the right hand to make a fist. Asked to keep the fingers open during the next stimulation, the patient, whose fingers closed despite his best efforts, remarked, "I guess, Doctor, that your electricity is stronger than my will" (Delgado, 1969, p. 114).

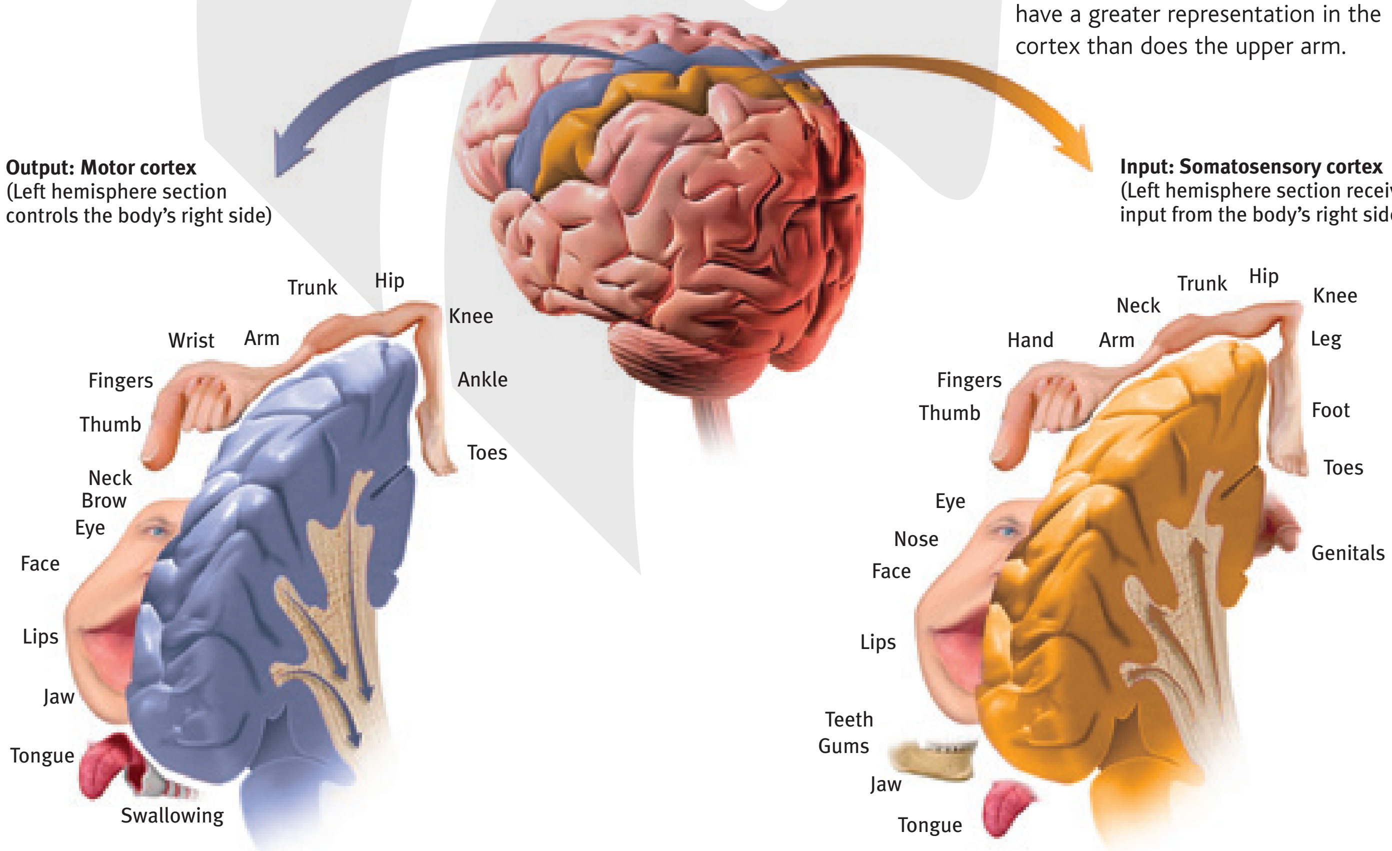


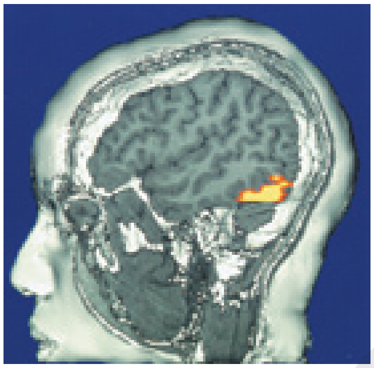
FIGURE 5.2 Left hemisphere tissue devoted to each body part in the motor cortex and the somatosensory cortex As you can see from this classic though inexact representation, the amount of cortex devoted to a body part in the motor cortex (in the frontal lobes) or in the somatosensory cortex (in the parietal lobes) is not proportional to that body part's size. Rather, the brain devotes more tissue to sensitive areas and to areas requiring precise control. Thus, the fingers have a greater representation in the cortex than does the upper arm.

somatosensory cortex area at the front of the parietal lobes that registers and processes body touch and movement sensations.

RETRIEVE IT

- Try moving your right hand in a circular motion, as if cleaning a table. Then start your right foot doing the same motion, synchronized with your hand. Now reverse the right foot's motion, but not the hand's. Finally, try moving the *left* foot opposite to the right hand.
  1. Why is reversing the right foot's motion so hard?
  2. Why is it easier to move the left foot opposite to the right hand?

ANSWERS: 1. The right limbs' opposed activities interfere with each other because both are controlled by the same (left) side of your brain. 2. Opposite sides of your brain control your left and right limbs, so the reversed motion causes less interference.



NeuroImage, Vol. 4, V.P. Clark, K. Keill, J. Ma. Maisog, S. Courtney, L. G. Ungerleider, and J. V. Haxby, Functional Magnetic Resonance Imaging of Human Visual Cortex during Face Matching: A Comparison with Positron Emission Tomography, August 1996, with permission from Elsevier.

FIGURE 5.3

The brain in action This fMRI (functional MRI) scan shows the visual cortex in the occipital lobes activated (color represents increased bloodflow) as a research participant looks at a photo. When the person stops looking, the region instantly calms down.

More recently, scientists were able to predict a monkey's arm motion a tenth of a second *before* it moved—by repeatedly measuring motor cortex activity preceding specific arm movements (Gibbs, 1996). Such findings have opened the door to research on brain-controlled computers.

What might happen, some researchers are asking, if we implant a device to detect motor cortex activity in humans? Could such devices help severely paralyzed people learn to command a cursor to write e-mail or work online? Clinical trials are now under way with people who have suffered paralysis or amputation (Andersen et al., 2010; Nurmikko et al., 2010). The first patient, a paralyzed 25-year-old man, was able to mentally control a TV, draw shapes on a computer screen, and play video games—all thanks to an aspirin-sized chip with 100 microelectrodes recording activity in his motor cortex (Hochberg et al., 2006). Since then, others with paralysis who have been given implants have learned to direct robotic arms with their thoughts (Collinger et al., 2013; Hochberg et al., 2012).

SENSORY FUNCTIONS If the motor cortex sends messages out to the body, where does the cortex receive incoming messages? Penfield identified a cortical area—at the front of the parietal lobes, parallel to and just behind the motor cortex—that specializes in receiving information from the skin senses and from the movement of body parts. We now call this area the **somatosensory cortex** (Figure 5.2). Stimulate a point on the top of this band of tissue and a person may report being touched on the shoulder; stimulate some point on the side and the person may feel something on the face.

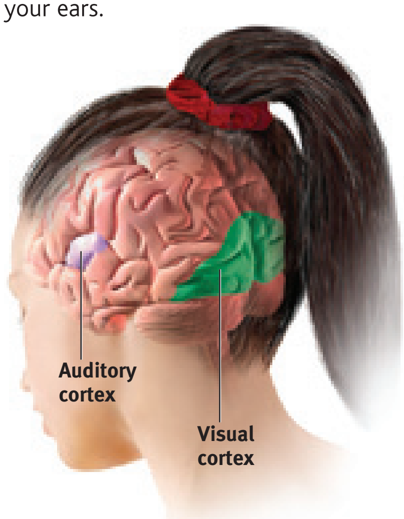
The more sensitive the body region, the larger the somatosensory cortex area devoted to it (Figure 5.2). Your supersensitive lips project to a larger brain area than do your toes, which is one reason we kiss rather than touch toes. Rats have a large area of the brain devoted to their whisker sensations, and owls to their hearing sensations.

Scientists have identified additional areas where the cortex receives input from senses other than touch. Any visual information you are receiving now is going to the visual cortex in your occipital lobes, at the back of your brain (**FIGURES 5.3** and **5.4**). Stimulated in the occipital lobes, you might see flashes of light or dashes of color. (In a sense, we *do* have eyes in the back of our head!) Having lost much of his right occipital lobe to a tumor removal, a friend of mine [DM's] was blind to the left half of his field of vision. Visual information travels from the occipital lobes to other areas that specialize in tasks such as identifying words, detecting emotions, and recognizing faces.

Any sound you now hear is processed by your auditory cortex in your temporal lobes (just above your ears; see Figure 5.4). Most of this auditory information travels a circuitous route from one ear to the auditory receiving area above your opposite ear. If stimulated in your auditory cortex, you might hear a sound. MRI scans of people with schizophrenia have revealed active auditory areas in the temporal lobes during the false sensory experience of auditory *hallucinations* (Lennox et al., 1999). Even the phantom ringing sound experienced by people with hearing loss is—if heard in one ear—associated with activity in the temporal lobe on the brain's opposite side (Muhlnickel, 1998).

FIGURE 5.4

The visual cortex and auditory cortex The visual cortex in the occipital lobes at the rear of your brain receives input from your eyes. The auditory cortex, in your temporal lobes—above your ears—receives information from your ears.



RETRIEVE IT

- Our brain's ______________ cortex registers and processes body touch and movement sensations. The ______________ cortex controls our voluntary movements.

ANSWERS: somatosensory; motor

association areas areas of the cerebral cortex that are not involved in primary motor or sensory functions; rather, they are involved in higher mental functions such as learning, remembering, thinking, and speaking

ASSOCIATION AREAS So far, we have pointed out small cortical areas that either receive sensory input or direct muscular output. Together, these occupy about one-fourth of the human brain's thin, wrinkled cover. What, then, goes on in the remaining vast regions of the cortex? In these **association areas** (the peach-colored areas in **FIGURE 5.5**), neurons are busy with higher mental functions—many of the tasks that make us human.

Electrically probing an association area won't trigger any observable response. So, unlike the somatosensory and motor areas, association area functions cannot be neatly mapped. Their silence has led to what Donald McBurney (1996, p. 44) called "one of the hardiest weeds in the garden of psychology": the claim that we ordinarily use only 10 percent of our brain. (If true, wouldn't this imply a 90 percent chance that a bullet to your brain would land in an unused area?) Surgically lesioned animals and brain-damaged humans bear witness that association areas are not dormant. Rather, these areas interpret, integrate, and act on sensory information and link it with stored memories—a very important part of thinking. Simple tasks often increase activity in small brain patches, involving far less than 10 percent of the brain. Yet complex tasks integrate many islands of brain activity, some performing automatic tasks and others requiring conscious control (Chein & Schneider, 2012). The brain is a whole system, with no dead spot for a stray bullet.

Association areas are found in all four lobes. The *prefrontal cortex* in the forward part of the frontal lobes enables judgment, planning, and processing of new memories. People with damaged frontal lobes may have intact memories, high scores on intelligence tests, and great cake-baking skills. Yet they would not be able to plan ahead to *begin* baking a cake for a birthday party (Huey et al., 2006).

Frontal lobe damage also can alter personality and remove a person's inhibitions. Consider the classic *case study* of railroad worker Phineas Gage. One afternoon in 1848, Gage, then 25 years old, was using a tamping iron to pack gunpowder into a rock. A spark ignited the gunpowder, shooting the rod up through his left cheek and out the top of his skull, leaving his frontal lobes damaged (**FIGURE 5.6**).

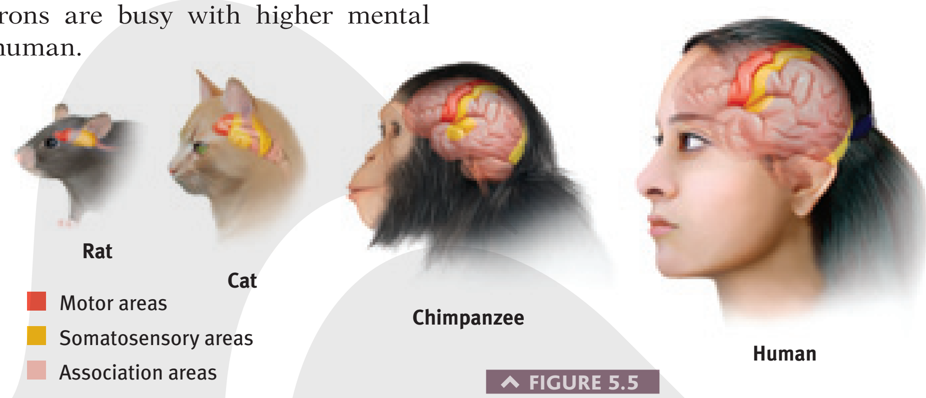
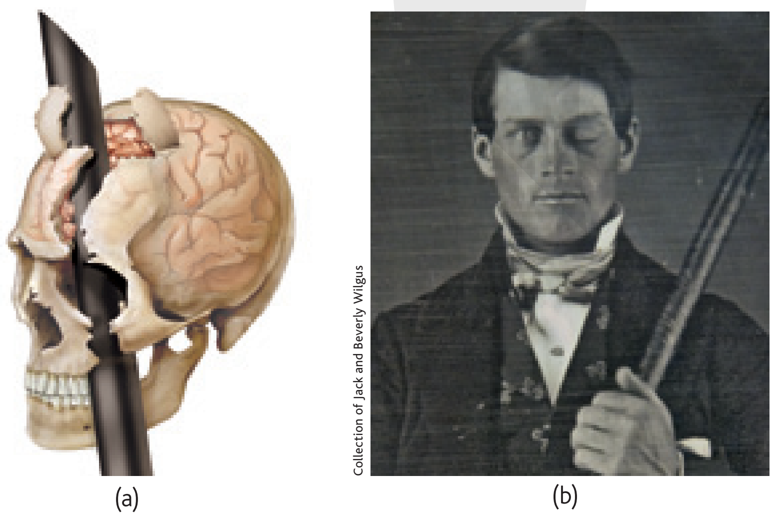


FIGURE 5.5

Areas of the cortex in four mammals More intelligent animals have increased "uncommitted" or association areas of the cortex. These vast areas of the brain are responsible for interpreting, integrating, and acting on sensory information and linking it with stored memories.

LaunchPad See LaunchPad's *Video: Case Studies* for a helpful tutorial animation.



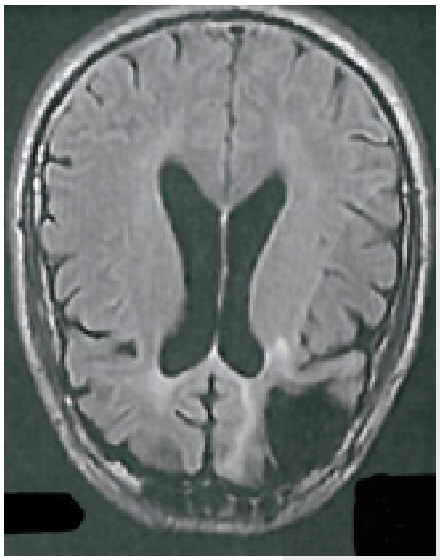
Collection of Jack and Beverly Wilgus

FIGURE 5.6

A blast from the past (a) Phineas Gage's skull was kept as a medical record. Using measurements and modern neuroimaging techniques, researchers have reconstructed the probable path of the rod through Gage's brain (Van Horn et al., 2012). (b) This photo shows Gage after his accident. (The image has been reversed to show the features correctly. Early photos, including this one, were actually mirror images.)

To everyone's amazement, Gage was immediately able to sit up and speak, and after the wound healed he returned to work. But having lost some of the neural tracts that enabled his frontal lobes to control his emotions (Van Horn et al., 2012), the affable, soft-spoken man was now irritable, profane, and dishonest. This person, said his friends, was "no longer Gage." His mental abilities and memories were intact, but his personality was not. (Although Gage lost his railroad job, he did, over time, adapt to his injury and find work as a stage coach driver [Macmillan & Lena, 2010].)

Studies of others with damaged frontal lobes have revealed similar impairments. Not only may they become less inhibited (without the frontal lobe brakes on their impulses), but their moral judgments may seem unrestrained. Cecil Clayton lost 20 percent of his left frontal lobe in a 1972 sawmill accident. Thereafter, his intelligence test score dropped to an elementary school level and he displayed increased impulsivity. In 1996, he fatally shot a deputy sheriff. In 2015, when he was 74, the State of Missouri executed him (Williams, 2015).



Cecil Clayton's brain scan, included with request for stay of execution filed with the Supreme Court, showing a missing portion of his frontal lobe.

Measuring frontal lobe brakes With part of his left frontal lobe (in this downward-facing brain scan) lost to injury, Cecil Clayton became more impulsive and killed a deputy sheriff, for which, nine years later, his state executed him.

Would you advocate pushing one person in front of a runaway trolley to save five others? Most people would not, but those with damage to a brain area behind the eyes are often untroubled by such ethical dilemmas (Koenigs et al., 2007). The frontal lobes help steer us away from violent actions (Molenberghs et al., 2015; Yang & Raine, 2009).

Association areas also perform other mental functions. The parietal lobes, parts of which were large and unusually shaped in Einstein's normal-weight brain, enable mathematical and spatial reasoning (Ibos & Freedman, 2014; Witelson et al., 1999). On the underside of the right temporal lobe, another association area enables us to recognize faces. If a stroke or head injury destroyed this area of your brain, you would still be able to describe facial features and to recognize someone's gender and approximate age, yet be strangely unable to identify the person as, say, Taylor Swift, or even your grandmother.

Nevertheless, complex mental functions don't reside in any one place. There is no one spot in a rat's small association cortex that, when damaged, will obliterate its ability to learn or remember a maze. Your memory, language, and attention result from synchronized activity among distinct brain areas and neural networks (Knight, 2007). Ditto for religious experience. More than 40 distinct brain regions become active in different religious states, such as prayer and meditation, indicating that there is no simple "God spot" (Fingelkurts & Fingelkurts, 2009). *The point to remember:* Our mental experiences arise from coordinated brain activity.

RETRIEVE IT [✖]

- Why are association areas important?

ANSWER: Association areas are involved in higher mental functions—interpreting, integrating, and acting on information processed in other areas.

The Brain's Plasticity

5-2 To what extent can a damaged brain reorganize itself, and what is neurogenesis?

Our brains are sculpted not only by our genes but also by our experiences. In other modules, we'll focus more on how experience molds the brain. For now, let's turn to another aspect of the brain's **plasticity:** its ability to modify itself after damage.

Some brain-damage effects described earlier can be traced to two hard facts: (1) Severed brain and spinal cord neurons, unlike cut skin, usually do not regenerate. (If your spinal cord were severed, you would probably be permanently paralyzed.) And (2) some brain functions seem preassigned to specific areas. One

plasticity the brain's ability to change, especially during childhood, by reorganizing after damage or by building new pathways based on experience.

neurogenesis the formation of new neurons.

newborn who suffered damage to temporal lobe facial recognition areas later remained unable to recognize faces (Farah et al., 2000). But there is good news: Some neural tissue can *reorganize* in response to damage. Under the surface of our awareness, the brain is constantly changing, building new pathways as it adjusts to little mishaps and new experiences.

Plasticity may also occur after serious damage, especially in young children (Kolb, 1989; see also **FIGURE 5.7**). The brain's plasticity is good news for those with vision or hearing loss. Blindness or deafness makes unused brain areas available for other uses (Amedi et al., 2005). If a blind person uses one finger to read Braille, the brain area dedicated to that finger expands as the sense of touch invades the visual cortex that normally helps people see (Barinaga, 1992; Sadato et al., 1996).

Plasticity also helps explain why some studies have found that deaf people have enhanced peripheral and motion-detection vision (Bosworth & Dobkins, 1999; Shiell et al., 2014). In deaf people whose native language is sign, the temporal lobe area normally dedicated to hearing waits in vain for stimulation. Finally, it looks for other signals to process, such as those from the visual system.

Similar reassignment may occur when disease or damage frees up other brain areas normally dedicated to specific functions. If a slow-growing left hemisphere tumor disrupts language (which resides mostly in the left hemisphere), the right hemisphere may compensate (Thiel et al., 2006). If a finger is amputated, the somatosensory cortex that received its input will begin to receive input from the adjacent fingers, which then become more sensitive (Fox, 1984). So what do you suppose was the sexual intercourse experience of one patient whose lower leg had been amputated? "I actually experience my orgasm in my [phantom] foot. [Note that in Figure 5.2, the toes region is adjacent to the genitals.] And there it's much bigger than it used to be because it's no longer just confined to my genitals" (Ramachandran & Blakeslee, 1998, p. 36).

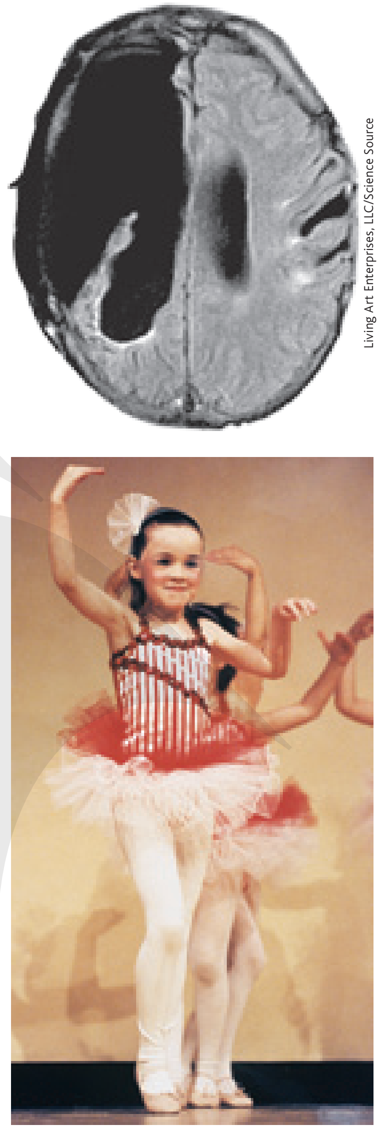
Although the brain often attempts self-repair by reorganizing existing tissue, it sometimes attempts to mend itself by producing new brain cells. This process, known as **neurogenesis,** has been found in adult mice, birds, monkeys, and humans (Jessberger et al., 2008). These baby neurons originate deep in the brain and may then migrate elsewhere and form connections with neighboring neurons (Aimone et al., 2010; Gould, 2007).

Master stem cells that can develop into any type of brain cell have also been discovered in the human embryo. If mass-produced in a lab and injected into a damaged brain, might neural stem cells turn themselves into replacements for lost brain cells? Might surgeons someday be able to rebuild damaged brains, much as landscapers reseed damaged lawns? Stay tuned. Today's biotech companies are exploring such possibilities. In the meantime, we can all benefit from natural promoters of neurogenesis, such as exercise, sleep, and nonstressful but stimulating environments (Iso et al., 2007; Pereira et al., 2007; Stranahan et al., 2006).

Our Divided Brain

5-3 What do split brains reveal about the functions of our two brain hemispheres?

Our brain's look-alike left and right hemispheres serve differing functions. This *lateralization* is apparent after brain damage. Research spanning more than a century has shown that left hemisphere accidents, strokes, and tumors can impair reading, writing, speaking, arithmetic reasoning, and understanding. Similar right hemisphere damage has less visibly dramatic effects. Does this mean that the right hemisphere is just along for the ride? Many believed this was the case until the 1960s, when a fascinating chapter in psychology's history began to unfold: Researchers found that the "minor" right hemisphere was not so limited after all.

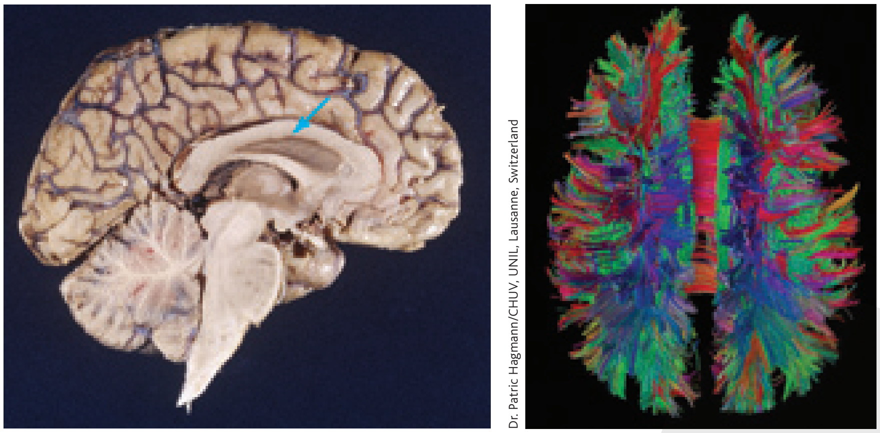


Living Art Enterprises, LLC/Science Source

Joe McNally/Joe McNally Photography/Getty Images

FIGURE 5.7

Brain plasticity This 6-year-old had surgery to end her life-threatening seizures. Although most of an entire hemisphere was removed (see MRI of hemispherectomy above), her remaining hemisphere compensated by putting other areas to work. One Johns Hopkins medical team reflected on the child hemispherectomies they had performed. Although use of the opposite arm was compromised, the team reported being "awed" by how well the children had retained their memory, personality, and humor (Vining et al., 1997). The younger the child, the greater the chance that the remaining hemisphere can take over the functions of the one that was surgically removed (Choi, 2008; Danelli et al., 2013).



Martin M. Rotker/Science Source

Dr. Patric Hagmann/CHUV, UNIL, Lausanne, Switzerland

FIGURE 5.8

The corpus callosum This large band of neural fibers connects the two brain hemispheres. To photograph the half brain above left, a surgeon separated the hemispheres by cutting through the corpus callosum (see blue arrow) and lower brain regions. The high-resolution diffusion spectrum image above right, showing a top-facing brain from above, reveals brain neural networks within the two hemispheres, and the corpus callosum neural bridge between them.

Splitting the Brain

In 1961, Los Angeles neurosurgeons Philip Vogel and Joseph Bogen speculated that major epileptic seizures were caused by an amplification of abnormal brain activity bouncing back and forth between the two cerebral hemispheres, which work together as a whole system. If so, they wondered, could they end this biological tennis match by severing the **corpus callosum,** the wide band of axon fibers connecting the two hemispheres and carrying messages between them (**FIGURE 5.8**)? Vogel and Bogen knew that psychologists Roger Sperry, Ronald Myers, and Michael Gazzaniga had divided cats' and monkeys' brains in this manner, with no serious ill effects.

So the surgeons operated. The result? The seizures all but disappeared. The patients with these **split brains** were surprisingly normal, their personality and intellect hardly affected. Waking from surgery, one even joked that he had a "splitting headache" (Gazzaniga, 1967). By sharing their experiences, these patients have greatly expanded our understanding of interactions between the intact brain's two hemispheres.

To appreciate these findings, we need to focus for a minute on the peculiar nature of our visual wiring, illustrated in **FIGURE 5.9**. Note that each eye receives sensory information from the entire visual field. But in each eye, information from the left half of your field of vision goes to your right hemisphere, and information from the right half of your visual field goes to your left hemisphere, which usually controls speech. Information received by either hemisphere is quickly transmitted to the other across the corpus callosum. In a person with a severed corpus callosum, this information-sharing does not take place.

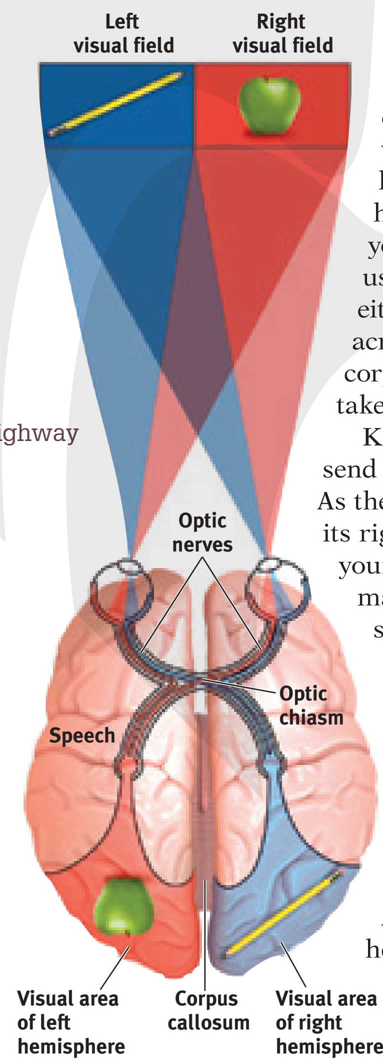


FIGURE 5.9

The information highway from eye to brain

Knowing these facts, Sperry and Gazzaniga could send information to a patient's left or right hemisphere. As the person stared at a spot, they flashed a stimulus to its right or left. They could do this with you, too, but in your intact brain, the hemisphere receiving the information would instantly pass the news to the other side. Because the split-brain surgery had cut the communication lines between the hemispheres, the researchers could, with these patients, quiz each hemisphere separately.

In an early experiment, Gazzaniga (1967) asked split-brain patients to stare at a dot as he flashed HE·ART on a screen (**FIGURE 5.10**). Thus, HE appeared in their left visual field (which transmits to the right hemisphere) and ART in the right field (which transmits to the left hemisphere). When he then asked them to *say* what they had seen, the patients reported that they had seen ART. But when asked to *point* to the word they had seen, they were startled when

corpus callosum [KOR-pus kah-LOW-sum] the large band of neural fibers connecting the two brain hemispheres and carrying messages between them.

split brain a condition resulting from surgery that isolates the brain's two hemispheres by cutting the fibers (mainly those of the corpus callosum) connecting them.

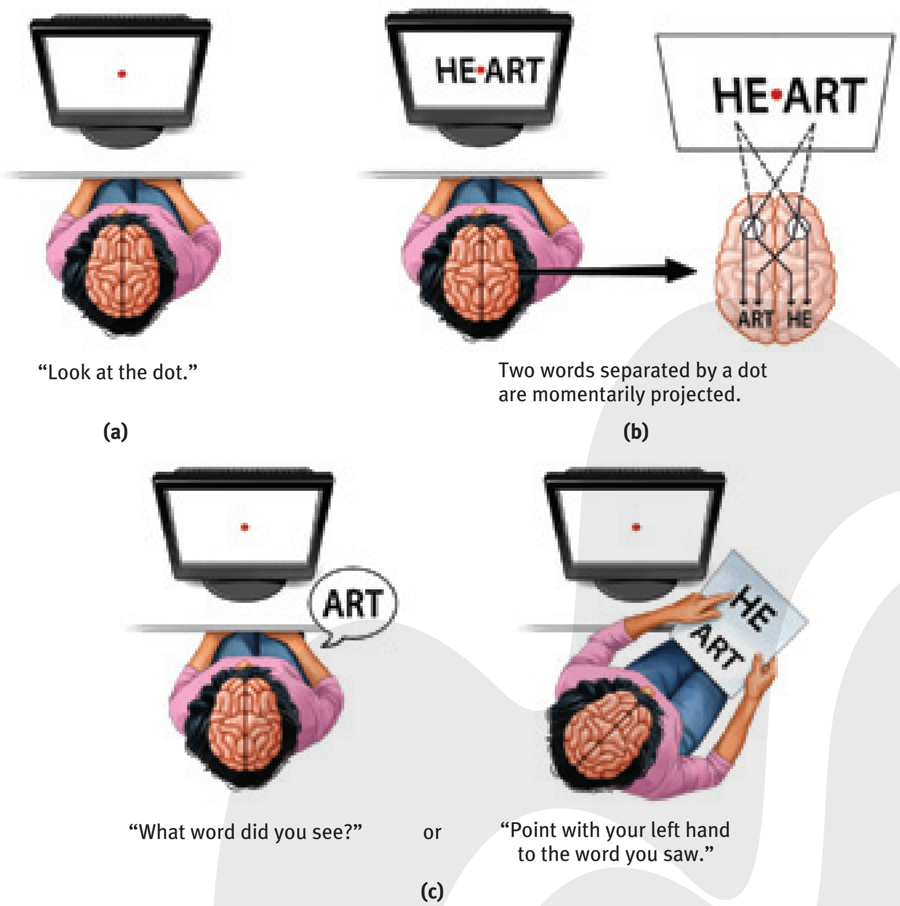


FIGURE 5.10
One skull, two minds When an experimenter flashes the word HEART across the visual field, a woman with a split brain verbally reports seeing the portion of the word transmitted to her left hemisphere. However, if asked to indicate with her left hand what she saw, she points to the portion of the word transmitted to her right hemisphere. (From Gazzaniga, 1983.)

their left hand (controlled by the right hemisphere) pointed to HE. Given an opportunity to express itself, each hemisphere indicated what it had seen. The right hemisphere (controlling the left hand) intuitively knew what it could not verbally report.

When a picture of a spoon was flashed to their right hemisphere, the patients could not *say* what they had viewed. But when asked to *identify* what they had viewed by feeling an assortment of hidden objects with their left hand, they readily selected the spoon. If the experimenter said, "Correct!" the patient might reply, "What? Correct? How could I possibly pick out the correct object when I don't know what I saw?" It is, of course, the left hemisphere doing the talking here, bewildered by what the nonverbal right hemisphere knows.

A few people who have had split-brain surgery have been for a time bothered by the unruly independence of their left hand, which might unbutton a shirt while the right hand buttoned it, or put grocery store items back on the shelf after the right hand put them in the cart. It was as if each hemisphere was thinking "I've half a mind to wear my green (blue) shirt today." Indeed, said Sperry (1964), split-brain surgery leaves people "with two separate minds." With a split brain, both hemispheres can comprehend and follow an instruction to copy—*simultaneously*—different figures with the left and right hands (Franz et al., 2000; see also **FIGURE 5.11**).

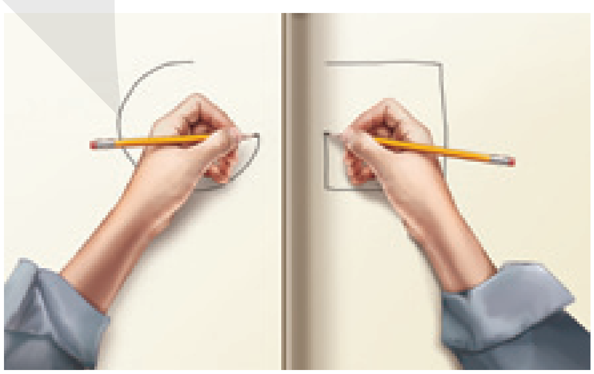


FIGURE 5.11
Try this! People who have had split-brain surgery can simultaneously draw two different shapes.

"Do not let your left hand know what your right hand is doing."

Matthew 6:3

LaunchPad IMMERSIVE LEARNING Have you ever been asked if you are "left-brained" or "right-brained"? Consider this popular misconception with LaunchPad's *How Would You Know If People Can Be "Left-Brained" or "Right-Brained"?*

(Reading these reports, one can fantasize a patient enjoying a solitary game of "rock, paper, scissors"—left versus right hand.)

When the "two minds" are at odds, the left hemisphere does mental gymnastics to rationalize reactions it does not understand. If a patient follows an order ("Walk") sent to the right hemisphere, a strange thing happens. The left hemisphere, unaware of the order, doesn't know why the patient begins walking. If asked why, the patient doesn't reply, "I don't know." Instead, the left hemisphere improvises—"I'm going into the house to get a Coke." Gazzaniga (2006), who described these patients as "the most fascinating people on earth," realized that the conscious left hemisphere is an "interpreter" that instantly constructs explanations. The brain, he concluded, often runs on autopilot; it acts first and then explains itself.

RETRIEVE IT

- (1) If we flash a red light to the right hemisphere of a person with a split brain, and flash a green light to the left hemisphere, will each observe its own color? (2) Will the person be aware that the colors differ? (3) What will the person verbally report seeing?

ANSWERS: 1. yes, 2. no, 3. green

Right-Left Differences in the Intact Brain

So, what about the 99.99+ percent of us with undivided brains? Does each of *our* hemispheres also perform distinct functions? Several different types of studies indicate they do. When a person performs a *perceptual* task, for example, brain waves, bloodflow, and glucose consumption reveal increased activity in the *right* hemisphere. When the person speaks or calculates, activity usually increases in the *left* hemisphere.

A dramatic demonstration of hemispheric specialization happens before some types of brain surgery. To locate the patient's language centers, the surgeon injects a sedative into the neck artery feeding blood to the left hemisphere, which usually controls speech. Before the injection, the patient is lying down, arms in the air, chatting with the doctor. Can you predict what probably happens when the drug puts the left hemisphere to sleep? Within seconds, the person's right arm falls limp. If the left hemisphere is controlling language, the patient will be speechless until the drug wears off. If the drug is injected into the artery to the right hemisphere, the *left* arm will fall limp, but the person will still be able to speak.

To the brain, language is language, whether spoken or signed. Just as hearing people usually use the left hemisphere to process spoken language, deaf people use the left hemisphere to process sign language (Corina et al., 1992; Hickok et al., 2001). Thus, a left hemisphere stroke disrupts a deaf person's signing, much as it would disrupt a hearing person's speaking (Corina, 1998).

Although the left hemisphere is skilled at making quick, literal interpretations of language, the right hemisphere excels at *making inferences* (Beeman & Chiarello, 1998; Bowden & Beeman, 1998; Mason & Just, 2004). It also *helps us modulate our speech* to make meaning clear—as when we say "Let's eat, Grandpa" instead of "Let's eat Grandpa" (Heller, 1990). The right hemisphere also *helps orchestrate our self-awareness*. People who suffer partial paralysis will sometimes stubbornly deny their impairment—strangely claiming they can move a paralyzed limb—if the damage is to the right hemisphere (Berti et al., 2005).

Simply looking at the two hemispheres, so alike to the naked eye, who would suppose they contribute uniquely to the harmony of the whole? Yet a variety of observations—of people with split brains, of people with normal brains, and even of other species' brains—converge beautifully, leaving little doubt that we have unified brains with specialized parts (Hopkins & Cantalupo, 2008; MacNeilage et al., 2009).

How does the brain's intricate networking emerge? How does our *heredity*—the legacy of our ancestral history—conspire with our experiences to organize and "wire" the brain? To that we turn next.

LaunchPad For a helpful animated review of split-brain research, see LaunchPad's *PsychSim 6: Hemispheric Specialization.*

MODULE 5 REVIEW The Cerebral Cortex and Our Divided Brain

Learning Objectives

Test Yourself by taking a moment to answer each of these Learning Objective Questions (repeated here from within the module). Then turn to Appendix D, Complete Module Reviews, to check your answers. Research suggests that trying to answer these questions on your own will improve your long-term memory of the concepts (McDaniel et al., 2009).

5-1 What are the functions of the various cerebral cortex regions?

5-2 To what extent can a damaged brain reorganize itself, and what is neurogenesis?

5-3 What do split brains reveal about the functions of our two brain hemispheres?

Terms and Concepts to Remember

Test yourself on these terms by trying to write down the definition in your own words before flipping back to the referenced page to check your answers.

cerebral [seh-REE-bruhl] cortex, p. 56
frontal lobes, p. 56
parietal [puh-RYE-uh-tuhl] lobes, p. 56
occipital [ahk-SIP-uh-tuhl] lobes, p. 56
temporal lobes, p. 56
motor cortex, p. 57
somatosensory cortex, p. 58
association areas, p. 59
plasticity, p. 60
neurogenesis, p. 61
corpus callosum [KOR-pus kah-LOW-sum], p. 62
split brain, p. 62

Experience the Testing Effect

Test yourself repeatedly throughout your studies. This will not only help you figure out what you know and don't know; the testing itself will help you learn and remember the information more effectively thanks to the *testing effect*.

1. If a neurosurgeon stimulated your right motor cortex, you would most likely
   a. see light.
   b. hear a sound.
   c. feel a touch on the right arm.
   d. move your left leg.
2. How do different neural networks communicate with one another to let you respond when a friend greets you at a party?
3. Which of the following body regions has the greatest representation in the somatosensory cortex?
   a. Upper arm
   b. Toes
   c. Lips
   d. All regions are equally represented.
4. Judging and planning are enabled by the ______________ lobes.
5. What would it be like to talk on the phone if you didn't have temporal lobe association areas? What would you hear? What would you understand?
6. The "uncommitted" areas that make up about three-fourths of the cerebral cortex are called ______________ ______________.
7. Plasticity is especially evident in the brains of
   a. split-brain patients.
   b. young adults.
   c. young children.
   d. right-handed people.
8. An experimenter flashes the word HERON across the visual field of a man whose corpus callosum has been severed. HER is transmitted to his right hemisphere and ON to his left hemisphere. When asked to indicate what he saw, the man says he saw ______________ but points to ______________.
9. Studies of people with split brains and brain scans of those with undivided brains indicate that the left hemisphere excels in
   a. processing language.
   b. visual perceptions.
   c. making inferences.
   d. neurogenesis.
10. Damage to the brain's right hemisphere is most likely to reduce a person's ability to
    a. recite the alphabet rapidly.
    b. make inferences.
    c. understand verbal instructions.
    d. solve arithmetic problems.

Find answers to these questions in Appendix E, in the back of the book.

Use LearningCurve to create your personalized study plan, which will direct you to the resources that will help you most in LaunchPad.

MODULE 6 Genetics, Evolutionary Psychology, and Behavior

A Thousand Words Photography by Erica Corner

The nurture of nature Parents everywhere wonder: Will my baby grow up to be peaceful or aggressive? Homely or attractive? Successful or struggling at every step? What comes built in, and what is nurtured—and how? Research reveals that nature and nurture together shape our development—every step of the way.

Behavior Genetics: Predicting Individual Differences

6-1 What are *chromosomes, DNA, genes,* and the human *genome?* How do behavior geneticists explain our individual differences?

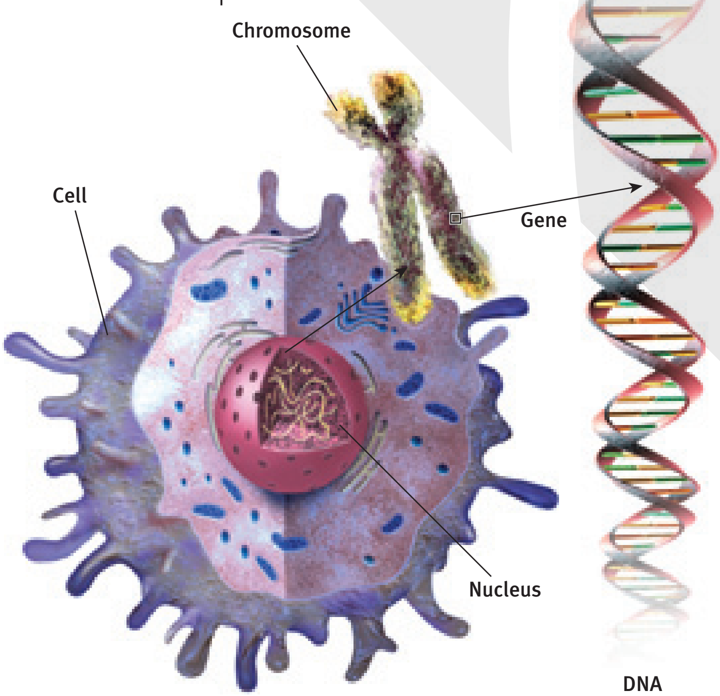
Our shared brain architecture predisposes some common behavioral tendencies. Whether we live in the Arctic or the tropics, we sense the world, develop language, and feel hunger through identical mechanisms. We prefer sweet tastes to sour. We divide the color spectrum into similar colors. And we feel drawn to behaviors that produce and protect offspring.

Our human family shares not only a common biological heritage—cut us and we bleed—but also common social behaviors. Whether named Gonzales, Nkomo, Smith, or Wong, we start fearing strangers at about eight months, and as adults we prefer the company of those with attitudes and attributes similar to our own. As members of one species, we affiliate, conform, return favors, punish offenses, organize hierarchies of status, and grieve a child's death. A visitor from outer space could drop in anywhere and find humans dancing and feasting, singing and worshiping, playing sports and games, laughing and crying, living in families and forming groups. We are the leaves of one tree.

But in important ways, we also are each unique. We look different. We sound different. We have varying personalities, interests, and cultural and family backgrounds. What causes our striking diversity? How much of it is shaped by our differing genes, and how much by our **environment**—by every external influence, from maternal nutrition while in the womb to social support while nearing the tomb? How does our **heredity** interact with our experiences to create both our universal human nature and our individual and social diversity? Such questions intrigue **behavior geneticists.**

FIGURE 6.1

The life code The nucleus of every human cell contains chromosomes, each of which is made up of two strands of DNA connected in a double helix. Genes are DNA segments that, when expressed (turned on), direct the development of proteins that influence a person's individual development.



Genes: Our Codes for Life

Barely more than a century ago, few would have guessed that every cell nucleus in your body contains the genetic master code for your entire body. It's as if every room in Dubai's Burj Khalifa (the world's tallest building) contained a book detailing the architect's plans for the entire structure. The plans for your own book of life run to 46 chapters—23 donated by your mother's egg and 23 by your father's sperm. Each of these 46 chapters, called a **chromosome,** is composed of a coiled chain of the molecule **DNA** *(deoxyribonucleic acid)*. **Genes,** small segments of the giant DNA molecules, form the words of those chapters (**FIGURE 6.1**). Altogether, you have 20,000 to 25,000 genes, which can be either active *(expressed)* or inactive. Environmental events "turn on" genes, rather like hot water enabling a tea bag to express its flavor. When turned on, genes provide the code for creating *protein molecules,* our body's building blocks.

Genetically speaking, every other human is nearly your identical twin. Human **genome** researchers have discovered the common sequence within human DNA. This shared genetic profile makes us humans, rather than tulips, bananas, or chimpanzees.

The occasional variations found at particular gene sites in human DNA fascinate geneticists and psychologists. Slight person-to-person variations from the common pattern give clues to our uniqueness—why one person has a disease that another does not, why one person is tall and another short, why one is anxious and another calm.

Most of our traits have complex genetic roots. How tall you are, for example, reflects the size of your face, vertebrae, leg bones, and so forth—each of which may be influenced by different genes interacting with your specific environment. Traits such as intelligence, happiness, and aggressiveness are similarly influenced by groups of genes. Thus, our genes help explain both our shared human nature and our human diversity. But knowing our heredity tells only part of our story. To form us, environmental influences interact with our genetic predispositions.

"Thanks for almost everything, Dad."

"We share half our genes with the banana."

Evolutionary biologist Robert May, president of Britain's Royal Society, 2001

"Your DNA and mine are 99.9 percent the same. . . . At the DNA level, we are clearly all part of one big worldwide family."

Francis Collins, Human Genome Project director, 2007

RETRIEVE IT [✖]

- Put the following cell structures in order from smallest to largest: nucleus, gene, chromosome

ANSWER: gene, chromosome, nucleus

- When the mother's egg and the father's sperm unite, each contributes 23 __________.

ANSWER: chromosomes

Twin and Adoption Studies

6-2 How do twin and adoption studies help us understand the effects and interactions of nature and nurture?

To scientifically tease apart the influences of environment and heredity, behavior geneticists could wish for two types of experiments. The first would control heredity while varying the home environment. The second would control the home environment while varying heredity. Although such experiments with human infants would be unethical, nature has done this work for us.

IDENTICAL VERSUS FRATERNAL TWINS **Identical** *(monozygotic)* **twins** develop from a single fertilized egg that splits in two. Thus they are *genetically* identical—nature's own human clones (**FIGURE 6.2**). Indeed, they are clones who share not only the same genes but the same conception and uterus, and usually the same birth date and cultural history.

LaunchPad See LaunchPad's *Video: Twin Studies* for a helpful tutorial animation.

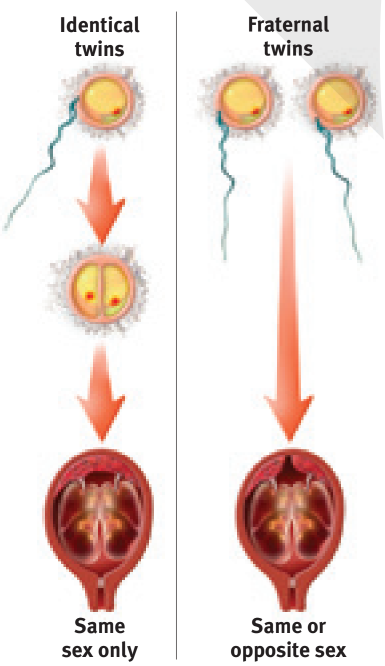


FIGURE 6.2
Same fertilized egg, same genes; different eggs, different genes Identical twins develop from a single fertilized egg, fraternal twins from two.

environment every nongenetic influence, from prenatal nutrition to the people and things around us.

heredity the genetic transfer of characteristics from parents to offspring.

behavior genetics the study of the relative power and limits of genetic and environmental influences on behavior.

chromosomes threadlike structures made of DNA molecules that contain the genes.

DNA (deoxyribonucleic acid) a complex molecule containing the genetic information that makes up the chromosomes.

genes the biochemical units of heredity that make up the chromosomes; segments of DNA capable of synthesizing proteins.

genome the complete instructions for making an organism, consisting of all the genetic material in that organism's chromosomes.

identical (monozygotic) twins develop from a single fertilized egg that splits in two, creating two genetically identical organisms.


twinstrangers.com

Skin deep Do identical twins have similar personalities because people respond to their similar looks? These women look like identical twins, but they aren't genetically related. Such "twins" do not report similar personalities (Segal, 2013).

Fraternal *(dizygotic)* **twins** develop from two separate fertilized eggs. As womb-mates, they share a prenatal environment, but they are genetically no more similar than ordinary brothers and sisters.

Shared genes can translate into shared experiences. A person whose identical twin has autism spectrum disorder, for example, has about a 3 in 4 risk of being similarly diagnosed. If the affected twin is fraternal, the co-twin has about a 1 in 3 risk (Ronald & Hoekstra, 2011). To study the effects of genes and environments, hundreds of researchers have studied some 800,000 identical and fraternal twin pairs (Johnson et al., 2009).

Are genetically identical twins also *behaviorally* more similar than fraternal twins? Studies of thousands of twin pairs have found that identical twins are much more alike in *extraversion* (outgoingness) and *neuroticism* (emotional instability) than are fraternal twins (Kandler et al., 2011; Laceulle et al., 2011; Loehlin, 2012).

Identical twins, more than fraternal twins, look alike. So, do people's responses to their looks account for their similarities? *No*. In one clever study, a researcher compared personality similarity between identical twins and unrelated look-alike pairs (Segal, 2013). Only the identical twins reported similar personalities. Other studies have shown that identical twins whose parents treated them alike (for example, dressing them identically) were not psychologically more alike than identical twins who were treated less similarly (Kendler et al., 1994; Loehlin & Nichols, 1976). In explaining individual differences, genes matter.

SEPARATED TWINS Imagine the following science fiction experiment: A mad scientist decides to separate identical twins at birth, then raise them in differing environments. Better yet, consider a *true* story:

Twins Lorraine and Levinia Christmas, driving to deliver Christmas presents to each other near Flitcham, England, collided (Shepherd, 1997).

On a chilly February morning in 1979, some time after divorcing his first wife, Linda, Jim Lewis awoke in his modest home next to his second wife, Betty. Determined to make this marriage work, Jim made a habit of leaving love notes to Betty around the house. As he lay in bed he thought about others he had loved, including his son, James Alan, and his faithful dog, Toy.

Jim looked forward to spending part of the day in his basement woodworking shop, where he enjoyed building furniture, picture frames, and other items, including a white bench now circling a tree in his front yard. Jim also liked to spend free time driving his Chevy, watching stock car racing, and drinking Miller Lite beer.

Jim was basically healthy, except for occasional half-day migraine headaches and blood pressure that was a little high, perhaps related to his chain-smoking habit. He had become overweight a while back but had shed some of the pounds. Having undergone a vasectomy, he was done having children.

What was extraordinary about Jim Lewis, however, was that at that same moment (we are not making this up) there existed another man—also named Jim—for whom all these things (right down to the dog's name) were also true.[1] This other Jim—Jim Springer—just happened, 38 years earlier, to have been his fetal partner. Thirty-seven days after their birth, these genetically identical twins were separated, adopted by blue-collar families, and raised with no contact or knowledge of each other's whereabouts until the day Jim Lewis received a call from his genetic clone (who, having been told he had a twin, set out to find him).

One month later, the brothers became the first of many separated twin pairs tested by University of Minnesota psychologist Thomas Bouchard and his

fraternal (dizygotic) twins develop from separate fertilized eggs. They are genetically no closer than ordinary brothers and sisters, but they share a prenatal environment.

1. Actually, this description of the two Jims errs in one respect: Jim Lewis named his son James Alan. Jim Springer named his James Allan.

colleagues (Miller, 2012). The brothers' voice intonations and inflections were so similar that, hearing a playback of an earlier interview, Jim Springer guessed "That's me." Wrong—it was Jim Lewis. Given tests measuring their personality, intelligence, heart rate, and brain waves, the Jim twins—despite 38 years of separation—were virtually as alike as the same person tested twice. Both married women named Dorothy Jane Scheckelburger. Okay, the last item is a joke. But as Judith Rich Harris (2006) has noted, it would hardly be weirder than some other reported similarities.

Aided by media publicity, Bouchard (2009) and his colleagues located and studied 74 pairs of identical twins raised apart. They continued to find similarities not only of tastes and physical attributes but also of personality (characteristic patterns of thinking, feeling, and acting), abilities, attitudes, interests, and even fears.

In Sweden, researchers identified 99 separated identical twin pairs and more than 200 separated fraternal twin pairs (Pedersen et al., 1988). Compared with equivalent samples of identical twins raised together, the separated identical twins had somewhat less identical personalities. Still, separated twins were more alike if genetically identical than if fraternal. And separation shortly after birth (rather than, say, at age 8) did not amplify their personality differences.

Stories of startling twin similarities have not impressed critics, who remind us that "The plural of *anecdote* is not *data*." They note that if any two strangers were to spend hours comparing their behaviors and life histories, they would probably discover many coincidental similarities. If researchers created a control group of biologically unrelated pairs of the same age, sex, and ethnicity, who had not grown up together but who were as similar to one another in economic and cultural background as are many of the separated twin pairs, wouldn't these pairs also exhibit striking similarities (Joseph, 2001)? Twin researchers have replied that separated fraternal twins do not exhibit similarities comparable with those of separated identical twins.

The impressive data from personality assessments are clouded by the reunion of many of the separated twins some years before they were tested. And adoption agencies also tend to place separated twins in similar homes. Despite these criticisms, the striking twin-study results helped shift scientific thinking toward a greater appreciation of genetic influences.

If genetic influences help explain individual differences, can the same be said of trait differences *between* groups? Not necessarily. Individual differences in height and weight, for example, are highly *heritable;* yet nutrition (an environmental factor) rather than genetic influences explains why, as a group, today's adults are taller and heavier than those of a century ago. The two groups differ, but not because human genes have changed in a mere century's eyeblink of time. Ditto aggressiveness, a genetically influenced trait. Today's peaceful Scandinavians differ from their more aggressive Viking ancestors, despite carrying many of the same genes.

BIOLOGICAL VERSUS ADOPTIVE RELATIVES For behavior geneticists, nature's second real-life experiment—adoption—creates two groups: *genetic relatives* (biological parents and siblings) and *environmental relatives* (adoptive parents and siblings). For personality or any other given trait, we can therefore ask whether adopted children are more like their biological parents, who contributed their genes, or their adoptive parents, who contribute a home environment. While sharing that home environment, do adopted siblings also come to share traits?

The stunning finding from studies of hundreds of adoptive families is that, with the exception of identical twins, people who grow up together do not much

In 2009, thieves broke into a Berlin store and stole jewelry worth $6.8 million. One thief left a drop of sweat—a link to his genetic signature. Police analyzed the DNA and encountered two matches: The DNA belonged to identical twin brothers. The court ruled that "at least one of the brothers took part in the crime, but it has not been possible to determine which one." Birds of a feather can rob together.

Coincidences are not unique to twins. Patricia Kern of Colorado was born March 13, 1941, and named Patricia Ann Campbell. Patricia DiBiasi of Oregon also was born March 13, 1941, and named Patricia Ann Campbell. Both had fathers named Robert, worked as bookkeepers, and at the time of this comparison had children ages 21 and 19. Both studied cosmetology, enjoyed oil painting as a hobby, and married military men, within 11 days of each other. They are not genetically related. (From an AP report, May 2, 1983.)

Mona Friis Bertheussen/Moment Film

Identical twins are people two Identical twin sisters Mia (left) and Alexandra (right), featured in the film *Twin Sisters* (2013), are nearly always worlds apart. Adopted to different families as infants, Mia lives in suburban California and Alexandra lives in a Norwegian village. Mia plays the piano and enjoys golf, whereas Alexandra roams the countryside and plays with her pet mouse. Despite these differences, they share striking similarities. Both girls dislike tomatoes, olives, and messy rooms but are wild about chocolate.

Charles Sykes/AP Photo

Nature or nurture or both? When talent runs in families, as with Wynton Marsalis, Branford Marsalis, and Delfeayo Marsalis, how do heredity and environment together do their work?

Edward Koren/The New Yorker Collection/Condé Nast

"Do you, Ashley, take Nesbitt and his genome to be your husband?"

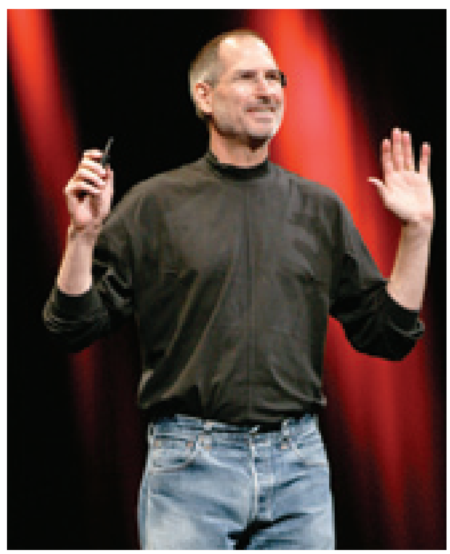
resemble one another in personality (McGue & Bouchard, 1998; Plomin, 2011; Rowe, 1990). In personality traits such as extraversion and agreeableness, people who have been adopted are more similar to their biological parents than to their caregiving adoptive parents.

The finding is important enough to bear repeating: *The environment shared by a family's children has virtually no discernible impact on their personalities.* Two adopted children raised in the same home are no more likely to share personality traits with each other than with the child down the block. Heredity shapes other primates' personalities, too. Macaque monkeys raised by foster mothers exhibited social behaviors that resembled their biological, rather than foster, mothers (Maestripieri, 2003). Add in the similarity of identical twins, whether they grow up together or apart, and the effect of a shared environment seems shockingly modest.

The genetic leash may limit the family environment's influence on personality, but it does not mean that adoptive parenting is a fruitless venture. As a new adoptive parent, I [ND] especially find it heartening to know that parents do influence their children's attitudes, values, manners, politics, and faith (Reifman & Cleveland, 2007). Religious involvement is genetically influenced (Steger et al., 2011). But a pair of adopted children or identical twins *will,* especially during adolescence, have more similar religious beliefs if raised together (Koenig et al., 2005). Parenting matters!

Moreover, child neglect and abuse and even parental divorce are rare in adoptive homes. (Adoptive parents are carefully screened; biological parents are not.) So it is not surprising that studies have shown that, despite a slightly greater risk of psychological disorder, most adopted children thrive, especially when adopted as infants (Loehlin et al., 2007; van IJzendoorn & Juffer, 2006; Wierzbicki, 1993). Seven in eight adopted children have reported feeling strongly attached to one or both adoptive parents. As children of self-giving parents, they have grown up to be more self-giving and altruistic than average (Sharma et al., 1998). Many scored higher than their biological parents and raised-apart biological siblings on intelligence tests, and most grew into happier and more stable adults (Kendler et al.,

Frederick Breedon IV/Getty Images



Ryan Anson/Bloomberg/Getty Images

Adoption matters As country music singer Faith Hill and late Apple founder Steve Jobs experienced, children benefit from one of the biggest gifts of love: adoption.

2015; van IJzendoorn et al., 2005). In one Swedish study, children adopted as infants grew up with fewer problems than were experienced by children whose biological mothers initially registered them for adoption but then decided to raise the children themselves (Bohman & Sigvardsson, 1990). Regardless of personality differences between adoptive family members, most adopted children benefit from adoption.

interaction the interplay that occurs when the effect of one factor (such as environment) depends on another factor (such as heredity).

RETRIEVE IT

- How do researchers use twin and adoption studies to learn about psychological principles?

ANSWER: Researchers use twin and adoption studies to understand how much variation among individuals is due to genetic makeup and how much to environmental factors. Some studies compare the traits and behaviors of identical twins (same genes) and fraternal twins (different genes, as in any two siblings). They also compare adopted children with their adoptive and biological parents. Some studies compare traits and behaviors of twins raised together or separately.

Gene-Environment Interaction

6-3 How do heredity and environment work together?

Among our similarities, the most important—the behavioral hallmark of our species—is our enormous adaptive capacity. Some human traits, such as having two eyes, develop the same in virtually every environment. But other traits are expressed only in particular environments. Go barefoot for a summer and you will develop toughened, callused feet—a biological adaptation to friction. Meanwhile, your shod neighbor will remain a tenderfoot. The difference between the two of you is an effect of environment. But it is also the product of a biological mechanism—adaptation.

Genes and environment—nature and nurture—work together, like two hands clapping. Genes are *self-regulating.* Rather than acting as blueprints that lead to the same result no matter the context, genes react. An African butterfly that is green in summer turns brown in fall, thanks to a temperature-controlled genetic switch. The same genes that produced green in one situation produce brown in another.

"Men's natures are alike; it is their habits that carry them far apart."
Confucius, Analects, *500* B.C.E.

To say that genes and experience are *both* important is true. But more precisely, they **interact.** Imagine two babies, one genetically predisposed to be attractive, sociable, and easygoing, the other less so. Assume further that the first baby attracts more affectionate and stimulating care and so develops into a warmer and more outgoing person. As the two children grow older, the more naturally outgoing child may seek more activities and friends that encourage further social confidence.

Robert Markowitz/N.A.S.A/SIPA/Newscom

Genetic space exploration In 2015, Scott (left) and Mark (right) Kelly embarked on a twin study that is literally out of this world. Scott will spend a year orbiting the planet in the International Space Station. His identical twin, Mark, will stay on Earth. Both twins will undergo the same physical and psychological testing. The study results will help scientists understand how genes and environment—in outer space and on Earth—interact.

epigenetics the study of environmental influences on gene expression that occur without a DNA change.

evolutionary psychology the study of the evolution of behavior and the mind, using principles of natural selection.

natural selection the principle that those chance inherited traits that better enable an organism to survive and reproduce in a particular environment will most likely be passed on to succeeding generations.

What has caused their resulting personality differences? Neither heredity nor experience act alone. Environments trigger gene activity. And our genetically influenced traits *evoke* significant responses in others. Thus, a child's impulsivity and aggression may evoke an angry response from a parent or teacher, who reacts warmly to well-behaved children in the family or classroom. In such cases, the child's nature and the adult's nurture interact. Gene and scene dance together.

Identical twins not only share the same genetic predispositions, they also seek and create similar experiences that express their shared genes (Kandler et al., 2012). Evocative interactions may help explain why identical twins raised in different families have recalled their parents' warmth as remarkably similar—almost as similar as if they had been raised by the same parents (Plomin et al., 1988, 1991, 1994). Fraternal twins have more differing recollections of their early family life—even if raised in the same family! "Children experience us as different parents, depending on their own qualities," noted Sandra Scarr (1990).

Recall that genes can be either active (expressed, as the hot water activates the tea bag) or inactive. **Epigenetics** (meaning "in addition to" or "above and beyond" genetics), studies the molecular mechanisms by which environments can trigger or block genetic expression. Our experiences create *epigenetic marks*, which are often organic methyl molecules attached to part of a DNA strand (**FIGURE 6.3**). If a mark instructs the cell to ignore any gene present in that DNA segment, those genes will be "turned off"—they will prevent the DNA from producing the proteins coded by that gene. As one geneticist said, "Things written in pen you can't change. That's DNA. But things written in pencil you can. That's epigenetics" (Reed, 2011).

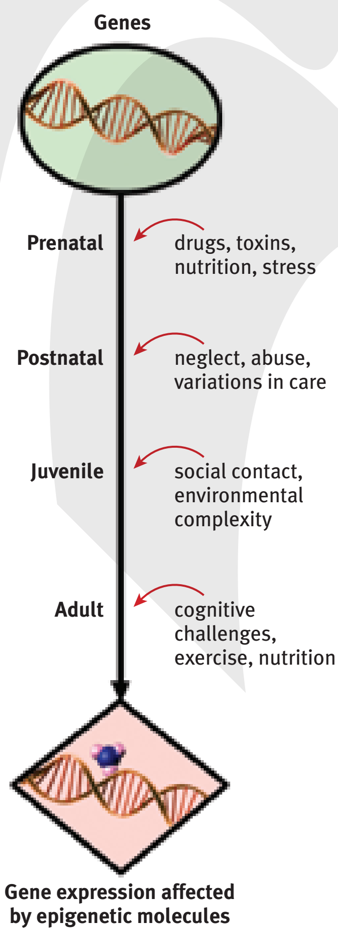


FIGURE 6.3

Epigenetics influences gene expression Life experiences beginning in the womb lay down epigenetic marks—often organic methyl molecules—that can affect the expression of any gene in the associated DNA segment. (Research from Champagne, 2010.)

Environmental factors such as diet, drugs, and stress can affect the epigenetic molecules that regulate gene expression. Mother rats normally lick their infants. Deprived of this licking in experiments, infant rats had more epigenetic molecules blocking access to their brain's "on" switch for developing stress hormone receptors. When stressed, those animals had above-average levels of free-floating stress hormones and were more stressed (Champagne et al., 2003; Champagne & Mashoodh, 2009). Epigenetics research may solve some scientific mysteries, such as why only one member of an identical twin pair may develop a genetically influenced mental disorder, and how childhood abuse leaves its fingerprints in a person's brain (Spector, 2012).

Epigenetics can also help explain why identical twins may look slightly different. Researchers studying mice have found that in utero exposure to certain chemicals can cause genetically identical twins to have different-colored fur (Dolinoy et al., 2007). Such discoveries will be made easier by efforts such as the National Institutes of Health–funded Roadmap Epigenetics Project, a massive undertaking aimed at making epigenetic data publicly available.

So, if Beyoncé and Jay Z's daughter, Blue Ivy, grows up to be a popular recording artist, should we attribute her musical talent to her "superstar genes"? To her growing up in a musically rich environment? To high expectations? The best answer seems to be "All of the above." From conception onward, we are the product of a cascade of interactions between our genetic predispositions and our surrounding environments (McGue, 2010). Our genes affect how people react to and influence us. Forget nature *versus* nurture; think nature *via* nurture.

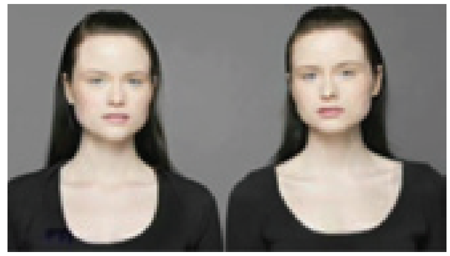
RETRIEVE IT

- Match the following terms to the correct explanation.

1. Epigenetics	a. Study of the relative effects of our genes and our environment on our behavior.
2. Behavior genetics	b. Study of environmental factors that affect how our genes are *expressed*.

ANSWERS: 1. b, 2. a

LaunchPad For a 7-minute explanation of genes and environment, visit LaunchPad's *Video: Behavior Genetics*.



Evolutionary Psychology: Understanding Human Nature

6-4 How do evolutionary psychologists use natural selection to explain behavior tendencies?

Behavior geneticists explore the genetic and environmental roots of human differences. **Evolutionary psychologists** instead focus mostly on what makes us so much alike as humans. They use Charles Darwin's principle of **natural selection** to understand the roots of behavior and mental processes. The idea, simplified, is this:

- Organisms' varied offspring compete for survival.
- Certain biological and behavioral variations increase organisms' reproductive and survival chances in their particular environment.
- Offspring that survive are more likely to pass their genes to ensuing generations.
- Thus, over time, population characteristics may change.

To see these principles at work, let's consider a straightforward example in foxes.

Natural Selection and Adaptation

A fox is a wild and wary animal. If you capture a fox and try to befriend it, be careful. Stick your hand in the cage and, if the timid fox cannot flee, it may snack on your fingers. Russian scientist Dmitry Belyaev wondered how our human ancestors had domesticated dogs from their equally wild wolf forebears. Might he, within a comparatively short stretch of time, accomplish a similar feat by transforming the fearful fox into a friendly fox?

To find out, Belyaev set to work with 30 male and 100 female foxes. From their offspring he selected and mated the tamest 5 percent of males and 20 percent of females. (He measured tameness by the foxes' responses to attempts to feed, handle, and stroke them.) Over more than 30 generations of foxes, Belyaev and his successor, Lyudmila Trut, repeated that simple procedure. Forty years and 45,000 foxes later, they had a new breed of foxes that, in Trut's (1999) words, were "docile, eager to please, and unmistakably domesticated. . . . Before our eyes, 'the Beast' has turned into 'beauty,' as the aggressive behavior of our herd's wild [ancestors] entirely disappeared." So friendly and eager for human contact

Eric Isselée/Shutterstock

mutation a random error in gene replication that leads to a change.

were these animals, so inclined to whimper to attract attention and to lick people like affectionate dogs, that the cash-strapped institute seized on a way to raise funds—marketing its foxes as house pets.

Over time, traits that give an individual or species a reproductive advantage are *selected* and will prevail. Animal-breeding experiments manipulate genetic selection. Dog breeders have given us sheepdogs that herd, retrievers that retrieve, trackers that track, and pointers that point (Plomin et al., 1997). Psychologists, too, have bred animals to be serene or reactive, quick learners or slow ones.

Does the same process work with naturally occurring selection? Does natural selection explain our human tendencies? Nature has indeed selected advantageous variations from the new gene combinations produced at each human conception plus the **mutations** (random errors in gene replication) that sometimes result. But the tight genetic leash that predisposes a dog's retrieving, a cat's pouncing, or a bird's nesting is looser on humans. The genes selected during our ancestral history provide more than a long leash; they give us a great capacity to learn and therefore to *adapt* to life in varied environments, from the tundra to the jungle. Genes and experience together wire the brain. Our adaptive flexibility in responding to different environments contributes to our *fitness*—our ability to survive and reproduce.

RETRIEVE IT

- How are Belyaev and Trut's breeding practices similar to, and how do they differ from, the way natural selection normally occurs?

ANSWER: Over multiple generations, Belyaev and Trut selected and bred foxes that exhibited a trait they desired: tameness. This process is similar to naturally occurring selection, but it differs in that natural selection is much slower, and normally favors traits (including those arising from mutations) that contribute to reproduction and survival.

Evolutionary Success Helps Explain Similarities

Our behavioral and biological similarities arise from our shared human genome, our common genetic profile. How did we develop our genetic kinship?

Gareth McConnell/eyevine/Redux

Differences grab attention, but our similarities run deep Lucky Diamond Rich, born Gregory Paul McLaren, is a New Zealand performance artist. He has held the world record for the most tattoos. But he also shares a common human concern for disadvantaged children.

OUR GENETIC LEGACY At the dawn of human history, our ancestors faced certain questions: Who is my ally, who is my foe? With whom should I mate? What food should I eat? Some individuals answered those questions more successfully than others. For example, women who experienced nausea in the critical first three months of pregnancy were genetically predisposed to avoid certain bitter, strongly flavored, and novel foods. Avoiding such foods has survival value, since they are the very foods most often toxic to prenatal development (Profet, 1992; Schmitt & Pilcher, 2004). Early humans disposed to eat nourishing rather than poisonous foods survived to contribute their genes to later generations. Those who deemed leopards "nice to pet" often did not.

Similarly successful were those whose mating helped them produce and nurture offspring. Over generations, the genes of individuals not so disposed tended to be lost from the human gene pool. As success-enhancing genes continued to be selected, behavioral tendencies and thinking and learning capacities emerged that prepared our Stone Age ancestors to survive, reproduce, and send their genes into the future, and into you.

As inheritors of this prehistoric legacy, we are genetically predisposed to behave in ways that promoted our ancestors' surviving and reproducing.

But in some ways, we are biologically prepared for a world that no longer exists. We face problems our ancestors could not imagine, such as how to create the perfect online dating profile or how to overcome the urge to constantly check our smart phones (Parkinson & Wheatley, 2015). We love the taste of sweets and fats, nutrients that prepared our physically active ancestors to survive food shortages. But few of us now hunt and gather our food. Too often, we search for sweets and fats in fast-food outlets and vending machines. Our natural dispositions, rooted deep in history, are mismatched with today's junk-food and often inactive lifestyle.

Despite high infant mortality and rampant disease in past millennia, not one of your countless ancestors died childless.

EVOLUTIONARY PSYCHOLOGY TODAY Darwin's theory of evolution has become one of biology's organizing principles. "Virtually no contemporary scientists believe that Darwin was basically wrong," noted Jared Diamond (2001). Today, Darwin's theory lives on in the *second Darwinian revolution,* the application of evolutionary principles to psychology. In concluding *On the Origin of Species,* Darwin (1859, p. 346) anticipated this, foreseeing "open fields for far more important researches. Psychology will be based on a new foundation."

Those who are troubled by an apparent conflict between scientific and religious accounts of human origins may find it helpful to consider that different perspectives of life can be complementary. For example, the scientific account attempts to tell us *when* and *how;* religious creation stories usually aim to tell about an ultimate *who* and *why.* As Galileo explained to the Grand Duchess Christina, "The Bible teaches how to go to heaven, not how the heavens go."

Elsewhere in this text, we address questions that intrigue evolutionary psychologists: Why do infants start to fear strangers about the time they become mobile? Why are biological fathers so much less likely than unrelated boyfriends to abuse and murder the children with whom they share a home? Why do so many more people have phobias about spiders, snakes, and heights than about more dangerous threats, such as guns and electricity? And why do we fear air travel so much more than driving?

Jacob Hamblin/Shutterstock

* * *

We know from our correspondence and from surveys that some readers are troubled by the naturalism and evolutionism of contemporary science. (A note to readers from other nations: In the United States there is a wide gulf between scientific and lay thinking about evolution.) "The idea that human minds are the product of evolution is . . . unassailable fact," declared a 2007 editorial in *Nature,* a leading science journal. In *The Language of God,* Human Genome Project director Francis Collins (2006, pp. 141, 146), a self-described evangelical Christian, compiled the "utterly compelling" evidence that led him to conclude that Darwin's big idea is "unquestionably correct." Yet Gallup pollsters report that 42 percent of U.S. adults believe that humans were created "pretty much in their present form" within the last 10,000 years (Newport, 2014). Many people who dispute the scientific story worry that a science of behavior (and evolutionary science in particular) will destroy our sense of the beauty, mystery, and spiritual significance of the human creature. For those concerned, we offer some reassuring thoughts.

When Isaac Newton explained the rainbow in terms of light of differing wavelengths, the British poet John Keats feared that Newton had destroyed the rainbow's mysterious beauty. Yet, as evolutionary biologist Richard Dawkins (1998) noted in *Unweaving the Rainbow,* Newton's analysis led to an even deeper mystery—Einstein's theory of special relativity. Nothing about Newton's optics need diminish our appreciation for the dramatic elegance of a rainbow arching across a brightening sky.

When Galileo assembled evidence that Earth revolved around the Sun, not vice versa, he did not offer irrefutable proof for his theory. Rather, he offered a coherent explanation for a variety of observations, such as the changing shadows cast by the Moon's mountains. His explanation eventually won the day because it described and explained things in a way that made sense, that hung together.

Darwin's theory of evolution likewise is a coherent view of natural history. It offers an organizing principle that unifies various observations.

Many people of faith find the scientific idea of human origins congenial with their spirituality. In the fifth century, St. Augustine (quoted by Wilford, 1999) wrote, "The universe was brought into being in a less than fully formed state, but was gifted with the capacity to transform itself from unformed matter into a truly marvelous array of structures and life forms." Some 1600 years later, Pope Francis in 2014 welcomed a science-religion dialogue, saying, "Evolution in nature is not inconsistent with the notion of creation, because evolution requires the creation of beings that evolve."

Meanwhile, many people of science are awestruck at the emerging understanding of the universe and the human creature. It boggles the mind—the entire universe popping out of a point some 14 billion years ago, and instantly inflating to cosmological size. Had the energy of this Big Bang been the tiniest bit less, the universe would have collapsed back on itself. Had it been the tiniest bit more, the result would have been a soup too thin to support life. Astronomer Sir Martin Rees has described *Just Six Numbers* (1999), any one of which, if changed ever so slightly, would produce a cosmos in which life could not exist. Had gravity been a tad stronger or weaker, or had the weight of a carbon proton been a wee bit different, our universe just wouldn't have worked.

What caused this almost-too-good-to-be-true, finely tuned universe? Why is there something rather than nothing? How did it come to be, in the words of Harvard-Smithsonian astrophysicist Owen Gingerich (1999), "so extraordinarily right, that it seemed the universe had been expressly designed to produce intelligent, sentient beings"? On such matters, a humble, awed, scientific silence is appropriate, suggested philosopher Ludwig Wittgenstein: "Whereof one cannot speak, thereof one must be silent" (1922, p. 189).

Rather than fearing science, we can welcome its enlarging our understanding and awakening our sense of awe. In *The Fragile Species,* Lewis Thomas (1992) described his utter amazement that Earth in time gave rise to bacteria and eventually to Bach's Mass in B Minor. In a short 4 billion years, life on Earth has come from nothing to structures as complex as a 6-billion-unit strand of DNA and the incomprehensible intricacy of the human brain. Atoms no different from those in a rock somehow formed dynamic entities that produce extraordinary, self-replicating, information-processing systems—us (Davies, 2007). Although we appear to have been created from dust, over eons of time, the end result is a priceless creature, one rich with potential beyond our imagining.

MODULE 6 REVIEW Genetics, Evolutionary Psychology, and Behavior

Learning Objectives

Test Yourself by taking a moment to answer each of these Learning Objective Questions (repeated here from within the module). Then turn to Appendix D, Complete Module Reviews, to check your answers. Research suggests that trying to answer these questions on your own will improve your long-term memory of the concepts (McDaniel et al., 2009).

6-1 What are *chromosomes, DNA, genes,* and the human *genome?* How do behavior geneticists explain our individual differences?

6-2 How do twin and adoption studies help us understand the effects and interactions of nature and nurture?

6-3 How do heredity and environment work together?

6-4 How do evolutionary psychologists use natural selection to explain behavior tendencies?

Terms and Concepts to Remember

Test yourself on these terms by trying to write down the definition in your own words before flipping back to the referenced page to check your answers.

environment, p. 66
heredity, p. 66
behavior genetics, p. 66
chromosomes, p. 66
DNA (deoxyribonucleic acid), p. 66
genes, p. 66
genome, p. 66
identical (monozygotic) twins, p. 67
fraternal (dizygotic) twins, p. 68
interaction, p. 71
epigenetics, p. 72
evolutionary psychology, p. 73
natural selection, p. 73
mutation, p. 74

Experience the Testing Effect

Test yourself repeatedly throughout your studies. This will not only help you figure out what you know and don't know; the testing itself will help you learn and remember the information more effectively thanks to the *testing effect.*

1. The threadlike structures made largely of DNA molecules are called ______________.

2. A small segment of DNA that codes for particular proteins is referred to as a ______________.

3. When the mother's egg and the father's sperm unite, each contributes
   a. one chromosome pair.
   b. 23 chromosomes.
   c. 23 chromosome pairs.
   d. 25,000 chromosomes.

4. Fraternal twins result when
   a. a single egg is fertilized by a single sperm and then splits.
   b. a single egg is fertilized by two sperm and then splits.
   c. two eggs are fertilized by two sperm.
   d. two eggs are fertilized by a single sperm.

5. ______________ twins share the same DNA.

6. Adoption studies seek to understand genetic influences on personality. They do this mainly by
   a. comparing adopted children with nonadopted children.
   b. evaluating whether adopted children's personalities more closely resemble those of their adoptive parents or their biological parents.
   c. studying the effect of prior neglect on adopted children.
   d. studying the effect of children's age at adoption.

7. Epigenetics is the study of the molecular mechanisms by which ______________ trigger or block genetic expression.

8. Behavior geneticists are most interested in exploring ______________ (commonalities/differences) in our behaviors. Evolutionary psychologists are most interested in exploring ______________ (commonalities/differences).

9. Evolutionary psychologists are most likely to focus on
   a. how individuals differ from one another.
   b. ancestral hunting and gathering behaviors.
   c. natural selection of the fittest adaptations.
   d. twin and adoption studies.

Find answers to these questions in Appendix E, in the back of the book.

Use LearningCurve to create your personalized study plan, which will direct you to the resources that will help you most in LaunchPad.