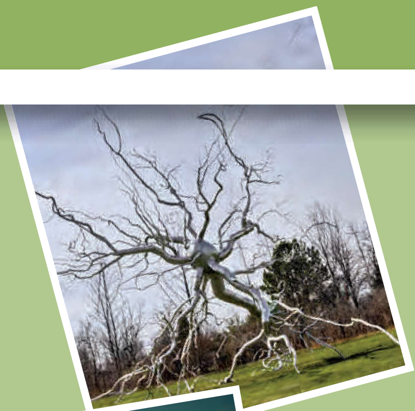
Unit III



Biological Bases of Behavior

Modules

Imagine that just moments before your death, someone removed your brain from your body and kept it alive by floating it in a tank of fluid while feeding it enriched blood. Would you still be in there? Further imagine that your still-living brain was transplanted into the body of a person whose own brain had been severely damaged. To whose home should the recovered patient return? If you say the patient should return to your home, you illustrate what most of us believe—that we reside in our head. An acquaintance of mine received a new heart from a woman who had received a 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 inside her skull. We rightly presume that our brain enables our mind. Indeed, no principle is more central to today's psychology, or to this book, than this: *Everything psychological is simultaneously biological.*

Module 9

Biological Psychology and Neurotransmission

AP Photo/Frederik Meijer Gardens & Sculpture Park, Chuck Heiney

Module Learning Objectives

9-1 Explain why psychologists are concerned with human biology.

9-2 Describe the parts of a neuron, and explain how its impulses are generated.

9-3 Describe how nerve cells communicate with other nerve cells.

9-4 Describe how neurotransmitters influence behavior, and explain how drugs and other chemicals affect neurotransmission.

Biology, Behavior, and Mind

9-1 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. Although we find it convenient to talk separately of biological and psychological influences on behavior, we need to remember: To think, feel, or act without a body would be like running without legs.

ScienceCartoonsPlus.com

"Then it's agreed—you can't have a mind without a brain, but you can have a brain without a mind."

Our understanding of how the brain gives birth to the mind has come a long way. The ancient Greek philosopher Plato correctly located the mind in the spherical head—his idea of the perfect form. His student, Aristotle, believed the mind was in the heart, which pumps warmth and vitality to the body. The heart remains our symbol for love, but science has long since overtaken philosophy on this issue. It's your brain, not your heart, that falls in love.

In the early 1800s, German physician Franz Gall proposed that *phrenology,* studying bumps on the skull, could reveal a person's mental abilities and character traits (**FIGURE 9.1**). At one point, Britain had 29 phrenological societies, and phrenologists traveled North America giving skull readings (Hunt, 1993).

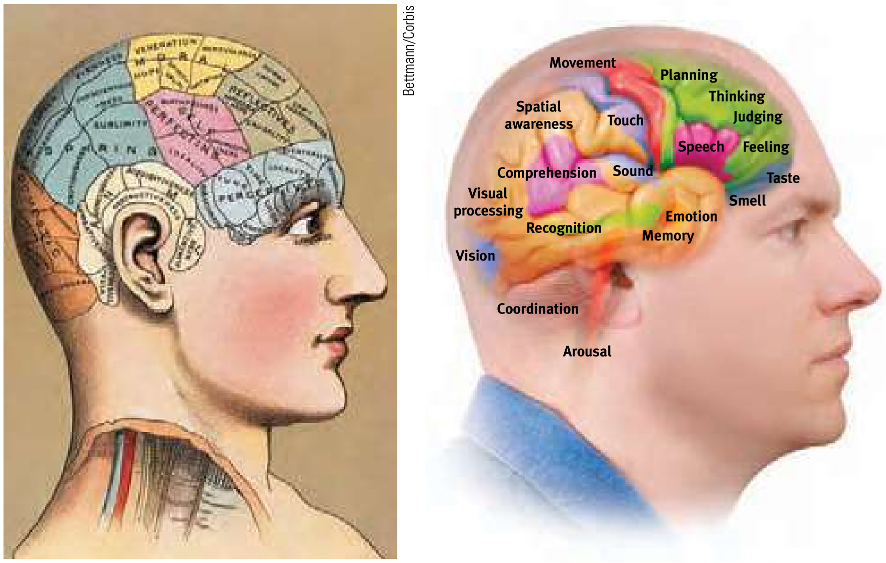


Figure 9.1
A wrongheaded theory Despite initial acceptance of Franz Gall's speculations, bumps on the skull tell us nothing about the brain's underlying functions. Nevertheless, some of his assumptions have held true. Though they are not the functions Gall proposed, different parts of the brain do control different aspects of behavior, as suggested here (from *The Human Brain Book*) and as you will see throughout this unit.

Using a false name, humorist Mark Twain put one famous phrenologist to the test. "He found a cavity [and] startled me by saying that that cavity represented the total absence of the sense of humor!" Three months later, Twain sat for a second reading, this time identifying himself. Now "the cavity was gone, and in its place was . . . the loftiest bump of humor he had ever encountered in his life-long experience!" (Lopez, 2002). Although its initial popularity faded, phrenology succeeded in focusing attention on the *localization of function*—the idea that various brain regions have particular functions.

You and I are living in a time Gall could only dream about. By studying the links between biological activity and psychological events, **biological psychologists** are announcing discoveries about the interplay of our biology and our behavior and mind at an exhilarating pace. Within little more than the past century, researchers seeking to understand the biology of the mind have discovered that

- the body is composed of cells.
- among these are nerve cells that conduct electricity and "talk" to one another by sending chemical messages across a tiny gap that separates them.
- specific brain systems serve specific functions (though not the functions Gall supposed).
- we integrate information processed in these different brain systems to construct our experience of sights and sounds, meanings and memories, pain and passion.
- our adaptive brain is wired by our experience.

We have also realized that we are each a system composed of subsystems that are in turn composed of even smaller subsystems. Tiny cells organize to form body organs. These organs form larger systems for digestion, circulation, and information processing. And those systems are part of an even larger system—the individual, who in turn is a part of a family, culture, and community. Thus, we are *biopsychosocial* systems. To understand our behavior, we need to study how these biological, psychological, and social systems work and interact.

In this unit we start small and build from the bottom up—from nerve cells up to the brain, and then to the environmental influences that interact with our biology. We will also work from the top down, as we consider how our thinking and emotions influence our brain and our health.

AP® Exam Tip

There is a ton of vocabulary in this unit. However, learning vocabulary is really not so hard: The secret is to work on it every day. Try flash cards. Work with a study buddy. Impress your non-psych friends with your new vocabulary. Just don't leave it until the night before the test. If you rehearse the vocabulary throughout the unit, you will do better on the unit test. The big bonus is that you will also retain far more information for the AP® exam.

"If I were a college student today, I don't think I could resist going into neuroscience."
-Novelist Tom Wolfe, 2004

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.*)

Neural Communication

For scientists, it is a happy fact of nature that the information systems of humans and other animals operate similarly—so similarly 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, such as squids and sea slugs, to discover how our neural systems operate. It allows them to study other mammals' brains to understand the organization of our own. Cars differ, but all have engines, accelerators, steering wheels, and brakes. An 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.

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

dendrites a neuron's 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 sausage-like node to the next.

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

"I sing the body electric." -WALT WHITMAN, "CHILDREN OF ADAM" (1855)

Neurons

9-2 What are the parts of a neuron, and how are neural impulses generated?

Our body's neural information system is complexity built from simplicity. Its building blocks are **neurons,** or nerve cells. To fathom our thoughts and actions, memories and moods, we must first understand how neurons work and communicate.

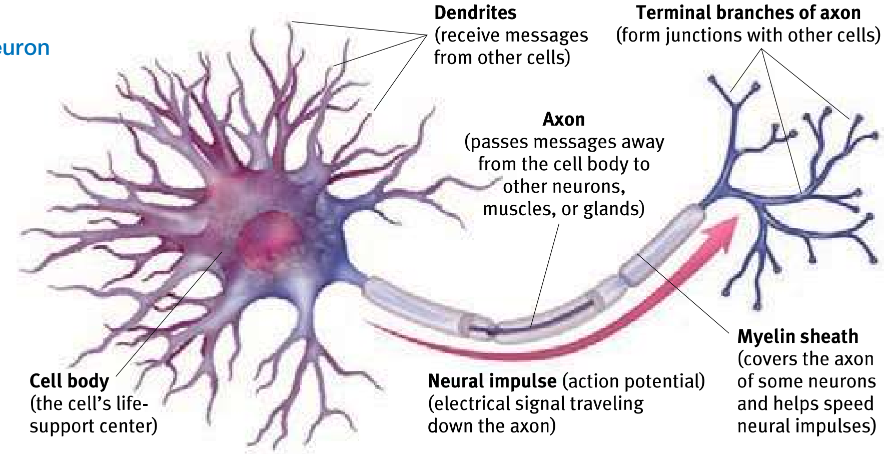
Neurons differ, but all are variations on the same theme (**FIGURE 9.2**). Each consists of a *cell body* and its branching fibers. The bushy **dendrite** fibers receive information and conduct it toward the cell body. From there, the cell's lengthy **axon** fiber passes the message through its terminal branches to other neurons or to muscles or glands. Dendrites listen. Axons speak.

Unlike the short dendrites, axons may be very long, projecting several feet through the body. A 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 rope 4 miles long. 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.

Neurons transmit messages when stimulated by signals from our senses or when triggered by chemical signals from neighboring neurons. In response, a neuron fires 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 a breakneck 180 miles per hour. But even this top speed is 3 million times slower than that of electricity through a wire. We measure brain activity in

Figure 9.2
A motor neuron



milliseconds (thousandths of a second) and computer activity in nanoseconds (billionths of a second). Thus, unlike the nearly instantaneous reactions of a high-speed computer, your reaction to a sudden event, such as a book slipping off your desk during class, 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 are 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 for a tiny shrew—reflexes are 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 ions; a resting axon's fluid interior has mostly negatively charged ions. This positive-outside/negative-inside state is called the *resting potential.* Like a tightly guarded facility, the axon's surface is very selective about what it allows through its gates. We say the axon's surface is *selectively permeable.*

When a neuron fires, however, the security parameters change: The first section of the axon opens its gates, rather like sewer covers flipping open, and positively charged sodium ions flood through the cell membrane (**FIGURE 9.3**). This *depolarizes* that axon section, causing another axon channel to open, and then another, like a line of falling dominos, each tripping the next.

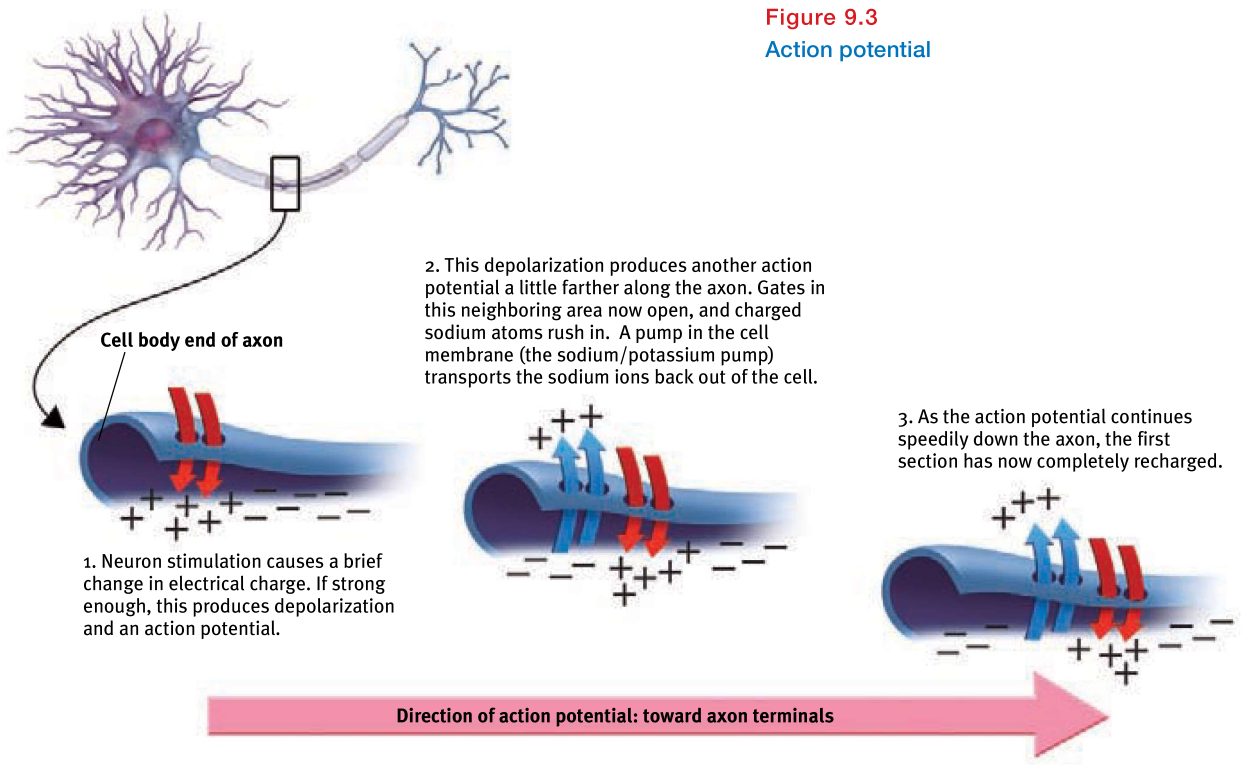
During a resting pause called the **refractory period,** rather like a web page pausing to refresh, the neuron pumps the positively charged sodium ions back outside. Then it can fire again. (In myelinated neurons, as in Figure 9.2, the action potential speeds up by hopping from the end of one myelin "sausage" to the next.) The mind boggles when imagining this electrochemical process repeating up to 100 or even 1000 times a second. But this is just the first of many astonishments.

Each neuron is itself a miniature decision-making device performing complex calculations as it receives signals from hundreds, even thousands, of other neurons. Most signals are *excitatory,* somewhat like pushing a neuron's accelerator. Some are *inhibitory,* more like

refractory period a period of inactivity after a neuron has fired.

"What one neuron tells another neuron is simply how much it is excited." -Francis Crick, *The Astonishing Hypothesis*, 1994

Figure 9.3
Action potential



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

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

pushing its brake. If excitatory signals exceed inhibitory signals by a minimum intensity, or **threshold,** the combined signals trigger an action potential. (Think of it as a class vote: If the excitatory people with their hands up outvote the inhibitory people with their hands down, then the vote passes.) 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.

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.

AP® Exam Tip

Note the important shift here. So far, you have been learning about how just one neuron operates. The action potential is the mechanism for communication *within* a single neuron. Now you are moving on to a discussion of two neurons and how communication occurs *between* them. Very different, but equally important.

"All information processing in the brain involves neurons 'talking to' each other at synapses."
-Neuroscientist Solomon H. Snyder (1984)

How Neurons Communicate

9-3 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 1 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," notes 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.

When an action potential reaches the knob-like terminals at an axon's end, it triggers the release of chemical messengers, called **neurotransmitters** (**FIGURE 9.4**). 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 ions flow in, exciting or inhibiting the receiving neuron's readiness to fire. Then, in a process called **reuptake,** the sending neuron reabsorbs the excess neurotransmitters.

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.*

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.

How Neurotransmitters Influence Us

9-4 How do neurotransmitters influence behavior, and how do drugs and other chemicals affect neurotransmission?

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

Later 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 our emotions. A particular brain pathway may use only one or two neurotransmitters (**FIGURE 9.5**), and particular neurotransmitters may affect specific

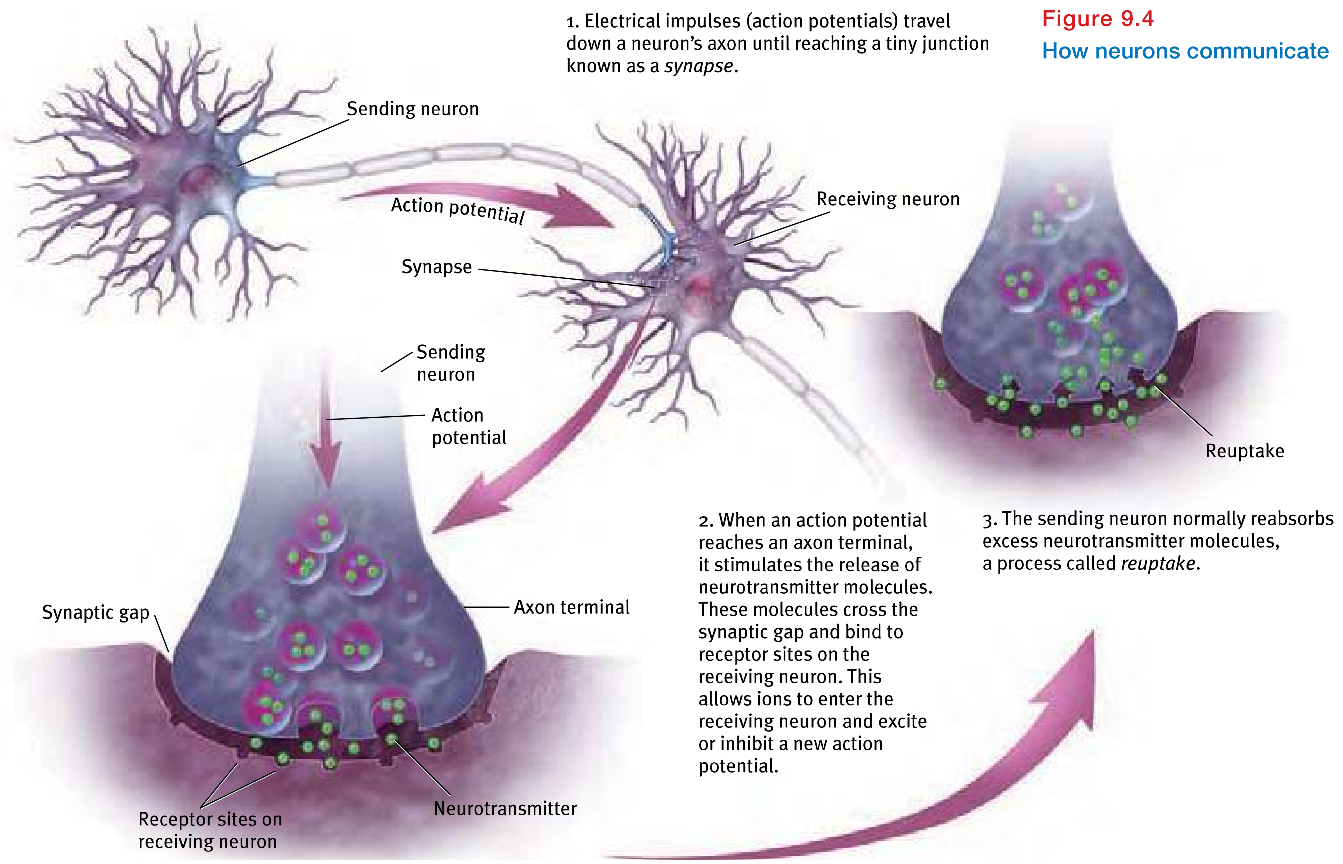


Figure 9.4
How neurons communicate

behaviors and emotions (**TABLE 9.1** on the next page). But neurotransmitter systems don't operate in isolation; they interact, and their effects vary with the receptors they stimulate. *Acetylcholine (ACh),* which is one of the best-understood neurotransmitters, 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, the muscles cannot contract and we are paralyzed.

"When it comes to the brain, if you want to see the action, follow the neurotransmitters."
-Neuroscientist Floyd Bloom (1993)


Both photos from *Mapping the Mind*, Rita Carter, 1989 Moonrunner Ltd.

Serotonin pathways

Dopamine pathways

Figure 9.5
Neurotransmitter pathways Each of the brain's differing chemical messengers has designated pathways where it operates, as shown here for serotonin and dopamine (Carter, 1998).

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AP® Exam Tip

As the text indicates, there are dozens of different neurotransmitters. Though there's no way to predict exactly which ones you'll see on the AP® exam, it's quite possible that the ones in Table 9.1 are ones you'll be asked about.

Table 9.1 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 antidepressant drugs raise serotonin levels.
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 the brain, producing migraines or seizures (which is why some people avoid MSG, monosodium glutamate, in food).

Researchers 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 (Pert & Snyder, 1973). 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?

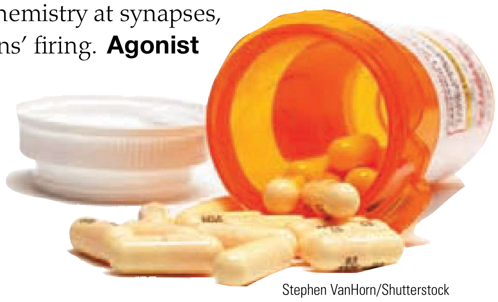
Researchers soon confirmed that the brain does indeed produce its own naturally occurring opiates. Our body releases several types of neurotransmitter molecules similar to morphine in response to pain and vigorous exercise. These **endorphins** (short for *endo*genous [produced within] m*orphine*) help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

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

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? One problem is that when flooded with opiate drugs such as heroin and morphine, the brain may stop producing its own natural 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 at synapses, often by either exciting or inhibiting neurons' firing. **Agonist** molecules may be similar enough to a neurotransmitter to bind to its receptor and mimic its effects. Some opiate drugs are agonists and produce a temporary "high" by amplifying normal sensations of arousal or pleasure.



Stephen VanHorn/Shutterstock

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

agonist a molecule that, by binding to a receptor site, stimulates a response.

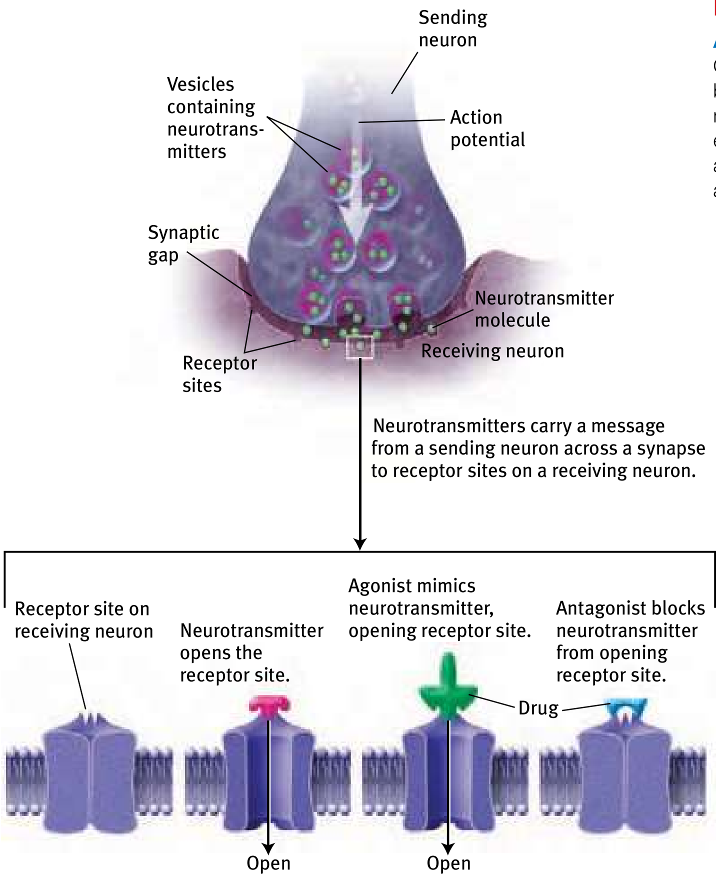


Figure 9.6
Agonists and antagonists
Curare poisoning paralyzes its victims by blocking ACh receptors involved in muscle movements. Morphine mimics endorphin actions. Which is an agonist, and which is an antagonist? (Art adapted from Higgins & George, 2007.)

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

Antagonists also bind to receptors but their effect is instead to block a neurotransmitter's functioning. 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, as in **FIGURE 9.6**, 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 animals struck by the darts.

antagonist a molecule that, by binding to a receptor site, inhibits or blocks a response.

AP® Exam Tip

Be very clear on this. Neurotransmitters are produced inside the body. They can excite and inhibit neural communication. Drugs and other chemicals come from outside the body. They can have an agonistic effect or an antagonistic effect on neurotransmission.

Before You Move On

▶ **ASK YOURSELF**

Can you recall a time when the endorphin response may have protected you from feeling extreme pain?

▶ **TEST YOURSELF**

How do neurons communicate with one another?

Answers to the Test Yourself questions can be found in Appendix E at the end of the book.

Module 9 Review

9-1 Why are psychologists concerned with human biology?

- Psychologists working from a *biological* perspective study the links between biology and behavior.
- We are biopsychosocial systems, in which biological, psychological, and social-cultural factors interact to influence behavior.

9-2 What are the parts of a neuron, and how are neural impulses generated?

- *Neurons* are the elementary components of the nervous system, the body's speedy electrochemical information system.
- A neuron receives signals through its branching *dendrites,* and sends signals through its *axons.*
- Some axons are encased in a *myelin sheath,* which enables faster transmission.
- If the combined received signals exceed a minimum *threshold,* the neuron fires, transmitting an electrical impulse (the *action potential*) down its axon by means of a chemistry-to-electricity process. The neuron's reaction is an *all-or-none process.*

9-3 How do nerve cells communicate with other nerve cells?

- When action potentials reach the end of an axon (the axon terminals), they stimulate the release of *neurotransmitters.*
- These chemical messengers carry a message from the sending neuron across a *synapse* to receptor sites on a receiving neuron.
- The sending neuron, in a process called *reuptake,* then reabsorbs the excess neurotransmitter molecules in the synaptic gap.
- If incoming signals are strong enough, the receiving neuron generates its own action potential and relays the message to other cells.

9-4 How do neurotransmitters influence behavior, and how do drugs and other chemicals affect neurotransmission?

- Neurotransmitters travel designated pathways in the brain and may influence specific behaviors and emotions.
- Acetylcholine (ACh) affects muscle action, learning, and memory.
- *Endorphins* are natural opiates released in response to pain and exercise.
- Drugs and other chemicals affect brain chemistry at synapses.
- *Agonists* excite by mimicking particular neurotransmitters or by blocking their reuptake.
- *Antagonists* inhibit a particular neurotransmitter's release or block its effect.

Multiple-Choice Questions

1. Multiple sclerosis is a result of degeneration in the

a. dendrite.
b. axon.
c. myelin sheath.
d. terminal button.
e. neuron.

2. Junita does not feel like getting out of bed, has lost her appetite, and feels tired for most of the day. Which of the following neurotransmitters likely is in short supply for Junita?

a. Dopamine
b. Serotonin
c. Norephinephrine
d. Acetylcholine
e. Glutamate

3. Which neurotransmitter inhibits CNS activity in order to calm a person down during stressful situations?

a. GABA
b. Norepinephrine
c. Acetylcholine
d. Dopamine
e. Serotonin

4. Phrenology has been discredited, but which of the following ideas has its origins in phrenology?

a. Brain lateralization
b. Brain cavities contributing to sense of humor
c. Bumps in the left hemisphere leading to emotional responses
d. Brain function localization
e. Belief that the mind pumps warmth and vitality into the body

5. When there is a negative charge inside an axon and a positive charge outside it, the neuron is

a. in the process of reuptake.
b. not in the refractory period.
c. said to have a resting potential.
d. said to have an action potential.
e. depolarizing.

6. Morphine elevates mood and eases pain, and is most similar to which of the following?

a. Dopamine
b. Serotonin
c. Endorphins
d. Acetylcholine
e. GABA

7. Neurotransmitters cross the __________ to carry information to the next neuron.

a. synaptic gap
b. axon
c. myelin sheath
d. dendrites
e. cell body

8. What neurotransmitters are most likely in undersupply in someone who is depressed?

a. Dopamine and GABA
b. ACh and norepinephrine
c. Dopamine and norepinephrine
d. Serotonin and norepinephrine
e. Serotonin and glutamate

Practice FRQs

1. While hiking, Ken stumbled and fell down a 10-foot drop-off. Upon landing, he sprained his ankle badly. Ken was surprised that he felt very little pain for the first half hour. Explain how the following helped Ken feel little pain in the moments after the injury.

- Endorphins
- The synapse

Answer

1 point: Endorphins are natural, opiate-like neurotransmitters linked to controlling pain.

1 point: The synapse is the space between neurons where neurotransmitters like the endorphins carry information that influences how Ken feels.

2. Explain the role each of the following plays in sending a message through a neuron.

- Dendrites
- Axon
- Myelin sheath

(3 points)

Module 10

The Nervous and Endocrine Systems


Radius Images/Getty Images

Module Learning Objectives

10-1 Describe the functions of the nervous system's main divisions, and identify the three main types of neurons.

10-2 Describe the nature and functions of the endocrine system and its interaction with the nervous system.

My nervous system recently gave me an emotional roller-coaster ride. Before sending me into an MRI machine for a routine shoulder scan, a technician asked if I had issues with claustrophobia (fear of enclosed spaces). "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 nervous system had a different idea. As 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 suddenly felt my nervous system having a reverse calming influence. 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 roller-coaster ride.

What happens inside our brains and bodies to produce such surging and subsiding emotions? Is the nervous system that stirs us the same nervous system that soothes us?

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.

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

The Nervous System

10-1 What are the functions of the nervous system's main divisions, and what are the three main types of neurons?

To live is 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. All this happens thanks to our body's **nervous system** (**FIGURE 10.1**). 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 to the brain and spinal cord for processing. **Motor neurons** carry instructions from the central

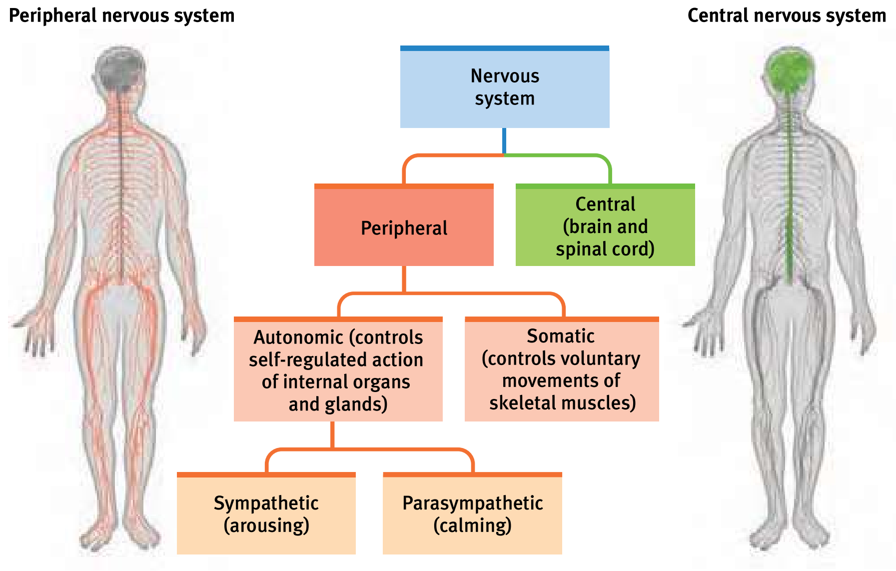


Figure 10.1
The functional divisions of the human nervous system

AP® Exam Tip

You've heard the word peripheral before, right? How does your knowledge of peripheral vision help you understand what the peripheral nervous system is? It's always good to create mental linkages between what you're learning and what you already know.

nervous system out to the body's muscles and glands. Between the sensory input and motor output, information is processed in the brain's internal communication system via its **interneurons.** Our complexity resides mostly in our interneuron systems. 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 the bell signals the end of class, your somatic nervous system reports to your brain the current state of your skeletal muscles and carries instructions back, triggering your body to rise from your seat.

Our **autonomic nervous system (ANS)** controls our glands and the muscles of our internal organs, influencing such functions as glandular activity, heartbeat, and digestion. Like an automatic pilot, this system may be consciously overridden, but usually operates on its own (autonomously).

The autonomic nervous system serves two important, basic functions (**FIGURE 10.2** on the next page). The **sympathetic nervous system** arouses and expends energy. If something alarms or challenges you (such as taking the AP® Psychology exam, or being stuffed in an MRI machine), your sympathetic 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 AP® exam or MRI is over), your **parasympathetic nervous system** will produce the opposite effects, conserving energy as it calms you by decreasing your heartbeat, lowering your blood sugar, and so forth. In everyday situations, the sympathetic and parasympathetic nervous systems work together to keep us in a steady internal state.

The Central Nervous System

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

interneurons neurons within the brain and spinal cord that communicate internally and intervene 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.*

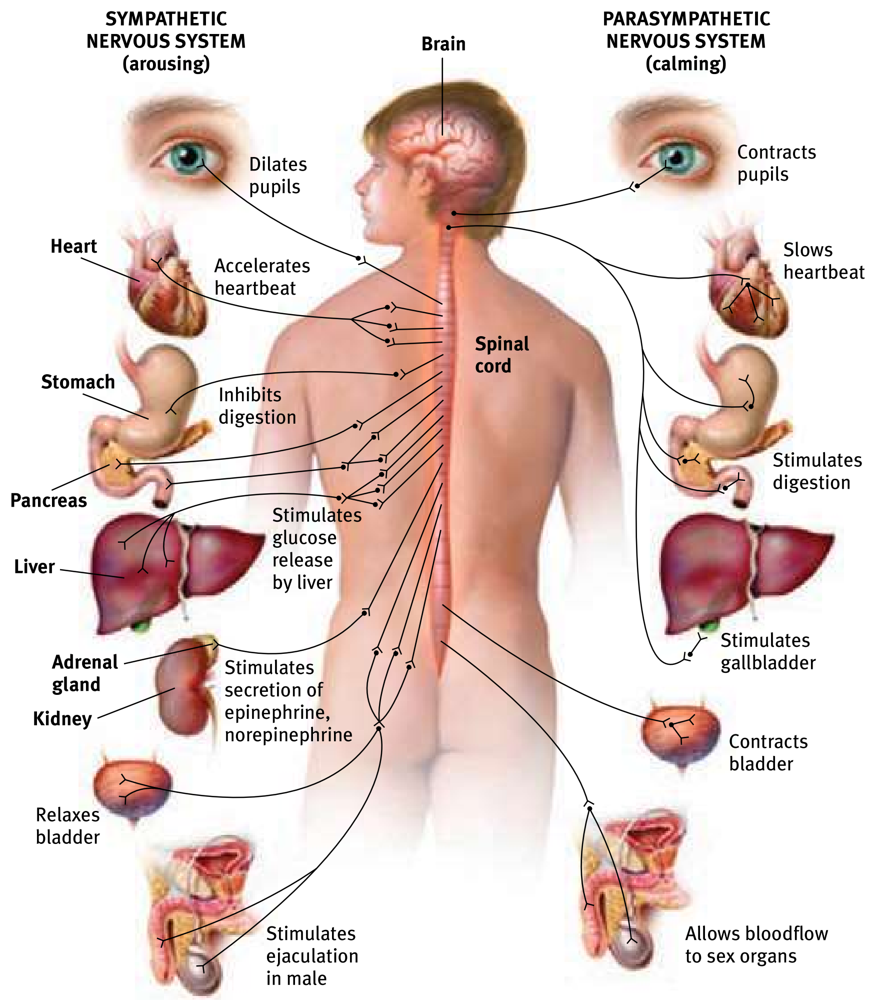
autonomic [aw-tuh-NAHM-ik] **nervous system (ANS)** the part of the peripheral nervous system that controls the glands and the muscles of the internal organs (such as the heart). Its sympathetic division arouses; its parasympathetic division calms.

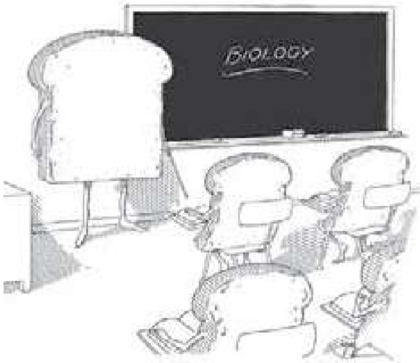
sympathetic nervous system the division of the autonomic nervous system that arouses the body, mobilizing its energy in stressful situations.

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

Figure 10.2

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.





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

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 everchanging wiring diagram. With some 40 billion neurons, each connecting with roughly 10,000 other neurons, we end up with perhaps 400 trillion synapses—places where neurons meet and greet their neighbors (de Courten-Myers, 2005).[1] A grain-of-sand-sized speck of your brain contains some 100,000 neurons and 1 billion "talking" synapses (Ramachandran & Blakeslee, 1998).

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. As in **FIGURE 10.3,** each layer's cells connect with various cells in the neural network's next layer. Learning—to play the violin, speak a foreign language, solve a math problem—occurs as experience strengthens connections. Neurons that fire together wire together.

[1] Another research team, projecting from representative tissue samples, has estimated that the adult human male brain contains 86 billion neurons—give or take 8 billion (Azevedo et al., 2009). One moral: Distrust big round numbers, such as the familiar, undocumented claim that the human brain contains 100 billion neurons.

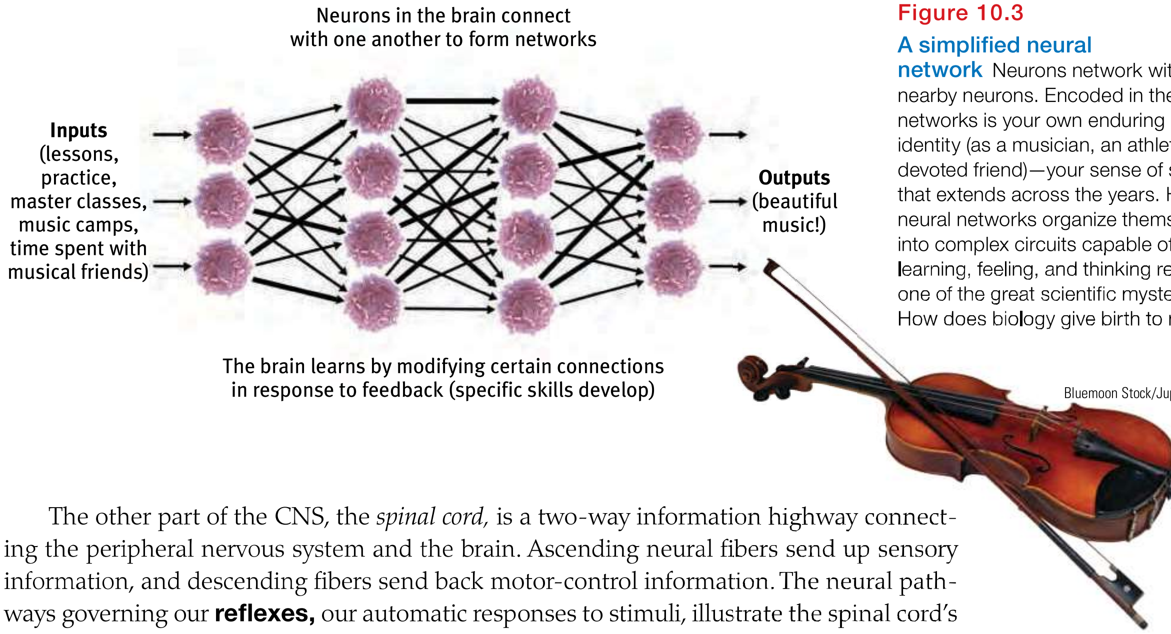

Figure 10.3
A simplified neural network Neurons network with nearby neurons. Encoded in these networks is your own enduring identity (as a musician, an athlete, a devoted friend)—your sense of self that extends across the years. How neural networks organize themselves into complex circuits capable of learning, feeling, and thinking remains one of the great scientific mysteries. How does biology give birth to mind?

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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.

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

Another such pathway enables the pain reflex (**FIGURE 10.4**). When your finger touches a flame, neural activity (excited by the heat) travels via sensory neurons 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

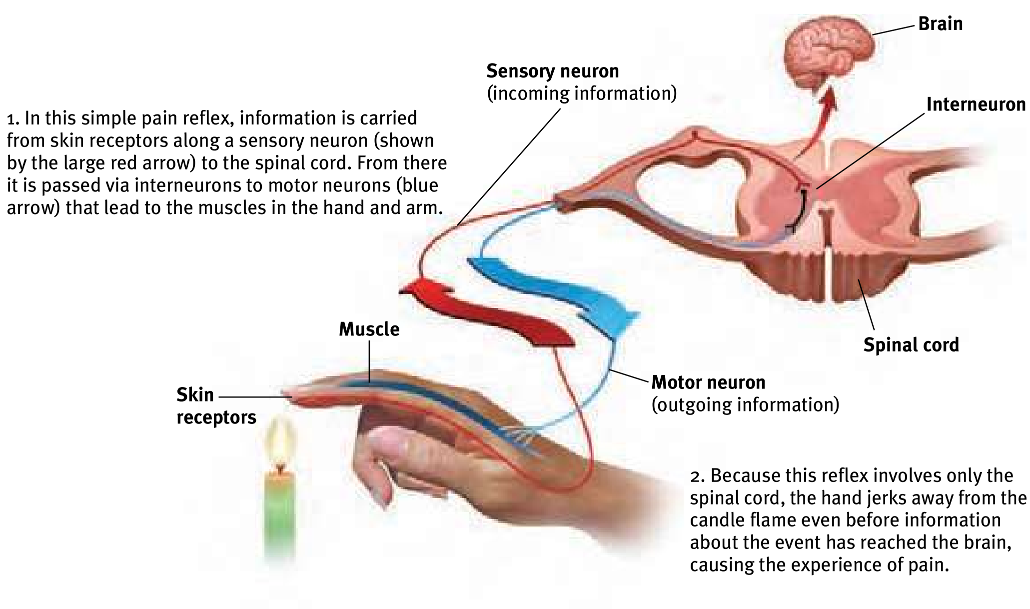


Figure 10.4
A simple reflex

"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

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 without feeling the tap. To produce bodily pain or pleasure, the sensory information must reach the brain.

Before You Move On

► ASK YOURSELF

Does our nervous system's design—with its synaptic gaps that chemical messenger molecules cross in an imperceptibly brief instant—surprise you? Would you have designed yourself differently?

► TEST YOURSELF

How does information flow through your nervous system as you pick up a fork? Can you summarize this process?

Answers to the Test Yourself questions can be found in Appendix E at the end of the book.

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

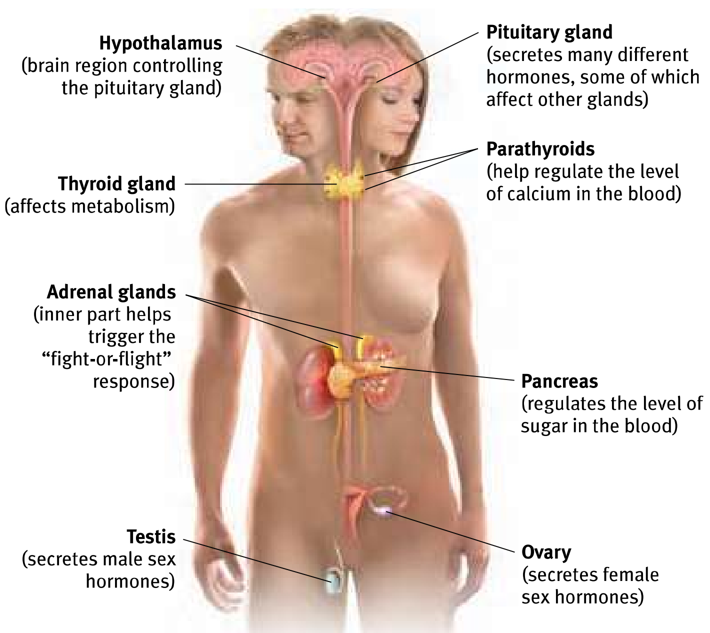
hormones chemical messengers that are manufactured by the endocrine glands travel through the bloodstream and affect other tissues.

The Endocrine System

10-2 What is the nature and what are the functions of the endocrine system, and how does it 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 10.5**). 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.

Figure 10.5
The endocrine system



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, 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's communication delivers messages with the speed of a text message, the endocrine system is more like sending a letter through the mail.

But slow and steady sometimes wins the race. 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 us with a surge of energy, known as the *fight-or-flight* response. When the emergency passes, the hormones—and the feelings of excitement—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* (more on that shortly). The pituitary releases certain hormones. One is a growth hormone that stimulates physical development. Another, oxytocin, 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). During a laboratory game, those given a nasal squirt of oxytocin rather than a placebo were more likely to trust strangers with their money (Kosfeld et al., 2005).

Pituitary secretions also influence the release of hormones by other endocrine glands. The pituitary, then, is a sort of 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. So, too, with stress. A stressful event triggers your hypothalamus to instruct your pituitary to release a hormone that causes your adrenal glands to flood your body with cortisol, a stress hormone that increases blood sugar.

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.

Before You Move On

▶ ASK YOURSELF

Can you remember feeling an extended period of discomfort after some particularly stressful event? How long did those feelings last?

▶ TEST YOURSELF

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

Answers to the Test Yourself questions can be found in Appendix E at the end of the book.

Module 10 Review

10-1 What are the functions of the nervous system's main divisions, and what are the three main types of neurons?

- The *central nervous system (CNS)*—the brain and the spinal cord—is the *nervous system*'s decision maker.
- The *peripheral nervous system (PNS),* which connects the CNS to the rest of the body by means of *nerves,* gathers information and transmits CNS decisions to the rest of the body.
- The two main PNS divisions are the *somatic nervous system* (which enables voluntary control of the skeletal muscles) and the *autonomic nervous system* (which controls involuntary muscles and glands by means of its *sympathetic* and *parasympathetic divisions).*
- Neurons cluster into working networks.
- There are three types of neurons:

  (1) *Sensory neurons* carry incoming information from sense receptors to the brain and spinal cord.

  (2) *Motor neurons* carry information from the brain and spinal cord out to the muscles and glands.

  (3) *Interneurons* communicate within the brain and spinal cord and between sensory and motor neurons.

10-2 What is the nature and what are the functions of the endocrine system, and how does it interact with the nervous system?

- The *endocrine system* is a set of glands that secrete *hormones* into the bloodstream, where they travel through the body and affect other tissues, including the brain. The *adrenal glands,* for example, release the hormones that trigger the fight-or-flight response.
- The endocrine system's master gland, the *pituitary,* influences hormone release by other glands. In an intricate feedback system, the brain's *hypothalamus* influences the pituitary gland, which influences other glands, which release hormones, which in turn influence the brain.

Multiple-Choice Questions

1. Which of the following carries the information necessary to activate withdrawal of the hand from a hot object?

a. Sensory neuron
b. Motor neuron
c. Interneuron
d. Receptor neuron
e. Reflex

2. Hormones are __________ released into the __________.

a. neurons; neurotransmitters
b. chemical messengers; bloodstream
c. electrical messengers; bloodstream
d. electrical messengers; synapse
e. chemical messengers; synapse

3. Which division of the nervous system produces the startle response?

a. Parasympathetic
b. Central
c. Somatic
d. Sympathetic
e. Autonomic

4. Which of the following endocrine glands may explain unusually tall height in a 12-year-old?

a. Pituitary
b. Adrenal
c. Pancreas
d. Parathyroid
e. Testes

5. Which of the following communicates with the pituitary, which in turn controls the endocrine system?

a. Parathyroids
b. Autonomic nervous system
c. Hypothalamus
d. Spinal cord
e. Pancreas

6. Which branch of the nervous system calms a person?

a. Central nervous system
b. Sympathetic
c. Parasympathetic
d. Somatic
e. Endocrine

7. Epinephrine and norepinephrine increase energy and are released by the

a. thyroid glands.
b. pituitary gland.
c. hypothalamus.
d. thalamus.
e. adrenal glands.

8. Interneurons are said to

a. send messages from specific body parts to the brain.
b. transmit and process information within the brain and spinal cord.
c. act as connectors, supporting other neurons in the brain.
d. send messages from the brain to body parts.
e. influence the pituitary gland.

Practice FRQs

1. While walking barefoot, you step on a piece of glass. Before you have a chance to consciously process what has happened, you draw your foot away from the glass. Identify and explain the three types of neurons that deal with information regarding this painful stimulus.

Answer

1 point: Sensory neurons carry information from the point of the injury to the central nervous system.

1 point: Interneurons are neurons within the brain and spinal cord. Interneurons would help you interpret the pain and enable your brain to send out marching orders.

1 point: Motor neurons carry the instruction from the central nervous system to activate the muscles in your leg and foot.

2. Name and describe the components and subcomponents of the peripheral nervous system.

(4 points)