Module 10

The Nervous and Endocrine Systems

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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 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.

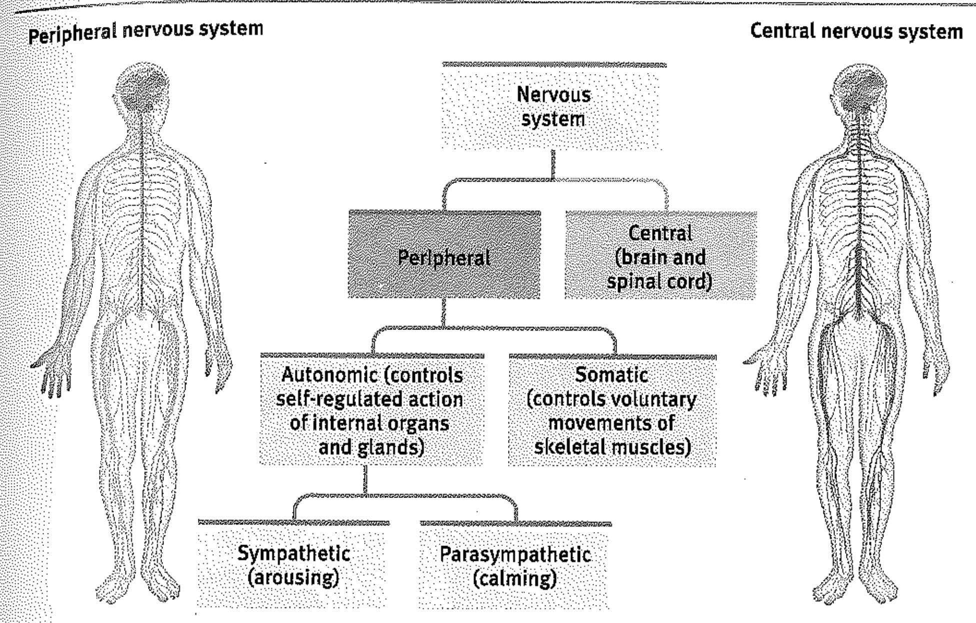


Figure 10.1
The functional divisions of the human nervous system

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.

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.

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.

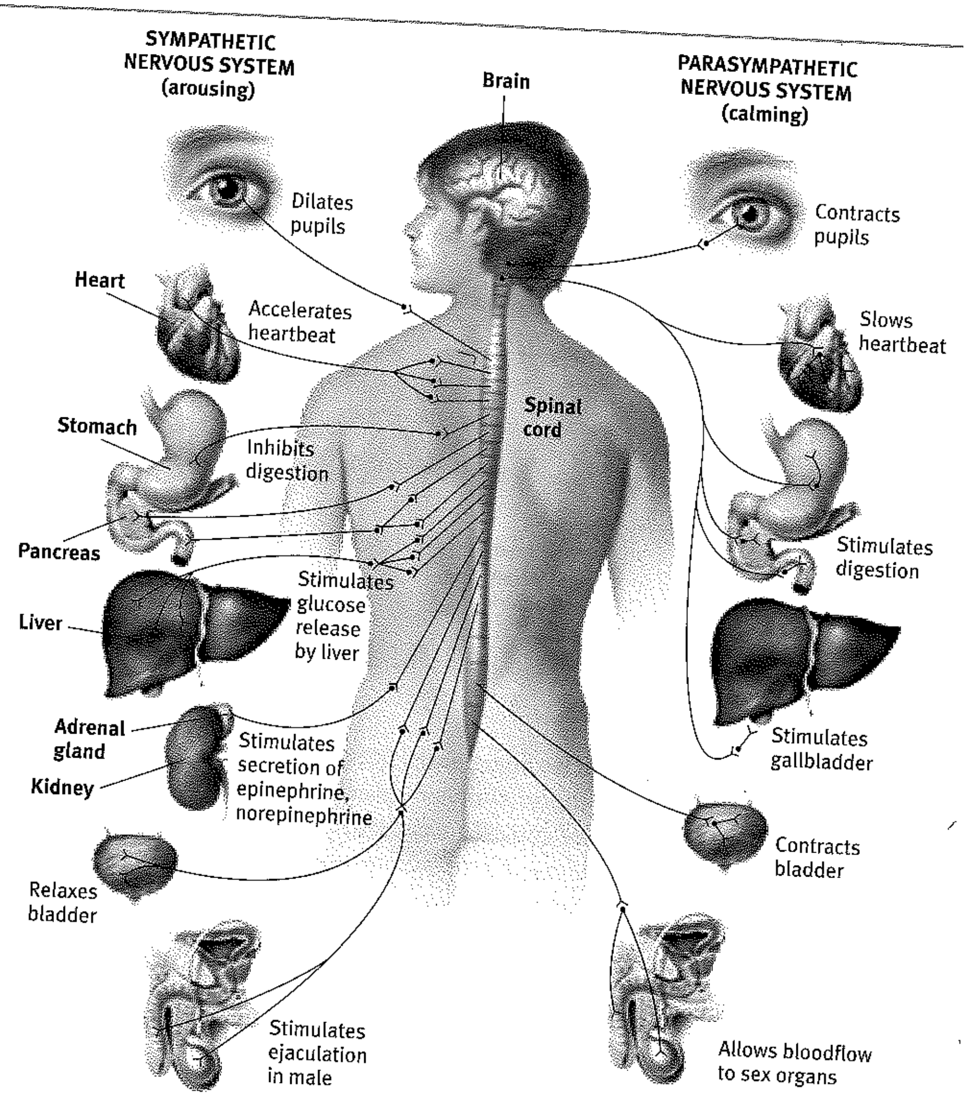
Our **autonomic nervous system (ANS)** controls our glands and the muscles of our internal organs, influencing such functions as glandular activity, heartbeat, and digestion. Like an automatic pilot, this system may be consciously overridden, but usually operates on its own (autonomously).

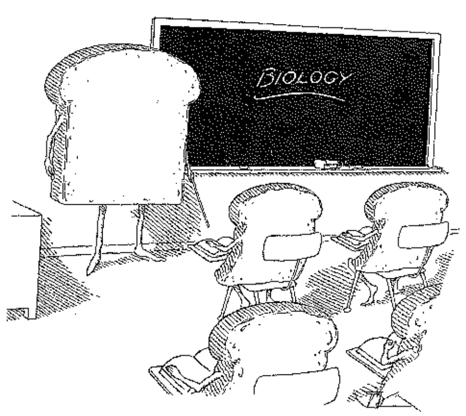
The autonomic nervous system serves two important, basic functions (**FIGURE 10.2** on the next page). The **sympathetic nervous system** arouses and expends energy. If something alarms or challenges you (such as taking the AP® Psychology exam, or being stuffed in an MRI machine), your sympathetic nervous 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.

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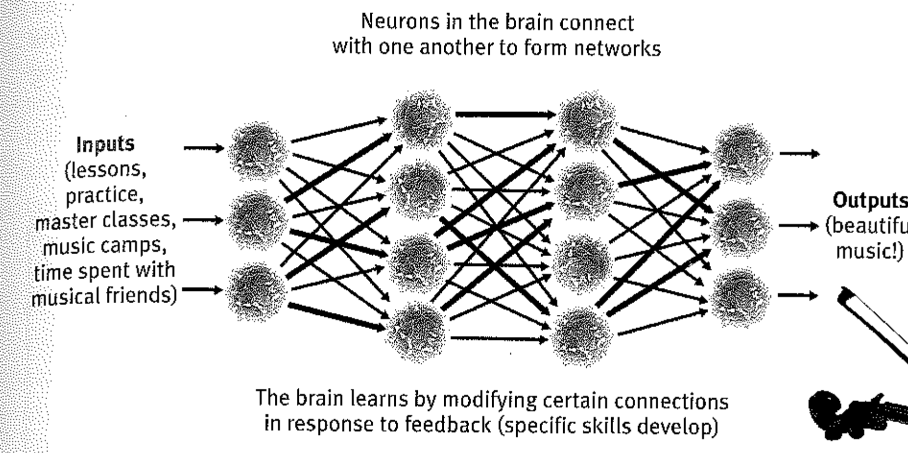
"The body is made up of millions and millions of crumbs."

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.



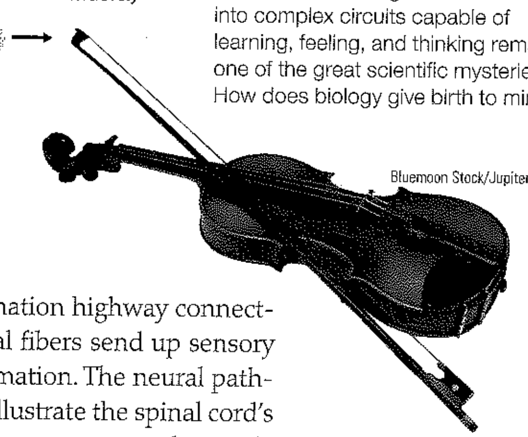


Figure 10.3
A simplified neural network Neurons network with nearby neurons. Encoded in these networks is your own enduring identity (as a musician, an athlete, a devoted friend)—your sense of self that extends across the years. How neural networks organize themselves into complex circuits capable of 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

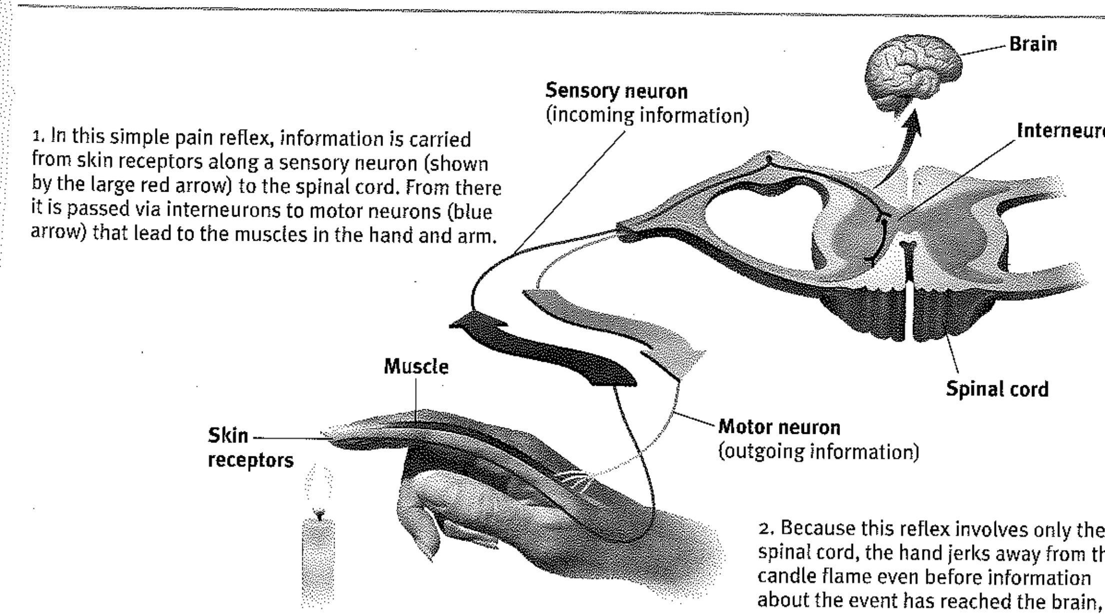


Figure 10.4
A simple reflex

"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.

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.

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.

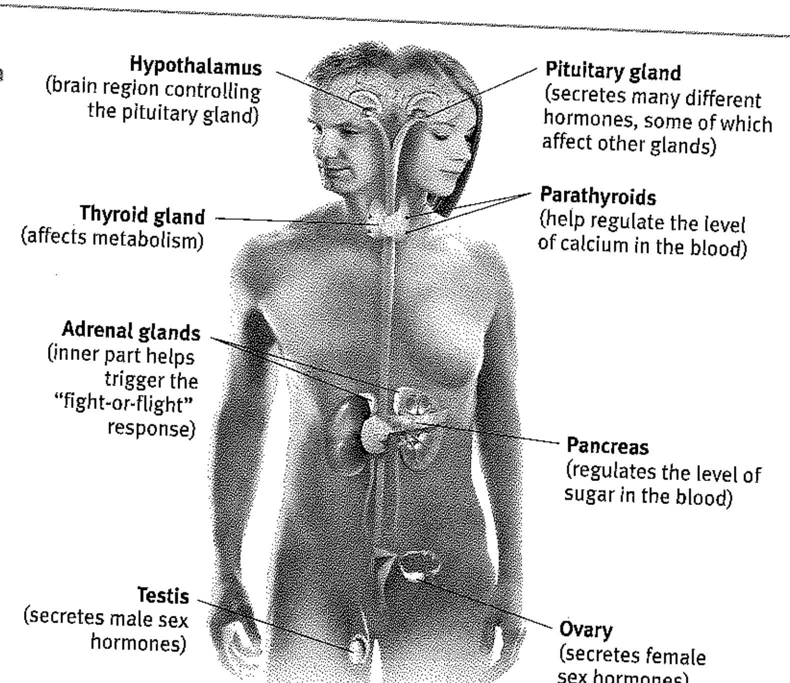


Figure 10.5
The endocrine system

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.

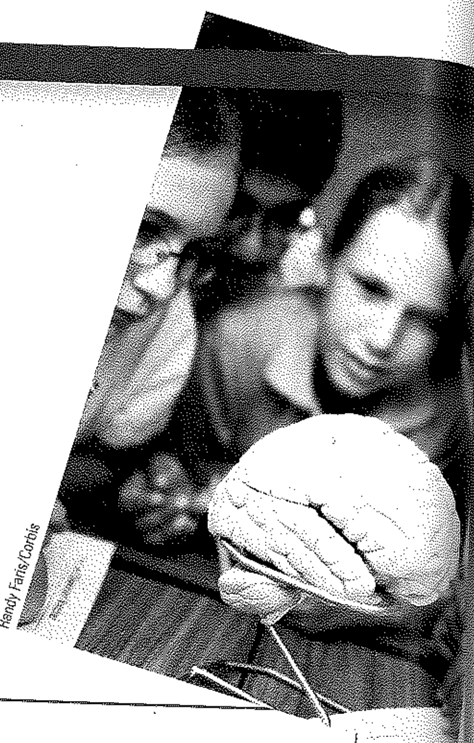
1 point: Motor neurons carry the instruction from the central nervous system to activate the muscles in your leg and foot.

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

(4 points)

Module 11

Studying the Brain, and Older Brain Structures



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Module Learning Objectives

11-1 Describe several techniques for studying the brain's connections to behavior and mind.

11-2 Describe the components of the brainstem, and summarize the functions of the brainstem, thalamus, and cerebellum.

11-3 Describe the limbic system's structures and functions.

The brain enables the mind—seeing, hearing, smelling, feeling, remembering, thinking, speaking, dreaming, loving. Moreover, it is the brain that self-reflectively analyzes the brain. When we're thinking *about* our brain, we're thinking *with* our brain—by firing across millions of synapses and releasing billions of neurotransmitter molecules. Neuroscientists tell us that the *mind is what the brain does.* Brain, behavior, and cognition are an integrated whole. But precisely where and how are the mind's functions tied to the brain? Let's first see how scientists explore such questions.

"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"

The Tools of Discovery: Having Our Head Examined

11-1 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 of patients by physicians and others helped localize some of the brain's functions. Damage to one side of the brain often caused numbness or paralysis on the body's 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 to the left-front part of the brain produced speech difficulties. Gradually, these early explorers were mapping the brain.

Now, within a lifetime, a new generation of neural cartographers is probing and mapping the known universe's most amazing organ. Scientists can selectively **lesion** (destroy) tiny clusters of brain cells, leaving the surrounding tissue unharmed. In the laboratory, such studies have revealed, for example, that damage to one area of the hypothalamus in a rat's brain reduces eating, to the point of starvation, whereas damage in another area produces overeating.

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

Today's neuroscientists can also electrically, chemically, or magnetically *stimulate* various parts of the brain and note the effect. Depending on the stimulated brain part, people may—to name a few examples—giggle, hear voices, turn their head, feel themselves falling, or have an out-of-body experience (Selimbeyoglu & Parvizi, 2010). Scientists can even snoop on the messages of individual neurons. With tips so small they can detect the electrical pulse in a single neuron, modern microelectrodes can, for example, now detect exactly where the information goes in a cat's brain when someone strokes its whisker. Researchers can also eavesdrop on the chatter of billions of neurons and can see color representations of the brain's energy-consuming activity.

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. Researchers record the brain waves through a shower-cap-like hat that is filled with electrodes covered with a conductive gel. Studying an EEG of the brain's activity is like studying a car engine by listening to its hum. With no direct access to the brain, researchers present a stimulus repeatedly and have a computer filter out brain activity unrelated to the stimulus. What remains is the electrical wave evoked by the stimulus (**FIGURE 11.1**).

AJPhoto/Science Source

Figure 11.1
An electroencephalogram providing amplified tracings of waves of electrical activity in the brain Here it is displaying the brain activity of this 4-year-old who has epilepsy.

"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. For example, the **CT (computed tomography) scan** examines the brain by taking X-ray photographs that can reveal brain damage. Even more dramatic is the **PET (positron emission tomography) scan** (**FIGURE 11.2** on the next page), which depicts brain activity by showing each brain area's consumption of its chemical fuel, the sugar glucose. Active neurons are glucose hogs, and after a person receives temporarily radioactive glucose, the PET scan can track the gamma rays released by this "food for thought" as the person performs a given task. Rather like weather radar showing rain activity, PET-scan "hot spots" show which brain areas are most active 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

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.

CT (computed tomography) scan a series of X-ray photographs taken from different angles and combined by computer into a composite representation of a slice of the brain's structure. *(Also called CAT scan.)*

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.

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.