31.1 The Neuron

Key Questions

🔑 *What are the functions of the nervous system?*

🔑 *What is the function of neurons?*

🔑 *How does a nerve impulse begin?*

Vocabulary

peripheral nervous system • central nervous system • cell body • dendrite • axon • myelin sheath • resting potential • action potential • threshold • synapse • neurotransmitter

Taking Notes

Outline Before you read, use the green and blue headings to make an outline. As you read, fill in the subtopics and smaller topics. Then, add phrases or a sentence after each to provide key information.

THINK ABOUT IT All of us are aware of the world outside our bodies. How do we know about that world? How do you really know what's happening outside? When you reached for this book and opened it to this page, how did you make these things happen? Even more mysteriously, how did the words on this page that you are reading right now get into your mind? The answers to all these questions are to be found in the nervous system.

Functions of the Nervous System

🔑 *What are the functions of the nervous system?*

The nervous system is our window on the world. 🔑 **The nervous system collects information about the body's internal and external environment, processes that information, and responds to it.** These functions are accomplished by the peripheral nervous system and the central nervous system. The **peripheral nervous system,** which consists of nerves and supporting cells, collects information about the body's external and internal environment. The **central nervous system,** which consists of the brain and spinal cord, processes that information and creates a response that is delivered to the appropriate part of the body through the peripheral nervous system.

Think about what happens when you search through your backpack for a pencil. Information is sent to your central nervous system about the objects you are touching. Your brain processes the information and determines that the first object you touch is too square to be a pencil. Then your brain sends messages via your peripheral nervous system to the muscles in your hand, commanding them to keep searching.

Imagine the billions of messages that are sent throughout your body at any given moment. The messages may tell you to laugh at a funny joke, or they may tell your brain that it's cold outside. These messages enable the different organs of the body to act together and also to react to conditions in the world around us. How does this communication occur?

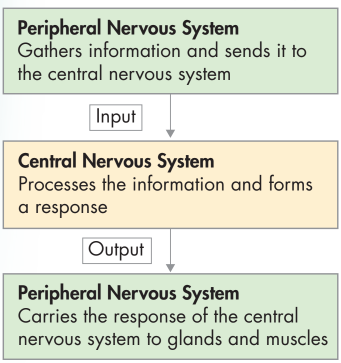


FIGURE 31–1 Information Flow in the Nervous System

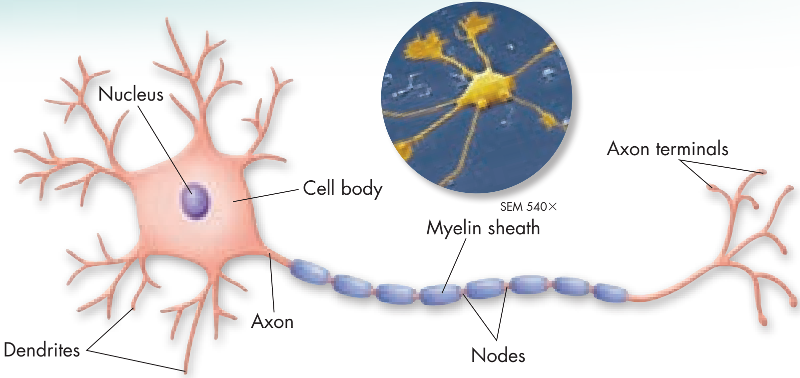


FIGURE 31–2 The Neuron The nervous system controls and coordinates functions throughout the body. The basic unit of the nervous system is the neuron.

Neurons

What is the function of neurons?

The messages carried by the nervous system are electrical signals called impulses. **Nervous system impulses are transmitted by cells called neurons.**

Types of Neurons Neurons can be classified into three types according to the direction in which an impulse travels. Sensory neurons carry impulses from the sense organs, such as the eyes and ears, to the spinal cord and brain. Motor neurons carry impulses from the brain and the spinal cord to muscles and glands. Interneurons do the high-level work. They process information from sensory neurons and then send commands to other interneurons or motor neurons.

Structure of Neurons Although neurons come in many shapes and sizes, they all have certain features in common. As shown in **Figure 31–2,** the largest part of a typical neuron is its **cell body,** which contains the nucleus and much of the cytoplasm.

Spreading out from the cell body are short, branched extensions called dendrites. **Dendrites** receive impulses from other neurons and carry impulses to the cell body. The long fiber that carries impulses away from the cell body is the **axon.** An axon ends in a series of small swellings called axon terminals. Neurons may have dozens of dendrites, but usually they have only one axon. In most animals, axons and dendrites of different neurons are clustered into bundles of fibers called nerves. Some nerves contain fibers from only a few neurons, but others contain hundreds or even thousands of neurons.

In some neurons, the axon is surrounded by an insulating membrane known as the **myelin** (MY uh lin) **sheath.** The myelin sheath that surrounds a single, long axon has many gaps, called nodes, where the axon membrane is exposed. As an impulse moves along the axon, it jumps from one node to the next. This arrangement causes an impulse to travel faster than it would through an axon without a myelin sheath.

In Your Notebook *Make a two-column table that lists the structures of a neuron in one column and their functions in the next column.*

BUILD Vocabulary

MULTIPLE MEANINGS The word *terminal* can be a noun or adjective. As a noun, it may refer to a place where information is entered into a computer or a station where people or goods are moved from one place to another. As an adjective, it may describe something that is beyond rescue or placed at the end of a structure.

The Nerve Impulse

How does a nerve impulse begin?

Nerve impulses are a bit like the flow of an electric current through a wire. To see how this occurs, let's first examine a neuron at rest.

The Resting Neuron Neurons, like most cells, have a charge, or electrical potential, across their cell membranes. The inside of a neuron has a voltage of −70 millivolts (mV) compared to the outside. This difference, or **resting potential,** is roughly one-twentieth the voltage in a flashlight battery. Where does this potential come from?

Active transport proteins pump sodium ions (Na^+) out of the cell and potassium ions (K^+) into it as shown in **Figure 31–3.** Since both ions are positively charged, this alone doesn't produce a potential across the membrane. However, ungated potassium channel proteins make it easier for K^+ ions than Na^+ ions to diffuse back across the membrane. Because there is a higher concentration of K^+ ions inside the cell as a result of active transport, there is a net movement of positively charged K^+ ions out of the cell. As a result, the inside becomes negatively charged compared to the outside, producing the resting potential.

The toxin found in this fish binds to gated sodium channels, blocking the flow of Na^+ ions into a cell. How do you think this might affect muscle movement?

The Moving Impulse A neuron remains in its resting state until it receives a stimulus large enough to start a nerve impulse. **An impulse begins when a neuron is stimulated by another neuron or by the environment.** Once it begins, the impulse travels quickly down the axon away from the cell body toward the axon terminals. In myelinated axons, the impulse moves even more rapidly as its skips from one node to the next.

What actually happens during an impulse? As **Figure 31–5** shows, the impulse itself is a sudden reversal of the resting potential. The neuron cell membrane contains thousands of "gated" ion channels. At the leading edge of an impulse, gated sodium channels open, allowing positively charged Na^+ ions to flow into the cell. The inside of the membrane temporarily becomes more positive than the outside, reversing the resting potential. This reversal of charges, from more negatively charged to more positively charged, is called a nerve impulse, or an **action potential.**

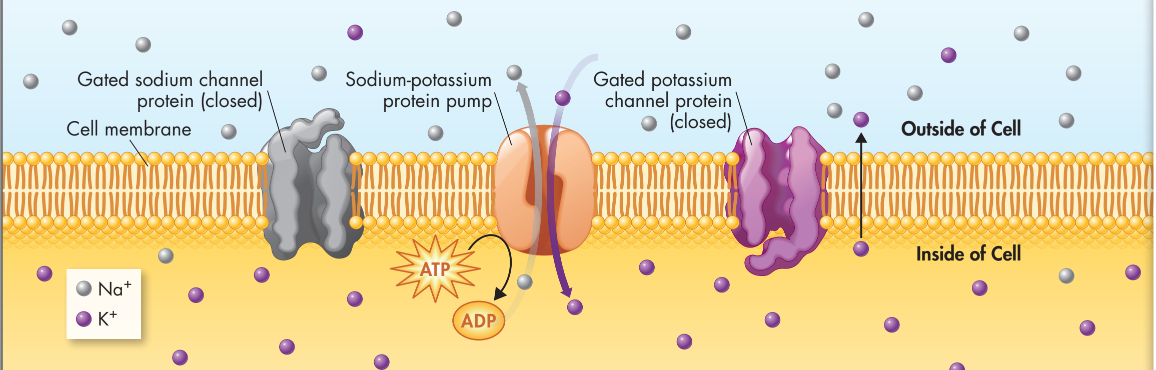


FIGURE 31–3 The Resting Neuron The sodium-potassium pump in the neuron cell membrane uses ATP to pump Na^+ ions out of the cell and to pump K^+ ions in. A small amount of K^+ ions diffuse out of the cell (through ungated channels), but gated channels block Na^+ ions from flowing into the resting neuron. **Apply Concepts** ***Is the action of the sodium-potassium pump an example of diffusion or active transport? Explain.***

VISUAL ANALOGY

A CHAIN REACTION

FIGURE 31–4 With a strong enough push, the fall of one domino leads to the fall of the next. An action potential moves along a neuron in a similar manner. **Use Analogies** ***Compare and contrast how an action potential traveling along an axon is like the fall of a row of dominoes.***

Once the impulse passes, sodium gates close and gated potassium channels open, allowing K^+ ions to flow out. This restores the resting potential so that the neuron is once again negatively charged on the inside. All the while, the sodium-potassium pump keeps working, ensuring that the axon will be ready for more action potentials.

A nerve impulse is self-propagating; that is, the flow of ions at the point of the impulse causes sodium channels just ahead of it to open. This allows the impulse to move rapidly along the axon. You could compare the flow of an impulse to the fall of a row of dominoes. As each domino falls, it causes the next domino to fall.

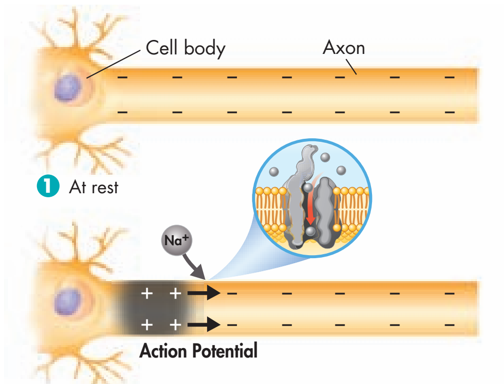
In Your Notebook *In your own words, summarize what happens across a neuron's membrane when it is at rest and during an action potential.*

Threshold Not all stimuli are capable of starting an impulse. The minimum level of a stimulus that is required to cause an impulse in a neuron is called its **threshold.** Any stimulus that is weaker than the threshold will not produce an impulse. A nerve impulse is an all-or-none response. Either the stimulus produces an impulse, or it does not produce an impulse.

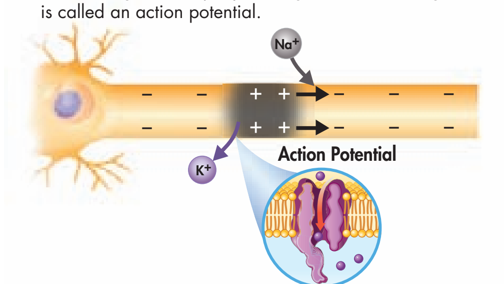
The threshold principle can also be illustrated by using a row of dominoes. If you were to gently press the first domino in a row, it might not move at all. A slightly harder push might make the domino teeter back and forth but not fall. A push strong enough to cause the first domino to fall into the second, and start the whole row falling, is like a threshold stimulus.

If all action potentials have the same strength, how do we sense if a stimulus, like touch or pain, is strong or weak? The brain determines this from the frequency of action potentials. A weak stimulus might produce three or four action potentials per second, while a strong one might result in as many as 100 per second. If you accidentally hit your finger with a hammer, those action potentials fire like mad!

FIGURE 31–5 The Moving Impulse Once an impulse begins, it will continue down an axon until it reaches the end. In an axon with a myelin sheath, the impulse jumps from node to node.



2 At the leading edge of the impulse, gated sodium channels open. Na^+ ions flow into the cell, reversing the potential between the cell membrane and its surroundings. This rapidly moving reversal of charge is called an action potential.



3 As the action potential passes, gated potassium channels open, allowing K^+ ions to flow out and restoring the resting potential inside the axon.

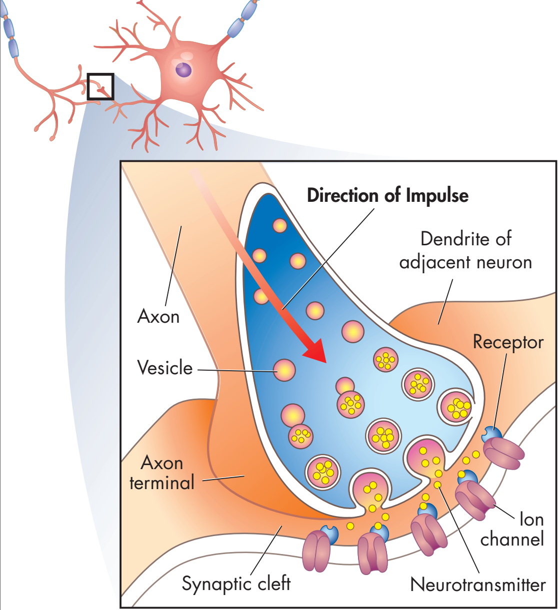


FIGURE 31–6 The Synapse When an impulse reaches the end of the axon of one neuron, neurotransmitters are released into the synaptic cleft. The neurotransmitters bind to receptors on the membrane of an adjacent cell.
Apply Concepts ***What are three types of cells that could be on the receiving end of an impulse?***

The Synapse At the end of the neuron, the impulse reaches an axon terminal, which may pass the impulse along to another cell. A motor neuron, for example, may pass impulses to a muscle cell, causing the muscle cell to contract. The point at which a neuron transfers an impulse to another cell is called a **synapse** (SIN aps). As shown in **Figure 31–6,** a space, called the synaptic cleft, separates the axon terminal from the adjacent cell.

The axon terminal at a synapse contains tiny vesicles filled with neurotransmitters. **Neurotransmitters** are chemicals that transmit an impulse across a synapse to another cell. When an impulse arrives at the synapse, neurotransmitters are released from the axon, diffuse across the synaptic cleft, and bind to receptors on the membrane of the receiving cell. This binding opens ion channels in the membrane of the receiving cell. If the stimulation exceeds the cell's threshold, a new impulse begins.

Once they have done their work, the neurotransmitters are released from the receptors on the cell surface. They are then broken down by enzymes in the synaptic cleft or taken up and recycled by the axon terminal.

31.1 Assessment

Review Key Concepts

1. a. Review Describe the functions of the nervous system.

b. Apply Concepts Describe how your peripheral nervous system and central nervous system were involved in a simple activity you performed today.

2. a. Review Name and describe the three types of neurons.

b. Predict The immune system of people with multiple sclerosis attacks myelin sheaths in the central nervous system. The myelin breaks down and scar tissue may result. How do you think this would affect the transmission of signals from the central nervous system?

3. a. Review What happens when a neuron is stimulated by another neuron?

b. Infer How can the level of pain you feel vary if a stimulus causes an all-or-none response?

VISUAL THINKING

4. Create a flowchart to show the events that occur as a nerve impulse travels from one neuron to the next. Include as much detail as you can. Use your flowchart to explain the process to a classmate.

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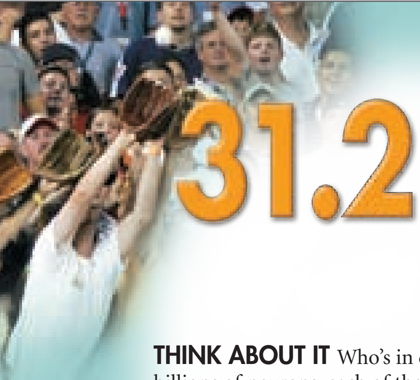


31.2 The Central Nervous System

THINK ABOUT IT Who's in charge? The nervous system contains billions of neurons, each of them capable of carrying impulses and sending messages. What keeps them from sending impulses everywhere and acting like an unruly mob? Is there a source of order in this complex system, a central place where information is processed, decisions are made, and order is enforced?

The Brain and Spinal Cord

Where does processing of information occur in the nervous system?

The control point of the central nervous system is the brain. **Each of the major areas of the brain—the cerebrum, cerebellum, and brain stem—are responsible for processing and relaying information.** Like the central processing unit of a computer, information processing is the brain's principal task. **Figure 31–8** on the next page provides details about the major areas of the brain.

While most organs in the body function to maintain homeostasis, the brain itself is constantly changed by its interactions with the environment. Sensory experience changes many of the patterns of neuron connections in the brain, and stem cells in the brain produce new neurons throughout life. Many of these new cells originate in regions associated with learning and memory. Far from staying the same, the highly flexible brain reacts to and changes constantly with the world around it.

Most of the neurons that enter and leave the brain do so in a large cluster of neurons and other cells known as the spinal cord. **The spinal cord is the main communication link between the brain and the rest of the body.** The spinal cord is a bit like a major telephone line, carrying thousands of signals at once between the central and peripheral nervous systems. Thirty-one pairs of spinal nerves branch out from the spinal cord, connecting the brain to different parts of the body. Certain kinds of information, including many reflexes, are processed directly in the spinal cord. A **reflex** is a quick, automatic response to a stimulus. The way in which you pull your hand back quickly when pricked by a pin is an example of a reflex.

In Your Notebook *Make a three-column table that lists the major structures of the brain described in **Figure 31–8**, their functions, and how they interact with at least one other brain structure.*

Key Questions

Where does processing of information occur in the nervous system?

How do drugs change the brain and lead to addiction?

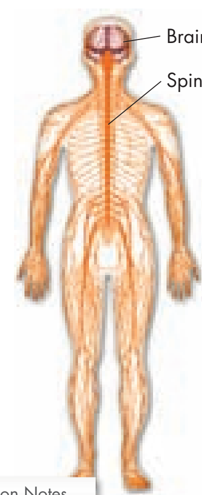
Vocabulary

reflex • cerebrum • cerebral cortex • thalamus • hypothalamus • cerebellum • brain stem • dopamine

Taking Notes

Concept Map As you read, construct a concept map that shows how the structures of the central nervous system are related to each other.

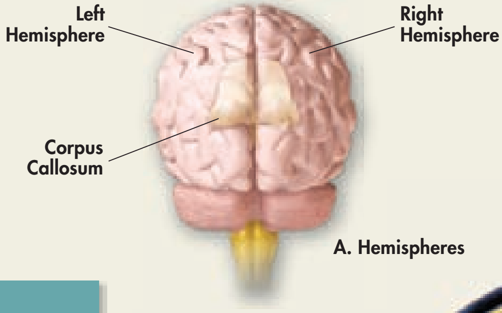
FIGURE 31–7 The Central Nervous System The central nervous system consists of the brain and spinal cord.



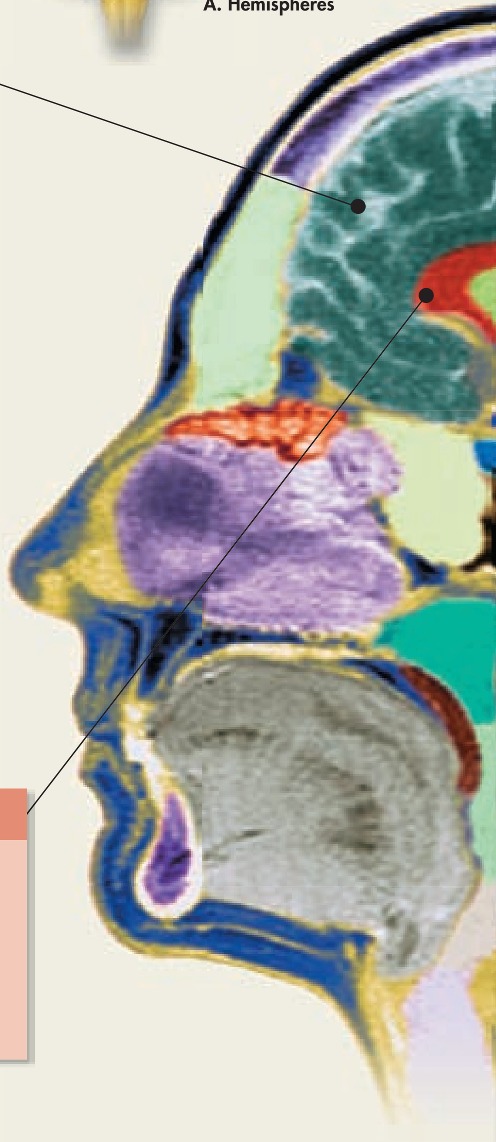
VISUAL SUMMARY

THE BRAIN

FIGURE 31–8 The brain contains billions of neurons and other supporting tissue that process, relay, and form responses to an incomprehensible amount of information every moment. **Infer** ***Which structure of the brain most likely filters information traveling from the spinal cord to the brain?***



A. Hemispheres



Cerebrum

The largest region of the human brain is the cerebrum. The **cerebrum** is responsible for the voluntary, or conscious, activities of the body. It is also the site of intelligence, learning, and judgment.

Hemispheres As shown in **Figure 31–8A** (a back view of the brain), a deep groove divides the cerebrum into left and right hemispheres. The hemispheres are connected by a band of tissue called the corpus callosum. Remarkably, each hemisphere deals mainly with the opposite side of the body. Sensations from the left side of the body go to the right hemisphere, and those from the right side go to the left hemisphere. Commands to move muscles are delivered in the same way.

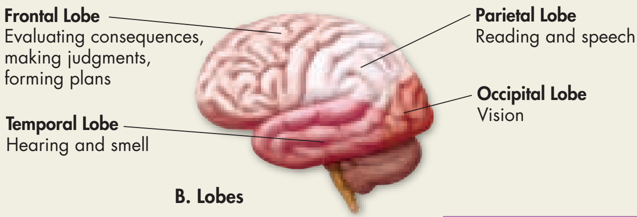
As shown in **Figure 31–8B,** each hemisphere is divided into regions called lobes. The four lobes are named for the skull bones that cover them. Each of these lobes are associated with different functions.

Cerebral Cortex The cerebrum consists of two layers. The outer layer of the cerebrum is called the **cerebral cortex** and consists of densely packed nerve cell bodies known as gray matter. The cerebral cortex processes information from the sense organs and controls body movements. It is also where thoughts, plans, and learning abilities are processed. Folds and grooves on the outer surface of the cerebral cortex greatly increase its surface area.

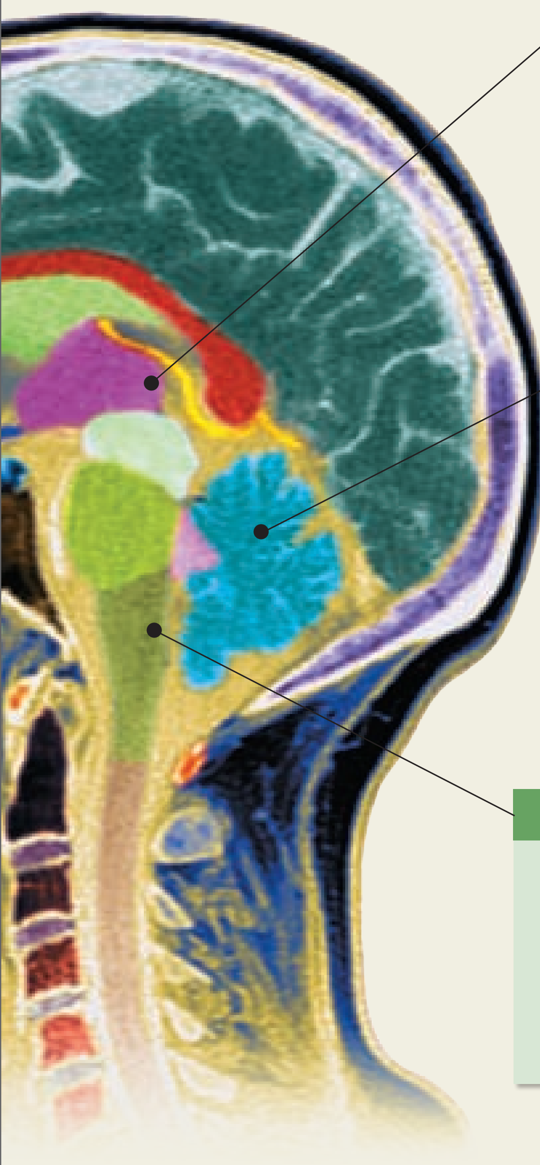
White Matter The inner layer of the cerebrum is known as white matter. Its whitish color comes from bundles of axons with myelin sheaths. These axons may connect different areas of the cerebral cortex, or they may connect the cerebrum to other areas of the brain such as the brain stem.

Limbic System

A number of important functions have been linked to the many structures that make up the limbic system including emotion, behavior, and memory. For example, a region deep within the brain called the amygdala (uh MIG duh luh) has been associated with emotional learning, including fear and anxiety, as well as the formation of long-term memories. The limbic system is also associated with the brain's pleasure center, a region that produces feelings of satisfaction and well-being.



B. Lobes



Thalamus and Hypothalamus

The thalamus and hypothalamus are found between the brain stem and the cerebrum. The **thalamus** receives messages from sensory receptors throughout the body and then relays the information to the proper region of the cerebrum for further processing. Just below the thalamus is the hypothalamus. The **hypothalamus** is the control center for recognition and analysis of hunger, thirst, fatigue, anger, and body temperature. The hypothalamus also helps to coordinate the nervous and endocrine systems.

Cerebellum

The second largest region of the brain is the **cerebellum.** Information about muscle and joint position, as well as other sensory inputs, are sent to the cerebellum. Although the commands to move muscles come from the cerebral cortex, sensory information allows the cerebellum to coordinate and balance the actions of these muscles. This enables the body to move gracefully and efficiently.

When you begin any new activity involving muscle coordination, such as hitting a golf ball or threading a needle, it is the cerebellum that actually learns the movements and coordinates the actions of scores of individual muscles when the movement is repeated.

Brain Stem

The **brain stem** connects the brain and spinal cord. Located just below the cerebellum, the brain stem includes three regions—the midbrain, the pons, and the medulla oblongata. Each of these regions regulates the flow of information between the brain and the rest of the body. Some of the body's most important functions—including regulation of blood pressure, heart rate, breathing, and swallowing—are controlled by the brain stem. The brain stem does the work of keeping the body functioning even when you have lost consciousness due to sleep or injury.

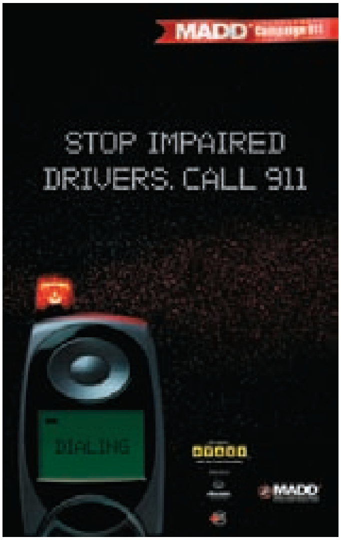


FIGURE 31–9 Drugs and Society The damage to the brain is only the start of the damage that drugs cause. For example, alcohol abuse costs the United States about $185 billion a year in health care costs, treatment services, property damage, and lost productivity.

Addiction and the Brain

How do drugs change the brain and lead to addiction?

Synapses make the brain work by transferring messages from cell to cell, doing the conscious work of thinking and the less conscious work of producing feelings and emotions. Can you guess what would happen if a chemical changed the way those synapses worked? If you guessed that such chemicals might change behavior, you'd be right.

Nearly every addictive substance, including illegal drugs such as heroin, methamphetamine, and cocaine, and legal drugs, such as tobacco and alcohol, affect brain synapses. Although the chemistry of each drug is different, they all produce changes in one particular group of synapses. These synapses use the neurotransmitter **dopamine** and are associated with the brain's pleasure and reward centers.

When we engage in an activity that brings us pleasure, whether it's eating a tasty snack or being praised by a friend, neurons in the hypothalamus and the limbic system release dopamine. Dopamine molecules stimulate other neurons across these synapses, producing the sensation of pleasure and a feeling of wellbeing.

Addictive drugs act on dopamine synapses in a number of ways. Methamphetamine releases a flood of dopamine, producing an instant "high." Cocaine keeps dopamine in the synaptic region longer, intensifying pleasure and suppressing pain. Drugs made from opium poppies, like heroin, stimulate receptors elsewhere in the brain that lead to dopamine release. Nicotine, the addictive substance in tobacco, and alcohol, the most widely abused drug in the United States, also cause increased release of dopamine.

The brain reacts to excessive dopamine levels by reducing the number of receptors for the neurotransmitter. As a result, normal activities no longer produce the sensations of pleasure they once did. Addicts feel depressed and sick without their drugs. Because there are fewer receptors, larger amounts of tobacco, alcohol, and illegal drugs are required to produce the same high. The result is a deeper and deeper spiral of addiction that is difficult to break.

31.2 Assessment

Review Key Concepts

1. a. **Review** What are the three major regions of the brain?
   b. **Describe** Explain the role of the spinal cord.
   c. **Infer** How do reflexes protect the body from injury?
2. a. **Review** Describe three ways that drugs affect synapses that use the neurotransmitter dopamine.
   b. **Apply Concepts** Why do many drug users begin to take more and more of the drug they abuse?

Apply the Big idea

Homeostasis

3. Explain the brain's role in homeostasis in regard to the body as a whole. How does homeostasis within the brain differ from the rest of the body? How must it be similar?

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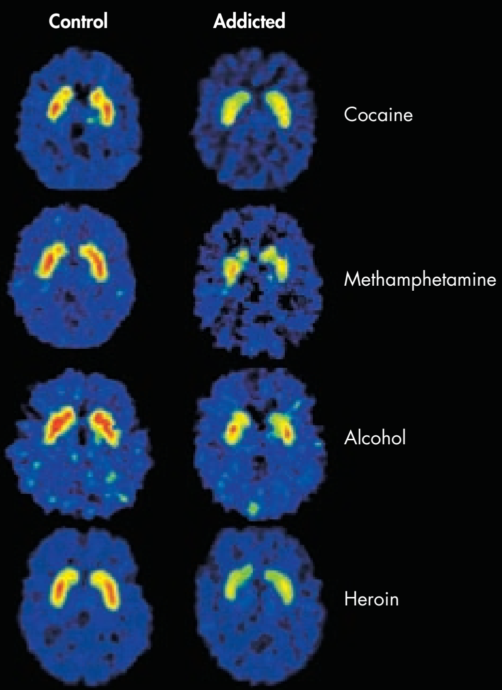
Technology & BIOLOGY

Studying the Brain and Addiction

Studies at the National Institute of Drug Abuse (NIDA) have demonstrated why drugs that stimulate dopamine produce a pattern of addiction that is difficult to break. The brain is a flexible organ that responds to its environment and continually adjusts its internal chemistry. When it senses increased levels of dopamine, it adjusts by cutting down on the number of receptors for the neurotransmitter.

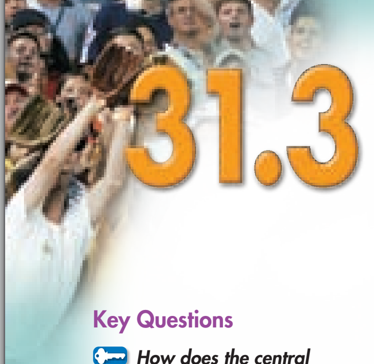
NIDA researchers used a powerful imaging technique known as positron emission tomography (PET) to visualize the density of dopamine receptors in brains affected by drug addition, and the results, shown here, are striking. Brains of individuals abusing alcohol and illegal drugs show dramatically lower concentrations of dopamine receptors than the brains of individuals not abusing the drugs.



Positron emission tomography (PET) allows researchers to visualize labeled molecules deep inside the body. PET is routinely used to pinpoint regions of cellular activity. To locate dopamine receptors, a molecule that binds to the receptor is labeled with a radioactive isotope of carbon. Within a few minutes, the isotope emits a subatomic particle called a positron. The location of the particle is revealed by gamma rays released when it collides with other particles. By locating thousands of positron emissions, computers can put together detailed images showing the location of the labeled molecules.

◀In these images, areas of highest dopamine receptor density appear red. Areas of lowest dopamine receptor density appear green.

WRITING **Using the information in this feature, create a poster to discourage peers from using addictive drugs.**



31.3 The Peripheral Nervous System

Key Questions

How does the central nervous system receive sensory information?

How do muscles and glands receive commands from the central nervous system?

Vocabulary

somatic nervous system
reflex arc
autonomic nervous system

Taking Notes

Flowchart As you read, make a flowchart that shows the flow of information between the divisions of the peripheral nervous system and the central nervous system.

THINK ABOUT IT It's all about input and output. No computer is worth much unless it can accept input from the world around it. And, no matter how quickly it calculates, no result is of any meaning unless there's a way to output it. The central nervous system faces the same issues. Can you guess what it uses for input and output devices?

The Sensory Division

How does the central nervous system receive sensory information?

The peripheral nervous system consists of all the nerves and associated cells that are not part of the brain or spinal cord. Cranial nerves go through openings in the skull and stimulate regions of the head and neck. Spinal nerves stimulate the rest of the body. The cell bodies of cranial and spinal nerves are arranged in clusters called ganglia.

The peripheral nervous system, our link with the outside world, consists of two major divisions—the sensory division and the motor division. **The sensory division of the peripheral nervous system transmits impulses from sense organs to the central nervous system.** The motor division transmits impulses from the central nervous system to the muscles and glands.

Sensory receptors are cells that transmit information about changes in the environment—both internal and external. These changes are called stimuli. Sensory receptors can be categorized by the type of stimuli to which they respond. **Figure 31–10** shows the functions and locations of several types of sensory receptors. When stimulated, sensory receptors transmit impulses to sensory neurons. Sensory neurons then transmit impulses to the central nervous system.

FIGURE 31–10 Sensory Receptors Sensory receptors react to a specific stimulus such as light or sound by sending impulses to sensory neurons. **Apply Concepts** *List three types of sensory receptors that are activated when you walk into a busy flower shop.*

Sensory Receptors

Type	Responds to	Some Locations
Chemoreceptor	Chemicals	Mouth, nose, blood vessels
Photoreceptor	Light	Eyes
Mechanoreceptor	Touch, pressure, vibrations, and stretch	Skin, hair follicles, ears, ligaments, tendons
Thermoreceptor	Temperature changes	Skin, hypothalamus
Pain receptor	Tissue injury	Throughout the body

The Motor Division

How do muscles and glands receive commands from the central nervous system?

The nervous system plays a key role in maintaining homeostasis by coordinating the activities of other systems and organs. Once it has gathered and processed sensory information, the nervous system sends commands to the rest of the body. **The motor division of the peripheral nervous system transmits impulses from the central nervous system to muscles or glands.** These messages are relayed through one of two divisions, the somatic nervous system or the autonomic nervous system.

MYSTERY CLUE

Based on Captain Cook's symptoms of weakness, what part of the nervous system is most affected by the consumption of even small amounts of this fish?

Somatic Nervous System

The **somatic nervous system** regulates body activities that are under conscious control, such as the movement of skeletal muscles. Most of the time you have control over skeletal muscle movement, but when your body is in danger the central nervous system may take over.

▶ ***Voluntary Control*** Every time you lift your finger or wiggle your toes, you are using motor neurons of the somatic nervous system. Impulses originating in the brain are carried through the spinal cord where they synapse with the dendrites of motor neurons. The axons from these motor neurons extend from the spinal cord carrying impulses directly to muscles, causing the contractions that produce voluntary movements.

▶ ***Reflex Arcs*** Although the somatic nervous system is generally considered to be under conscious control, some actions of the system occur automatically. If you accidentally step on a tack with your bare foot, your leg may recoil before you are even aware of the pain.

This rapid response (a reflex) is caused by impulses that travel a pathway known as a **reflex arc,** as shown in **Figure 31–11.** ❶ In this example, sensory receptors react to the sensation of the tack and send an impulse to sensory neurons. ❷ Sensory neurons relay the information to the spinal cord. ❸ An interneuron in the spinal cord processes the information and forms a response. ❹ A motor neuron carries impulses to its effector, a muscle that it stimulates. ❺ The muscle contracts and your leg moves. Meanwhile, impulses carrying information about the injury are sent to your brain. By the time your brain interprets the pain, however, your leg and foot have already moved. The spinal cord does not control all reflexes. Many reflexes that involve structures in your head, such as blinking or sneezing, are controlled by the brain.

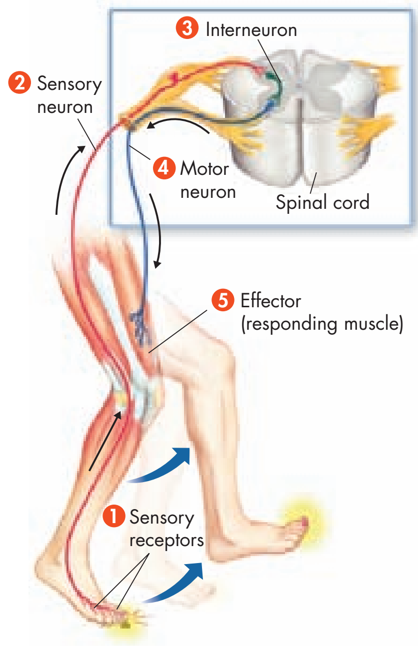


FIGURE 31–11 Reflex Arc When you step on a tack, sensory receptors stimulate a sensory neuron, which relays the signal to an interneuron within the spinal cord. The signal is then sent to a motor neuron, which in turn stimulates a muscle that lifts your leg.

In Your Notebook *In your own words, describe how a reflex arc works. Include the role of the three types of neurons in your description.*

Quick Lab
GUIDED INQUIRY

How Do You Respond To an External Stimulus?

1. Have your partner put on safety goggles.
2. Crumple up a sheet of scrap paper into a ball.
3. Watch your partner's eyes carefully as you toss the paper ball toward his or her face.
4. Repeat step 3, three times.
5. Exchange roles and repeat steps 1, 3, and 4.

Analyze and Conclude

1. **Observe** Describe your partner's reaction to step 3.
2. **Compare and Contrast** Did you see any change in behavior as you repeated step 3? Explain.
3. **Infer** What is the function of the blink reflex?

Autonomic Nervous System The **autonomic nervous system** regulates activities that are involuntary, or not under conscious control. For instance, when you start to run, the autonomic nervous system speeds up your heart rate and blood flow to the skeletal muscles, stimulates the sweat glands, and slows down the contractions of smooth muscles in the digestive system. You may not be aware of any of these activities, but all of them enable you to run faster and farther.

The autonomic nervous system consists of two equally important parts, the sympathetic nervous system and the parasympathetic nervous system. Why two systems? In general, the sympathetic and parasympathetic systems have opposite effects on each organ they influence. In the same way that a driver must be able to turn the steering wheel both left and right to keep a car on the road, the two systems produce a level of fine control that coordinates organs throughout the body.

For example, heart rate is increased by the sympathetic nervous system but decreased by the parasympathetic nervous system. In general, the sympathetic system prepares the body for intense activity. Its stimulation causes an increase in blood pressure, the release of energy-rich sugar into the blood, and shutting down of activities not related to the body's preparation to "fight or flee" in response to stress. In contrast, the parasympathetic system causes what might be called the "rest and digest" response. It lowers heart rate and blood pressure, activates digestion, and activates pathways that store food molecules in the tissues of the body.

31.3 Assessment

Review Key Concepts

1. a. **Review** Describe the role of the sensory division.
   b. **Explain** Give three examples of stimuli that your sensory receptors are responding to right now.
   c. **Infer** Which type of sensory receptors most likely responds to a change in blood pressure that causes more force to be exerted on your blood vessels? Explain.
2. a. **Review** Describe the function of the two parts of the motor division of the peripheral nervous system.
   b. **Explain** Is a reflex part of the central nervous system, the peripheral nervous system, or both?
   c. **Apply Concepts** Describe a situation in which you would expect your sympathetic nervous system to be more active than your parasympathetic nervous system.

Apply the Big idea

Structure and Function

3. Which part of the peripheral nervous system is involved in both innate behaviors and learned behaviors? Explain. (*Hint:* See Lesson 29.1.)

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31.4 The Senses

THINK ABOUT IT We live in a world of sensations. Think about how many of your experiences today can only be described in terms of what you felt, tasted, smelled, heard, and saw. Our senses are our link to experiencing the outside world, and we often take them for granted. Think for a moment of the color red. How would you describe the sensation of seeing red, as opposed to blue or green, to someone who was blind? Or, how would you describe the taste of an apple to someone who had never tasted one before? The inputs we get from our senses are almost impossible to describe, and yet we use them every moment of the day.

Touch and Related Senses

How does the body sense touch, temperature, and pain?

Because nearly all regions of the skin are sensitive to touch, your skin can be considered your largest sense organ. **Different sensory receptors in the body respond to touch, temperature, and pain.** All of these receptors are found in your skin, but some are also found in other areas.

Touch Human skin contains at least seven types of sensory receptors, including several that respond to different levels of pressure. Stimulation of these receptors creates the sensation of touch. Not all parts of the body are equally sensitive to touch. The skin on your fingers, as you might expect, has a much higher density of touch receptors than the skin on your back.

Temperature Thermoreceptors are sensory cells that respond to heat and cold. They are found throughout the skin, and also in the hypothalamus, part of the brain that senses blood temperature. Recently, researchers studying the cell membrane proteins that sense heat made an interesting discovery. The chemical substances that make jalapeño peppers taste "hot" actually bind to these very same proteins.

Pain Pain receptors are found throughout the body. Some, especially those in the skin, respond to physical injuries like cutting or tearing. Many tissues also have pain receptors that respond to chemicals released during infection or inflammation. The brain, interestingly, does not have pain receptors. For this reason, patients are often kept conscious during brain surgery, enabling them to tell surgeons what sensations are produced when parts of the brain are stimulated.

Key Questions

How does the body sense touch, temperature, and pain?

How are the senses of smell and taste similar?

How do the ears and brain process sounds and maintain balance?

How do the eyes and brain produce vision?

Vocabulary

taste bud • cochlea • semicircular canals • cornea • iris • pupil • lens • retina • rods • cones

Taking Notes

Preview Visuals Before reading, preview **Figure 31–14.** Write down at least two questions you have about the information in the figure.

MYSTERY CLUE

Based on Cook's symptoms, which of his senses was greatly affected by the toxin? Explain.

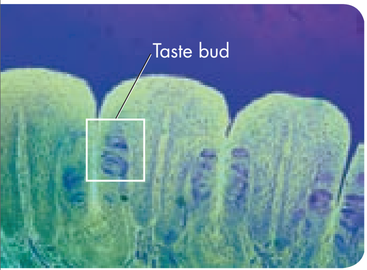


FIGURE 31–12 Taste Buds The surface of the tongue contains many tiny projections. Taste buds line the tops of some of these and line the sides of other projections (LM 80×).

Smell and Taste

How are the senses of smell and taste similar?

You may never have thought of it this way, but your senses of taste and smell actually involve the ability to detect chemicals. Chemical-sensing cells known as chemoreceptors in the nose and mouth are responsible for both of these senses. **Sensations of smell and taste are both the result of impulses sent to the brain by chemoreceptors.**

Your sense of smell is capable of producing thousands of different sensations. In fact, much of what we commonly call the "taste" of food and drink is actually smell. To prove this to yourself, eat a few bites of food while holding your nose. You'll discover that much of the taste of food disappears until you release your nose and breathe freely.

The sense organs that detect taste are the **taste buds.** Most of the taste buds are on the tongue, but a few are found at other locations in the mouth. The surface of the tongue is shown in **Figure 31–12.** Sensory cells in taste buds respond to salty, bitter, sweet, and sour foods. Recently, a fifth kind of taste sensation was identified, now called "umami," from the Japanese word for savory. Umami receptors are strongly stimulated by monosodium glutamate (MSG), a substance often added to Asian foods to enhance their flavor. They are also stimulated by meat and cheese, which typically contain the amino acid glutamate.

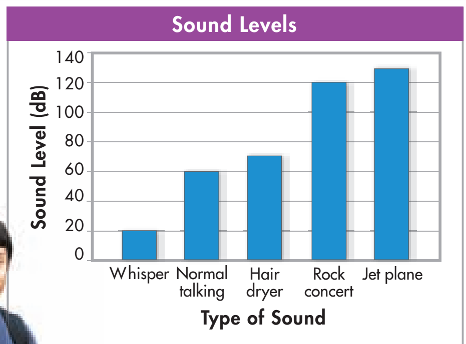
In Your Notebook *Explain the relationship between smell and taste.*

Analyzing Data

Sound Intensity

Sound intensity, or loudness, is measured in units called decibels (dB). The threshold of hearing for the human ear is 0 dB. For every 10 dB increase, the sound intensity increases ten times. Sound levels for several sound sources are shown in the bar graph.

Loud noises can permanently damage vibration-sensing cells in the cochlea. Exposure to sounds above 80 dB for several hours at a time can damage hearing. Exposure to sounds about 120 dB for even a few seconds can damage hearing.



1. Calculate How much more intense is normal talking than a whisper? Explain. MATH

2. Infer Why do you think that hearing damage caused by repeated exposure to loud noises, such as portable music devices set at a high volume, might not reveal itself for many years?

Hearing and Balance

How do the ears and brain process sounds and maintain balance?

The human ear has two sensory functions, one of which, of course, is hearing. The other function is detecting positional changes associated with movement. **Mechanoreceptors found in parts of the ear transmit impulses to the brain. The brain translates the impulses into sound and information about balance.**

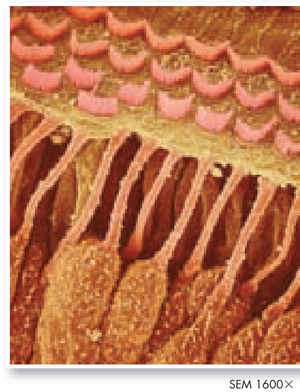
Hearing Sound is nothing more than vibrations moving through the air around us. The ears are the sensory organs that can distinguish both the pitch and loudness of those vibrations. The structure of the ear is shown in **Figure 31–13.**

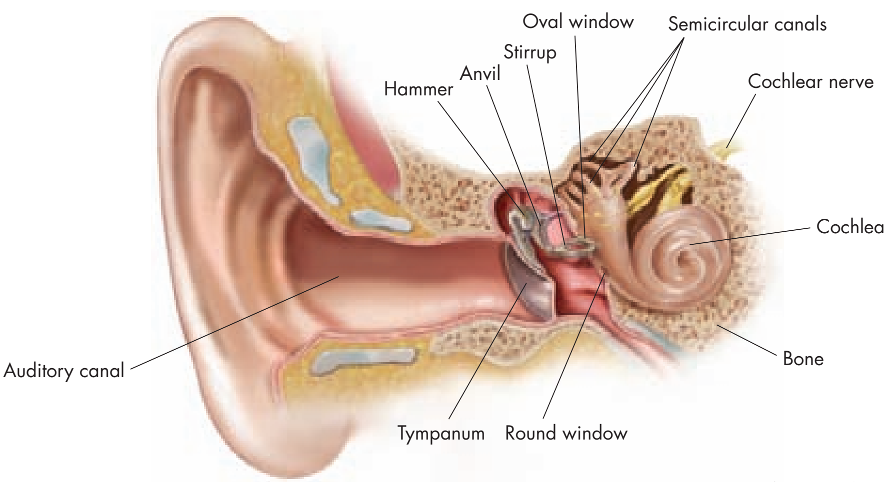
Vibrations enter the ear through the auditory canal and cause the tympanum (TIM puh num), or eardrum, to vibrate. Three tiny bones, commonly called the hammer, anvil, and stirrup, transmit these vibrations to a membrane called the oval window. Vibrations there create pressure waves in the fluid-filled **cochlea** (KAHK lee uh) of the inner ear. The cochlea is lined with tiny hair cells that are pushed back and forth by these pressure waves. In response, the hair cells send nerve impulses to the brain, which processes them as sounds.

Balance Your ears contain structures that help your central nervous system maintain your balance, or equilibrium. Within the inner ear just above the cochlea are three tiny canals. They are called semicircular canals because each forms a half circle. The **semicircular canals** and the two tiny sacs located behind them monitor the position of your body, especially your head, in relation to gravity.

The semicircular canals and the sacs are filled with fluid and lined with hair cells. As the head changes position, the fluid in the canals also changes position. This causes the hair on the hair cells to bend. This action, in turn, sends impulses to the brain that enable it to determine body motion and position.

FIGURE 31–13 The Ear The diagram shows the structures in the ear that transmit sound. The SEM shows hair cells in the inner ear. The motion of these sensitive hair cells produces nerve impulses that travel to the brain through the cochlear nerve. **Predict** ***How would frequent exposure to loud noises that damage hair cells affect a person's threshold for detecting sound?***





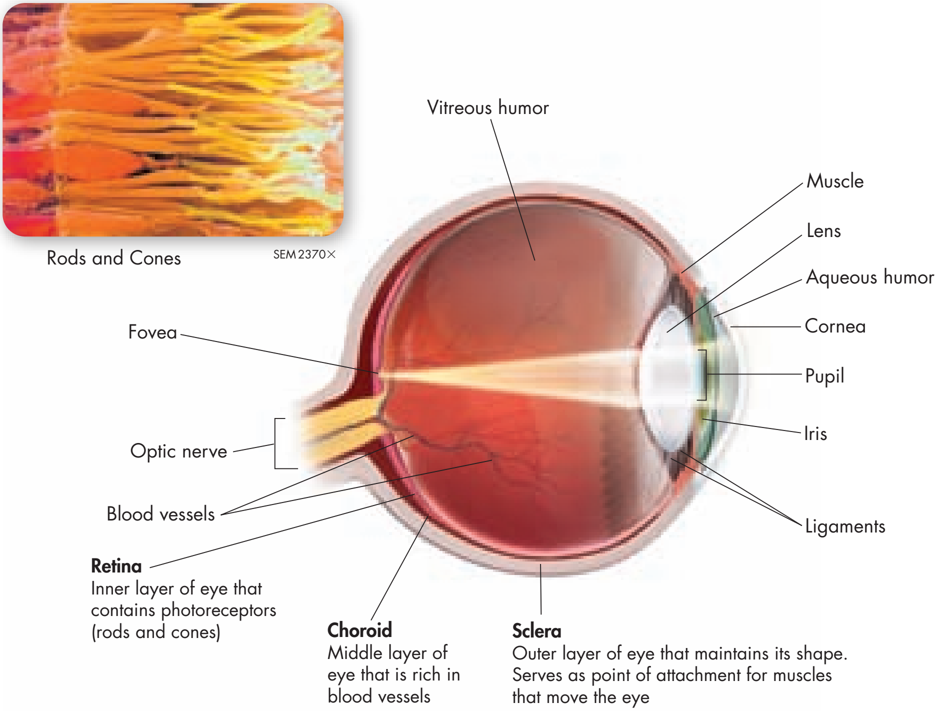


FIGURE 31–14 The Eye The eye is a complicated sense organ. The sclera, choroid, and retina are three layers of tissues that form the inner wall of the eyeball. **Interpret Graphics** *What is the function of the sclera?*

Vision

How do the eyes and brain produce vision?

The world around us is bathed in light, and the sense organs we use to detect that light are the eyes. **Vision occurs when photoreceptors in the eyes transmit impulses to the brain, which translates these impulses into images.**

Structures of the Eye The structures of the eye are shown in **Figure 31–14.** Light enters the eye through the **cornea,** a tough transparent layer of cells. The cornea helps to focus the light, which then passes through a chamber filled with a fluid called aqueous (AY kwee us) humor. At the back of the chamber is a disk-shaped structure called the **iris.** The iris is the colored part of the eye. In the middle of the iris is a small opening called the **pupil.** Tiny muscles in the iris adjust the size of the pupil to regulate the amount of light that enters the eye. In dim light, the pupil becomes larger and more light enters the eye. In bright light, the pupil becomes smaller and less light enters the eye.

Just behind the iris is the **lens.** Small muscles attached to the lens change its shape, helping to adjust the eyes' focus to see near or distant objects clearly. Behind the lens is a large chamber filled with a transparent, jellylike fluid called vitreous (VIH tree us) humor.

How You See The lens focuses light onto the **retina,** the inner layer of the eye. Photoreceptors are arranged in a layer in the retina. The photoreceptors convert light energy into nerve impulses that are carried to the brain through the optic nerve. There are two types of photoreceptors: rods and cones. **Rods** are extremely sensitive to light, but they do not distinguish different colors. They only allow us to see black and white. **Cones** are less sensitive than rods, but they do respond to different colors, producing color vision. Cones are concentrated in the fovea, the site of sharpest vision.

The impulses assembled by this complicated layer of interconnected cells leave each eye by way of the optic nerve, which carry the impulses to the appropriate regions of the brain. There are no photoreceptors where the optic nerve passes through the back of the eye, producing a blind spot in part of each image sent to the brain. During the processing of the nerve impulses, the brain fills in the holes of the blind spot with information.

If the eye merely took photographs, the images would be no more detailed than the blurry images taken by an inexpensive camera and would be incomplete. The images we actually see of the world, however, are much more detailed, and the reason is the sophisticated way in which the brain processes and interprets visual information.

BUILD Vocabulary

ACADEMIC WORDS **Distinguish** may mean "to recognize as different," "to perceive clearly with a sense," or "to show a difference."

In Your Notebook *Make a flowchart that shows the sequence of how light and nerve impulses travel from the outside environment to the brain.*

31.4 Assessment

Review Key Concepts

1. a. **Review** What three types of sensations do receptors in the skin respond to?
   b. **Predict** Do you think that the soles of your feet or the back of your neck has the greater concentration of sensory receptors? Explain.
2. a. **Review** What are the five basic tastes detected by taste buds?
   b. **Apply Concepts** Why can't you taste food when you have a bad cold?
3. a. **Review** Which structures in the ear gather information about the position of your body?
   b. **Apply Concepts** If you spin around for a time, the fluid in your semicircular canals also moves. When you stop suddenly, why do you think you feel like you are still moving?
4. a. **Review** Identify the relationship between the cornea, pupil, lens, retina, and optic nerve and the photoreceptors of the eye.
   b. **Infer** Some people suffer from night blindness. Which type of photoreceptor is likely not functioning correctly? Explain.

WRITE ABOUT SCIENCE

Creative Writing

5. Imagine that you have lost your sense of taste for one day. Write a 3- to 4-paragraph essay describing how the absence of this sense would affect your day.

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Real-World Lab

GUIDED INQUIRY

Pre-Lab: Testing Sensory Receptors for Touch

Problem What factors affect a person's ability to sense gentle pressure on skin?

Materials bent paper clips, metric ruler

Lab Manual Chapter 31 Lab

Skills Focus Measure, Analyze Data, Draw Conclusions

Connect to the Big idea Your nervous system coordinates your response to stimuli from outside your body and inside your body. Sensory receptors react to stimuli by sending impulses to sensory neurons. Each receptor can detect only one type of stimulus. Receptors are classified by the type of stimuli to which they respond. Some respond to light, some to pain, some to chemicals, and so on. Mechanoreceptors are cells that respond to touch, pressure, vibrations, and stretch.

In this lab, you will investigate the mechanoreceptors in your skin that respond to gentle touch. You will compare the relative density of these receptors in three areas of your skin. You will also identify other factors that could affect a person's response to touch.

Background Questions

a. **Review** Which division of the peripheral nervous system transmits signals from receptors in your skin to your brain?

b. **Relate Cause and Effect** List two reasons why a touch might not produce a nerve impulse?

c. **Infer** People who are visually impaired use their fingertips to read books that are printed in Braille. In Braille, each letter of the alphabet is represented by a unique pattern of dots. What feature of the dots allows a reader to distinguish one set of dots from another?

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Predict** Which area will have the highest density of receptors for gentle pressure—your fingertips, the back of your hand, or your forearm?
2. **Control Variables** Why must you have your eyes closed while your partner touches your skin with the bent paper clip?
3. **Predict** Will you and your partner have the same density of touch receptors in a given area of skin? Give a reason for your prediction.

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Data Analysis Investigate the relationship between the color of food and perception of flavor.

Art Review Review your understanding of the structures in the eyes and ears with this drag-and-drop activity.

InterActive Art Watch a nerve impulse move down a neuron.

Visual Analogy Compare an action potential moving along a neuron to a row of falling dominoes.

Art in Motion View a short animation that shows how a reflex arc works.