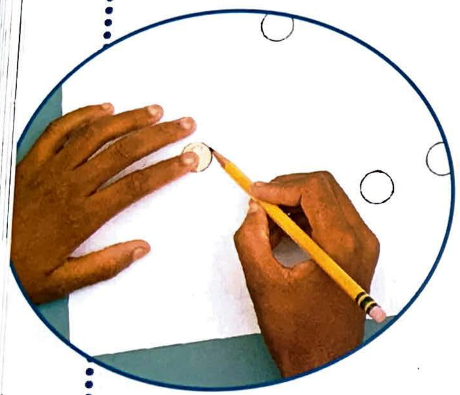
SECTION 1 How the Nervous System Works

DISCOVER ACTIVITY



How Simple Is a Simple Task?

1. Trace the outline of a penny in twelve different places on a piece of paper.
2. In no particular order, number the circles from 1 through 12.
3. Now pick up the penny again. Put it in each circle, one after another, in numerical order, beginning with 1 and ending with 12.

Think it Over

Inferring Make a list of all the sense organs, muscle movements, and thought processes in this activity. Compare your list with your classmates' lists. Identify the organ system that coordinated all the different processes involved in this task.

GUIDE FOR READING

- What are the functions of the nervous system?
- What are the three types of neurons and how do they interact?

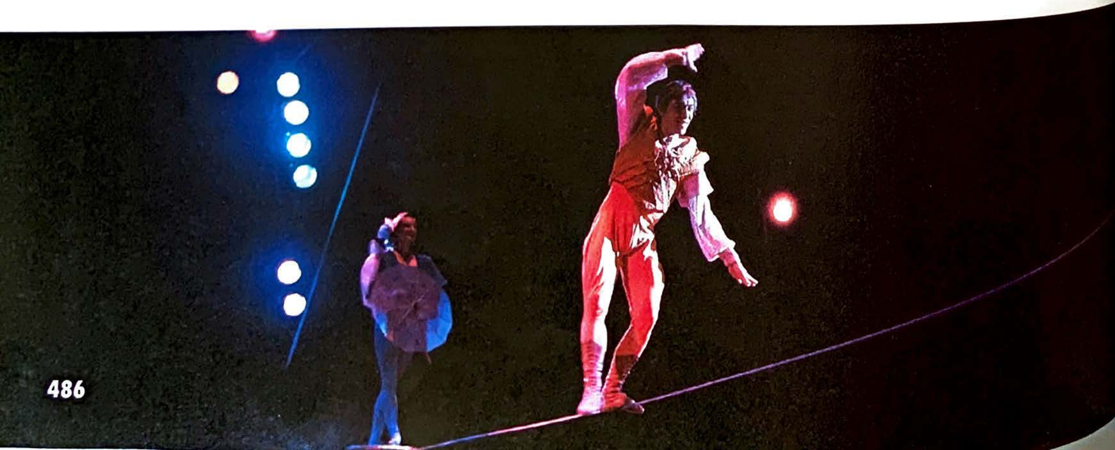
Reading Tip As you read, write a definition for each Key Term in your own words.

Key Terms neuron • nerve impulse • dendrite • axon • nerve • sensory neuron • interneuron • motor neuron • synapse

The drums roll, and the crowd suddenly becomes silent. The people in the audience hold their breaths as the tightrope walker begins his long and dangerous journey across the wire. High above the circus floor, he inches along, slowly but steadily. One wrong movement could mean disaster.

To keep from slipping, tightrope performers need excellent coordination and a keen sense of balance. In addition, they must remember what they have learned from years of practice.

Even though you aren't a tightrope walker, you also need coordination, a sense of balance, memory, and the ability to learn. Your nervous system carries out all those functions. The nervous system consists of the brain, spinal cord, and nerves that run throughout the body. It also includes sense organs such as the eyes and ears.



Functions of the Nervous System

Like the Internet, your nervous system is a communications network. Your nervous system is much more efficient, however. **The nervous system receives information about what is happening both inside and outside your body. It also directs the way in which your body responds to this information. In addition, your nervous system helps in maintaining stable internal conditions.** Without your nervous system, you could not move, think, feel pain, or taste a spicy taco.

Figure 1 The sparkling water is an external stimulus. This toddler responds by thrusting her hands into the water and splashing.

Receiving Information Because of your nervous system, you are aware of what is happening in the environment around you. For example, you know that a soccer ball is zooming toward you, that the wind is blowing, or that a friend is telling a funny joke. Your nervous system also checks conditions inside your body, such as the level of glucose in your blood.

Responding to Stimuli As you learned in Chapter 10, any change or signal in the environment that can make an organism react is a stimulus. Stimuli can come from the outside environment or from inside your body. A zooming soccer ball is an external stimulus. Hunger and tiredness are internal stimuli.

After your nervous system analyzes the stimulus, it causes a response. A response is what your body does in reaction to a stimulus—you kick the ball toward the goal, eat a peach, or take a nap. Some nervous system responses, such as kicking a ball, are voluntary, or under your control. However, many processes necessary for life, such as heart rate, are controlled by involuntary actions of the nervous system.

Maintaining Stable Internal Conditions The nervous system helps maintain homeostasis by directing the body to respond appropriately to the information it receives. For example, when you are hungry, your nervous system directs you to eat. This action maintains stable internal conditions by supplying your body with nutrients and energy it needs.

☑ *Checkpoint* *What does the nervous system do?*

The Neuron—A Message-Carrying Cell

The cells that carry information through your nervous system are called **neurons** (NOO rahnz), or nerve cells. The message that a neuron carries is called a **nerve impulse.** The structure of a neuron enables it to carry nerve impulses.

The Structure and Function of a Neuron The cell body of a neuron, which contains the nucleus, has threadlike extensions. One kind of extension, a **dendrite,** carries impulses toward the cell body. An **axon** carries impulses away from the cell body. Nerve impulses begin in a dendrite, move toward the cell body, and then move down the axon. A neuron can have many dendrites, but it has only one axon. An axon, however, can have more than one tip, so the impulse can go to more than one other cell.

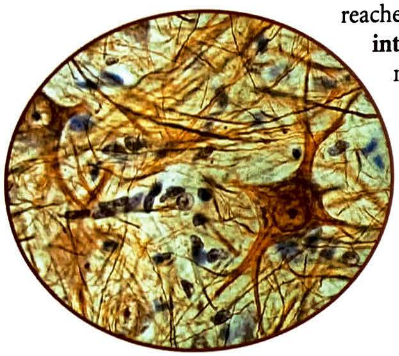
Axons and dendrites are sometimes called nerve fibers. Nerve fibers are often arranged in parallel bundles covered with connective tissue, something like a package of uncooked spaghetti wrapped in cellophane. A bundle of nerve fibers is called a **nerve.**

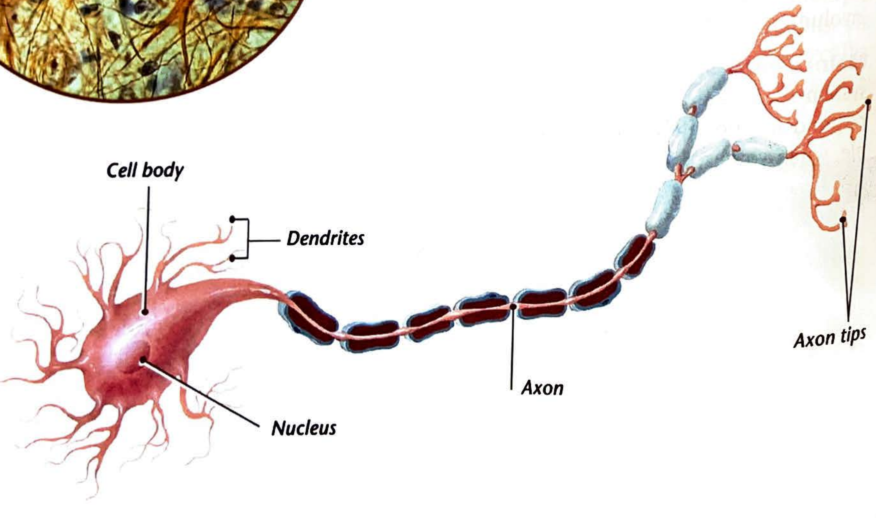
Kinds of Neurons Different kinds of neurons perform different functions. **Three kinds of neurons are found in the body—sensory neurons, interneurons, and motor neurons. Together they make up a chain of nerve cells that carry an impulse through the nervous system.** *Exploring the Path of a Nerve Impulse* shows how these three kinds of neurons work together.

A **sensory neuron** picks up stimuli from the internal or external environment and converts each stimulus into a nerve impulse. The impulse travels along the sensory neuron until it reaches an interneuron, usually in the brain or spinal cord. An **interneuron** is a neuron that carries nerve impulses from one neuron to another. Some interneurons pass impulses from sensory neurons to motor neurons. A **motor neuron** sends an impulse to a muscle, and the muscle contracts in response.

☑ *Checkpoint* *What is the function of an axon?*

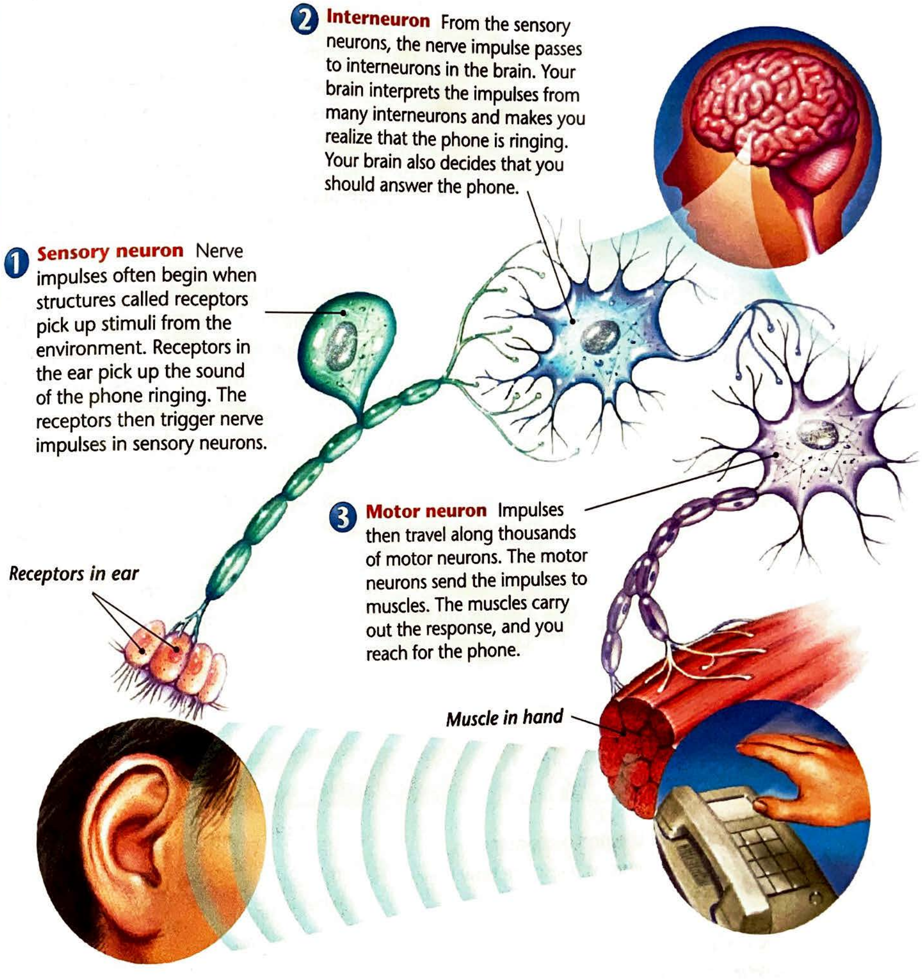
Figure 2 A neuron, or nerve cell, has one axon and many dendrites that extend from the cell body. The dendrites carry a nerve message toward the cell body, and the axon carries the message away from the cell body. *Applying Concepts How many axons can a neuron have?*





EXPLORING the Path of a Nerve Impulse

When you hear the phone ring, you pick it up to answer it. Many sensory neurons, interneurons, and motor neurons are involved in this response.



1 Sensory neuron Nerve impulses often begin when structures called receptors pick up stimuli from the environment. Receptors in the ear pick up the sound of the phone ringing. The receptors then trigger nerve impulses in sensory neurons.

2 Interneuron From the sensory neurons, the nerve impulse passes to interneurons in the brain. Your brain interprets the impulses from many interneurons and makes you realize that the phone is ringing. Your brain also decides that you should answer the phone.

3 Motor neuron Impulses then travel along thousands of motor neurons. The motor neurons send the impulses to muscles. The muscles carry out the response, and you reach for the phone.

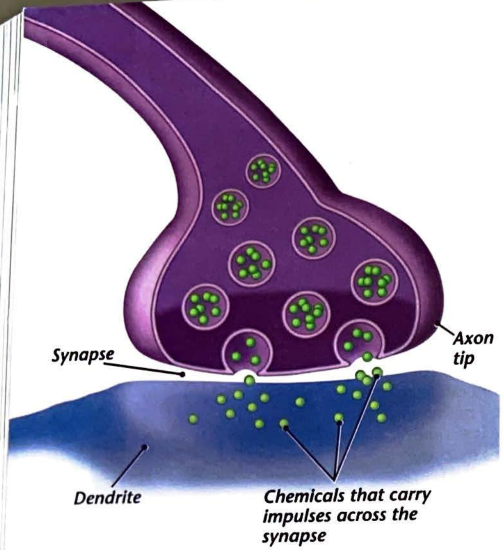


Figure 3 A synapse is the tiny space between the axon of one neuron and the dendrite of another neuron. When a nerve impulse reaches the end of an axon, chemicals are released into the synapse. These chemicals enable the nerve impulse to cross the synapse.

How a Nerve Impulse Travels

Every day of your life, millions of nerve impulses travel through your nervous system. Each of those nerve impulses begins in the dendrites of a neuron. The impulse moves rapidly toward the neuron's cell body and then down the axon until it reaches the axon tip. A nerve impulse travels along the neuron in the form of electrical and chemical signals. Nerve impulses can travel as fast as 120 meters per second!

There is a tiny space called a **synapse** (SIN aps) between each axon tip and the next structure. Sometimes this next structure is a dendrite of another neuron. Other times the next structure can be a muscle or a cell in another organ, such as a sweat gland. Figure 3 shows a synapse between the axon of one neuron and a dendrite of another neuron.

In order for a nerve impulse to be carried along, it must cross the gap between the axon and the next structure. The axon tips release chemicals that enable the impulse to cross the synapse. If that didn't happen, the impulse would stop at the end of the axon. The impulse would not be passed from sensory neuron, to interneuron, to motor neuron. Nerve impulses would never reach your brain or make your muscles contract.

You can think of a synapse as a river, and an axon as a road that leads up to the riverbank. The nerve impulse is like a car traveling on the road. To get to the other side, the car has to cross the river. The car gets on a ferry boat, which carries it across the river. The chemicals that the axon tips release are like a ferry that carries the nerve impulse across the synapse.

Section 1 Review

1. Describe three functions of the nervous system.
2. Identify the three kinds of neurons. Describe how they interact to carry nerve impulses.
3. Distinguish between external and internal stimuli. Give an example of each.
4. **Thinking Critically Predicting** What would happen to a nerve impulse carried by an interneuron if the tips of the interneuron's axon were damaged? Explain your answer.

Science at Home

Stimulus and Response During dinner, ask a family member to pass the salt and pepper to you. Observe what your family member then does. Explain that the words you spoke were an external stimulus and that the family member's reaction was a response. Discuss other examples of stimuli and responses with your family.

Designing Experiments

Skills Lab

Ready or Not

Do people carry out tasks better at certain times of day? In this lab, you will design an experiment to answer this question.

Problem

Do people's reactions vary at different times of day?

Materials

meter stick

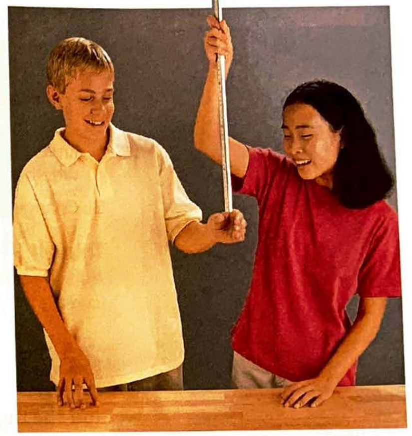
Design a Plan

Part 1 Observing a Response to a Stimulus

1. Have your partner hold a meter stick with the zero end about 50 cm above a table.
2. Get ready to catch the meter stick by positioning the top of your thumb and forefinger just at the zero position as shown in the photograph.
3. Your partner should drop the meter stick without any warning. Using your thumb and forefinger only (no other part of your hand), catch the meter stick as soon as you can. Record the distance in centimeters that the meter stick fell. This distance is a measure of your reaction time.

Part 2 Design Your Experiment

4. With your partner, discuss how you can use the activity from Part 1 to find out whether people's reactions vary at different times of day. Be sure to consider the questions below. Then write up your experimental plan.
   - What hypothesis will you test?
   - What variables do you need to control?
   - How many people will you test? How many times will you test each person?



5. Have your teacher review your plan. Make any recommended changes. Construct a data chart to organize, examine, and evaluate your data. Then perform your experiment.

Analyze and Conclude

1. In this lab, what is the stimulus? What is the response? Is this response voluntary or involuntary? Explain.
2. Why can you use the distance on the meter stick as a measure of reaction time?
3. Based on your results, do people's reactions vary at different times of day? Explain.
4. **Think About It** In Part 2, why is it important to control all variables except the time of day?

More to Explore

Do you think people can do arithmetic problems more quickly and accurately at certain times of the day? Design an experiment to investigate this question. Obtain your teacher's permission before trying your experiment.

SECTION 2

Divisions of the Nervous System

DISCOVER ACTIVITY

How Does Your Knee React?

1. Sit on a table or counter so that your legs dangle freely. Your feet should not touch the floor.
2. Have your partner use the side of his or her hand to *gently* tap one of your knees just below the kneecap. Observe what happens to your leg. Note whether you have any control over your reaction.
3. Change places with your partner. Repeat Steps 1 and 2.

Think It Over

Inferring When might it be an advantage for your body to react very quickly and without your conscious control?

GUIDE FOR READING

- What is the function of the central nervous system?
- What is the function of the peripheral nervous system?
- What is a reflex?

Reading Tip After you examine Figure 6, use your own words to describe the structure of the brain.

Key Terms central nervous system • peripheral nervous system • brain • spinal cord • cerebrum • cerebellum • brainstem • somatic nervous system • autonomic nervous system • reflex

A concert is about to begin. The conductor gives the signal, and the musicians begin to play. The sound of music, beautiful and stirring, fills the air.

To play music in harmony, an orchestra needs both musicians and a conductor. The musicians play the music, and the conductor directs the musicians and coordinates their playing.

Similarly, your nervous system has two divisions that work together—the central nervous system and the peripheral nervous system. The **central nervous system** consists of the brain and spinal cord. The **peripheral nervous system** consists of all the nerves located outside of the central nervous system. The central nervous system is like a conductor. The nerves of the peripheral nervous system are like the musicians.

Figure 4 In an orchestra, the conductor and musicians work together to make music.

Central Nervous System Functions

You can see the structure of the central and peripheral nervous systems in Figure 5. **The central nervous system is the control center of the body.** All information about what is happening in the world inside or outside your body is brought to the central nervous system. The **brain,** located in the skull, is the part of the central nervous system that controls most functions in the body. The **spinal cord** is the thick column of nerve tissue that links the brain to most of the nerves in the peripheral nervous system.

Most impulses from the peripheral nervous system travel through the spinal cord to get to the brain. Your brain then directs a response. The response usually travels from the brain, through the spinal cord, and then to the peripheral nervous system.

For example, here is what happens when you reach under the sofa to find a lost quarter. Your fingers move over the floor, searching for the quarter. When your fingers finally touch the quarter, the stimulus of the touch triggers nerve impulses in sensory neurons in your fingers. These impulses travel through nerves of the peripheral nervous system to your spinal cord. Then the impulses race up to your brain. Your brain interprets the impulses, telling you that you've found the quarter. Your brain starts nerve impulses that move down the spinal cord. From the spinal cord, the impulses travel through motor nerves in your arm and hand. The impulses in the motor neurons cause your fingers to grasp the quarter.

☑ ***Checkpoint*** *What does the spinal cord do?*

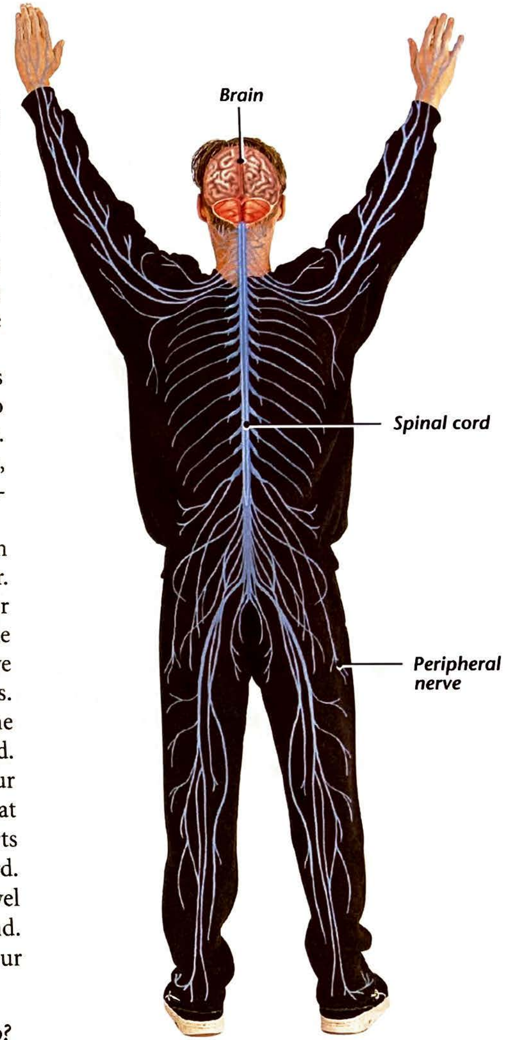
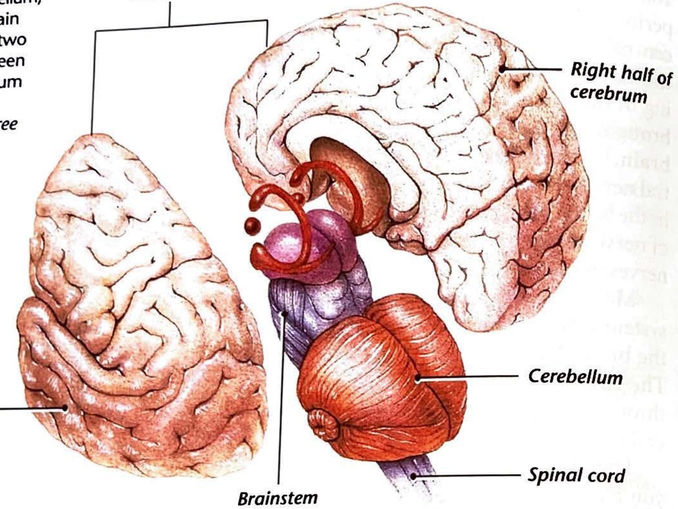


Figure 5 The central nervous system consists of the brain and spinal cord. The peripheral nervous system contains all the nerves that branch out from the brain and spinal cord.

The Structure and Functions of the Brain

Your brain contains about 100 billion neurons, most of which are interneurons. Each of those neurons may receive impulses from up to 10,000 other neurons and may send impulses to about 1,000 more! Three layers of connective tissue cover the brain. The space between the outermost layer and the middle layer is filled with a watery fluid. The skull, layers of connective tissue, and fluid all help protect the brain from injury.

Figure 6 The cerebrum, cerebellum, and brainstem are the three main parts of the human brain. The two halves of the cerebrum have been separated to show the cerebellum and the brainstem.
Applying Concepts *What are three functions of the cerebrum?*



TRY THIS

You've Got Nerve!

ACTIVITY

Use research materials to learn more about the human nervous system. Then construct a life-size model of the human nervous system. Use materials such as wire, string, papier mâché, and chicken wire. Label the parts of your model. Your labels should explain the function of the major structures in the nervous system.

Making Models What parts of the nervous system were difficult to show in your model?

Cerebrum There are three main regions of the brain. These are the cerebrum, the cerebellum, and the brainstem. Find each in Figure 6. The largest part of the brain is called the cerebrum. The **cerebrum** (suh REE brum) interprets input from the senses, controls the movement of skeletal muscles, and carries out complex mental processes such as learning, remembering, and making judgments. Because of your cerebrum, you can find the comics in a newspaper and locate your favorite comic strip on the page. Your cerebrum also enables you to read the comic strip and laugh at its funny characters.

Notice in Figure 6 that the cerebrum is divided into a right and a left half. The two halves have somewhat different functions. The right half of the cerebrum contains the neurons that send impulses to the skeletal muscles on the left side of the body. In contrast, the left half of the cerebrum controls the right side of the body. When you reach with your right hand for a pencil, the messages that tell you to do so come from the left half of your cerebrum.

In addition, each half of the cerebrum controls slightly different kinds of mental activity. The right half of the cerebrum is usually associated with creativity and artistic ability. The left half, in contrast, is associated with mathematical skills, speech, writing, and logical thinking.

Cerebellum and Brainstem The second largest part of your brain is called the cerebellum. The **cerebellum** (sehr uh BEL um) coordinates the actions of your muscles and helps you keep your balance. When you put one foot in front of the other as you walk, the motor neuron impulses that tell your feet to move start in your cerebrum. However, your cerebellum gives you the muscular coordination and sense of balance that keep you from falling down.

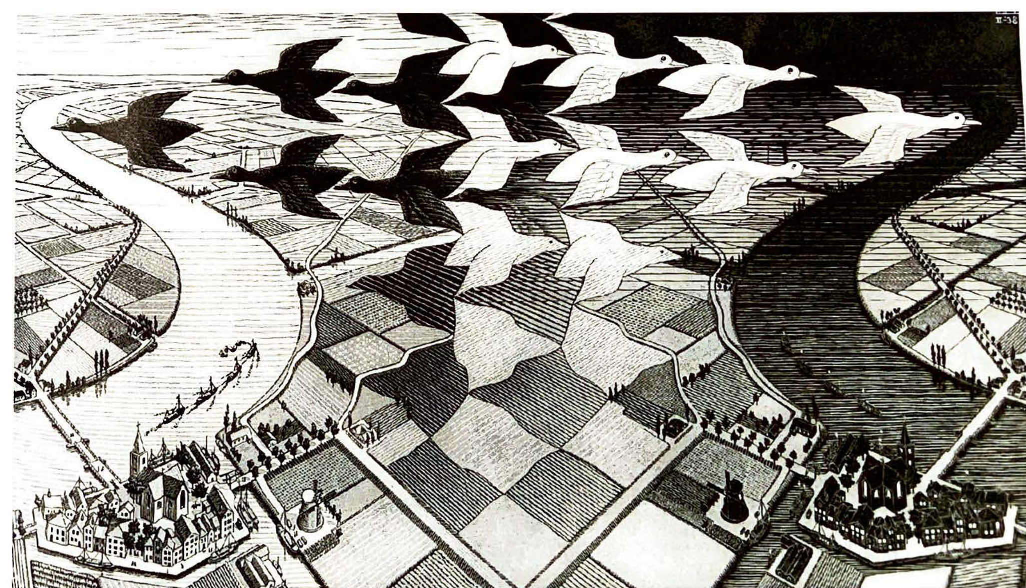
The **brainstem,** which lies between the cerebellum and spinal cord, controls your body's involuntary actions—those that occur automatically. For example, the brainstem regulates your breathing and helps control your heartbeat.

☑ ***Checkpoint*** ***What part of your brain coordinates the contractions of your muscles?***

The Spinal Cord

Run your fingers down the center of your back to feel the bones of the vertebral column. The vertebral column surrounds and protects the spinal cord. The spinal cord is the link between your brain and the peripheral nervous system. The layers of connective tissue that surround and protect the brain also cover the spinal cord. In addition, like the brain, the spinal cord is further protected by a watery fluid.

Figure 7 This illustration, by the Dutch artist M. C. Escher, is called "Day and Night." Escher drew this picture in 1938.



Visual Arts CONNECTION

Some artists deliberately create works of art that can be interpreted by the brain in more than one way. The Dutch artist M. C. Escher (1898–1972) delighted in drawing illustrations that played visual tricks on his viewers. Glance quickly at Escher's illustration in Figure 7. Then look at it again. Do you see the two different scenes in this single picture?

In Your Journal

Which scene did you see when you first looked at Figure 7? Did your brain interpret the picture differently the second time? Write a description of the visual trick that Escher has played in this illustration.

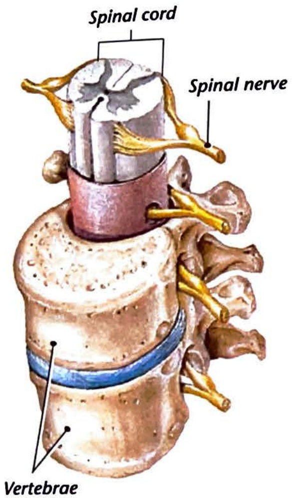


Figure 8 The spinal nerves, which connect to the spinal cord, emerge from spaces between the vertebrae. Each spinal nerve consists of both sensory and motor neurons.

Function of the Peripheral Nervous System

The second division of the nervous system is the peripheral nervous system. **The peripheral nervous system consists of a network of nerves that branch out from the central nervous system and function to connect it to the rest of your body.** A total of 43 pairs of nerves make up the peripheral nervous system. Twelve pairs originate in the brain. The other 31 pairs—the spinal nerves—begin in the spinal cord. One nerve in each pair goes to the left side of the body, and the other goes to the right. As you can see in Figure 8, spinal nerves leave the spinal cord through spaces between the vertebrae.

Two-Way Traffic A spinal nerve is a little bit like a two-lane highway. Impulses travel on a spinal nerve in two directions—both to and from the central nervous system. Each spinal nerve contains axons of both sensory and motor neurons. The sensory neurons carry impulses from the body to the central nervous system. The motor neurons carry impulses in the opposite direction—from the central nervous system to the body.

Somatic and Autonomic Systems The nerves of the peripheral nervous system can be divided into two groups, the somatic (soh MAT ik) and autonomic (awt uh NAHM ik) nervous systems. The nerves of the **somatic nervous system** control voluntary actions such as using a fork or tying your shoelaces. In contrast, nerves of the **autonomic nervous system** control involuntary actions. For example, the autonomic nervous system regulates the contractions of the smooth muscles that adjust the diameter of blood vessels.

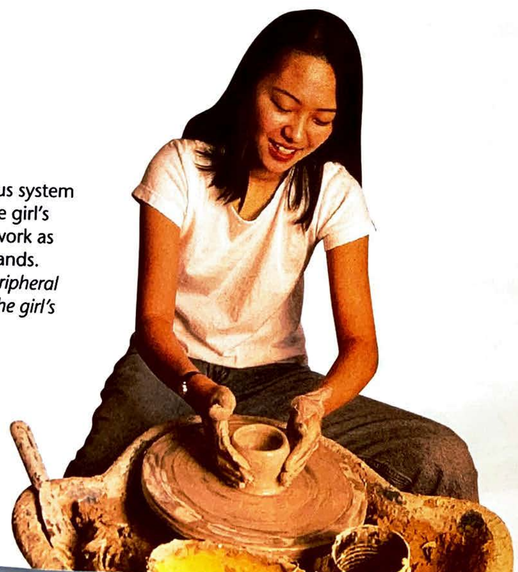


Figure 9 The somatic nervous system controls voluntary actions. The girl's somatic nervous system is at work as she shapes the pot with her hands.
Classifying What part of the peripheral nervous system helps regulate the girl's heartbeat?

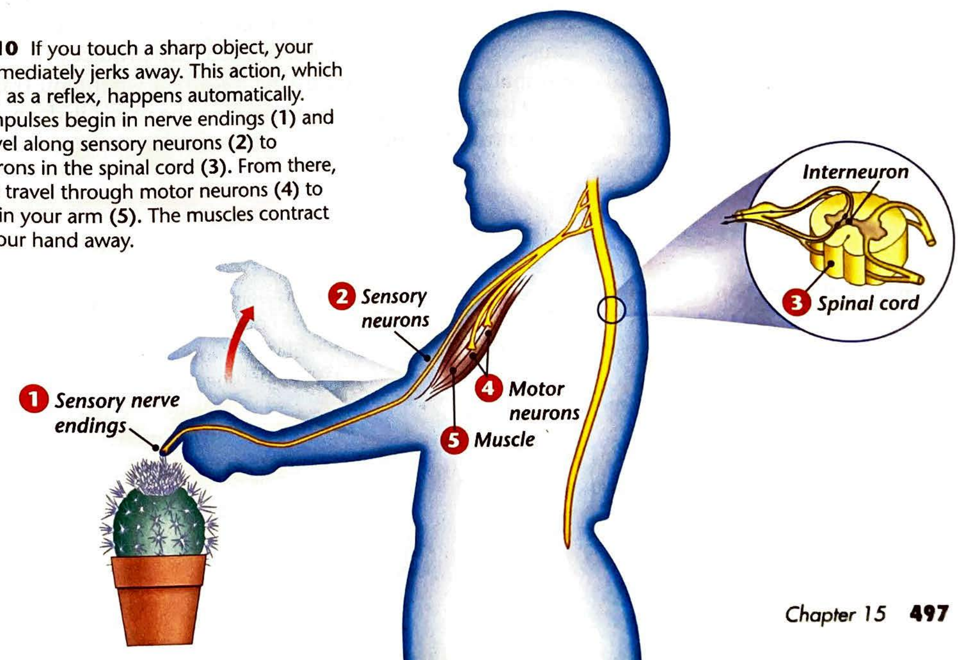
Reflexes

Imagine that you are watching an adventure movie. The movie is so thrilling that you don't notice a fly circling above your head. When the fly zooms right in front of your eyes, however, your eyelids immediately blink shut. You didn't decide to close your eyes. The blink, which is an example of a **reflex,** happened automatically. **A reflex is an automatic response that occurs very rapidly and without conscious control.** If you did the Discover activity, you experienced a reflex response.

As you have learned, the contraction of skeletal muscles is usually controlled by the brain. However, in some reflex actions, skeletal muscles contract with the involvement of the spinal cord only—not the brain. Figure 10 shows the reflex action that occurs when you touch a sharp object, such as a cactus thorn. When your finger touches the object, sensory neurons send impulses to the spinal cord. The impulses then pass to interneurons in the spinal cord. From there the impulses pass directly to motor neurons in your arm and hand. The muscles then contract, and your hand jerks up and away from the sharp object. By removing your hand quickly, this reflex protects you from getting badly cut.

At the same time that some nerve impulses make your arm muscles contract, other nerve impulses travel up your spinal cord and to your brain. When these impulses reach your brain, your brain interprets them. You then feel a sharp pain in your finger.

Figure 10 If you touch a sharp object, your hand immediately jerks away. This action, which is known as a reflex, happens automatically. Nerve impulses begin in nerve endings (1) and then travel along sensory neurons (2) to interneurons in the spinal cord (3). From there, impulses travel through motor neurons (4) to muscles in your arm (5). The muscles contract to pull your hand away.



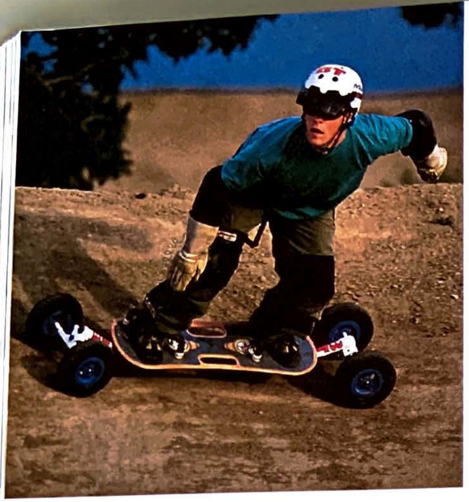


Figure 11 By wearing a helmet, this skateboarder is helping to prevent injury to his brain.

It takes longer for the pain impulses to get to the brain and be interpreted than it does for the reflex action to occur. By the time you feel the pain, you have already moved your hand away from the sharp object.

Safety and the Nervous System

INTEGRATING HEALTH Like other parts of the body, the nervous system can suffer injuries that interfere with its functioning. Concussions and spinal cord injuries are two ways in which the nervous system can be damaged.

A concussion is a bruiselike injury of the brain. A concussion occurs when soft tissue of the cerebrum bumps against the skull. Concussions can happen during a hard fall, an automobile accident, or contact sports such as football. With most concussions, you may have a headache for a short time, but the injured tissue heals by itself. However, if you black out, experience confusion, or feel drowsy after the injury, you should be checked by a doctor. To decrease your chances of getting a brain injury, wear a helmet when bicycling, skating, or performing other activities in which you risk bumping your head.

Spinal cord injuries occur when the spinal cord is cut or crushed. When the spinal cord is cut, all the nerve axons in that region are split, so impulses cannot pass through them. This type of injury results in paralysis, which is the loss of movement in some part of the body. Car crashes are the most common cause of spinal cord injuries. You can help protect yourself from a spinal cord injury by wearing a seatbelt when you travel in a car. Also, when you swim, make sure the water is deep enough before you dive in.

Section 2 Review

1. What is the function of the central nervous system? Which organs are part of this system?
2. What is the peripheral nervous system and what is its function?
3. Explain what a reflex is. How do reflexes help protect the body from injury?
4. **Thinking Critically Relating Cause and Effect** What symptoms might indicate that a person's cerebellum has been injured?

Check Your Progress

CHAPTER PROJECT

At this point, you should have chosen one or more illusions to investigate. Now write up the plan for your experiment. List some questions that you will ask to monitor people's responses to the illusions. (*Hint:* Try out your illusions and your questions on classmates to find out what responses to expect.) With your classmates, make plans for setting up the science fair.

Should People Be Required to Wear Bicycle Helmets?

Bicycle riding is an enjoyable activity. But unfortunately, many bicycle riders become injured while riding. Each year about 150,000 children alone are treated in hospitals for head injuries that occur while bicycling. Head injuries can affect everything your brain does—thinking, remembering, seeing, and being able to move. Experts estimate that as many as 85 percent of bicycle-related head injuries could be prevented if all bicyclists wore helmets. But only about 18 percent of bicyclists wear helmets. What is the best way to get bicycle riders to protect themselves from head injury?

The Issues

Should Laws Require the Use of Bicycle Helmets? About 15 states have passed laws requiring bicycle riders to wear helmets. Nearly all of these laws, however, apply only to children. Some supporters of bicycle laws want to see the laws extended to all bicycle riders. Supporters point out that laws increase helmet use by 47 percent. In contrast, educational programs without laws to back them up increase bicycle helmet use by only 18 percent.

What Are the Drawbacks of Helmet Laws? Opponents of helmet laws believe it is up to the individual, not the government, to decide whether or not to wear a helmet. They say it is not the role of the government to stop people from taking risks. Rather than making people who don't wear helmets pay fines, governments should educate people about the benefits of helmets. Car drivers should also be educated about safe driving procedures near bicycles.

Are There Alternatives to Helmet Laws? Instead of laws requiring people to wear helmets, some communities and organizations have set up educational programs that teach about the advantages of helmets. Effective programs teach about the dangers of head injuries and how helmets protect riders. In addition, they point out that safe helmets can be lightweight and comfortable. Effective education programs, though, can be expensive. They also need to reach a wide audience, including children, teens, and adults.

You Decide

1. **Identify the Problem**
   In your own words, explain the issues concerning laws requiring people to wear bicycle helmets.
2. **Analyze the Options**
   List two different plans for increasing helmet use by bicycle riders. List at least one advantage and one drawback of each plan.
3. **Find a Solution**
   You are a member of the city government hoping to increase helmet use. Write a speech outlining your position for either a helmet law or an alternative plan. Support your position.

SECTION 3 The Senses

DISCOVER ACTIVITY

What's in the Bag?

1. Your teacher will give you a paper bag that contains several objects. Your challenge is to use only your sense of touch to identify each object. You will not look inside the bag.
2. Put your hand in the bag and carefully touch each object. Observe the shape of each object. Note whether its surface is rough or smooth. Also note other characteristics, such as its size, what it seems to be made of, and whether it can be bent.
3. After you have finished touching each object, write your observations on a sheet of paper. Then write your inference about what each object is.

Think It Over

Observing What could you determine about each object without looking at it? What could you not determine?

GUIDE FOR READING

- What overall function do the senses perform?
- How do your eyes enable you to see?
- How do you hear?

Reading Tip As you read, write an outline of this section. Use the headings in the section as the main topics in the outline.

Key Terms cornea • pupil • iris • lens • retina • nearsightedness • farsightedness • eardrum • cochlea • semicircular canals

You waited in line to get on the ride, and now it's about to begin. You grip the bars as the ride suddenly starts to move. Before you know it, you are lifted high above the ground and you feel the air whipping by. All you see is a dizzy blur.

The thrill you experience from the speed of amusement park rides comes from your senses. **Each of your major senses—vision, hearing, balance, smell, taste, and touch—picks up a specific type of stimulus from your environment. The sense organs change those stimuli into nerve impulses and send the impulses to your brain.** Your brain then interprets the information. Because of the way in which your senses and brain work together, you learn a great deal about your environment.

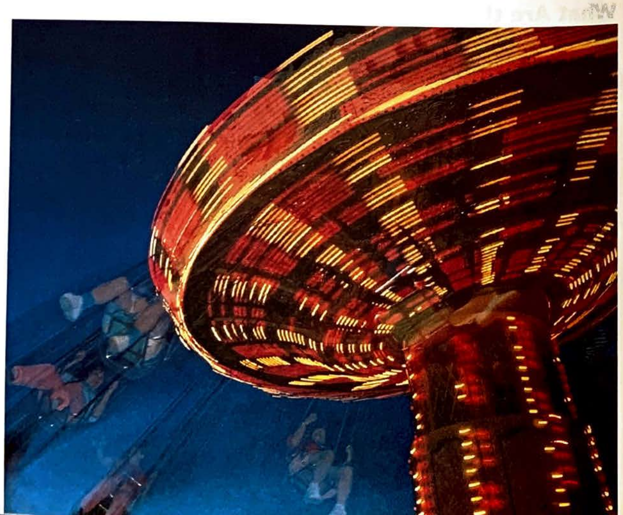


Figure 12 Riders and bright lights whizzing by—that's what you see when you watch this amusement park ride.

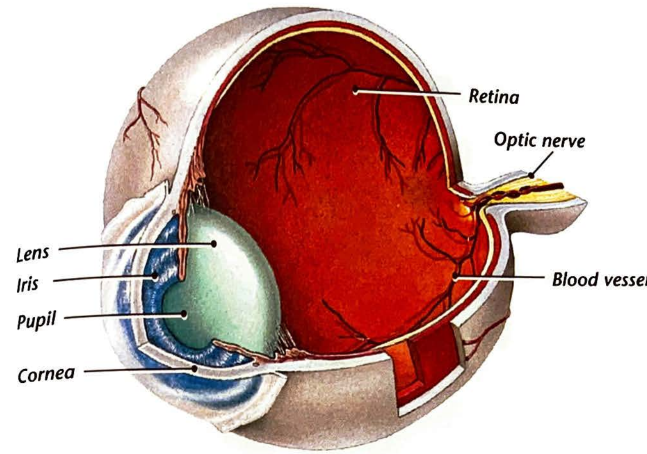


Figure 13 You see an object when light coming from the object enters your eye. The light produces an image on your retina. Receptors in your retina then send impulses to your cerebrum, and your cerebrum interprets these impulses. *Interpreting Diagrams What structures must light pass through before it reaches your retina?*

Vision

Your eyes are the sense organs that enable you to see the objects in your environment. They let you see this book in front of you, the window across the room, and the world outside the window. **Your eyes respond to the external stimulus of light. They convert that stimulus into impulses that your brain then interprets, enabling you to see.**

How Light Enters Your Eye When rays of light strike the eye, they pass through the structures shown in Figure 13. First, the light strikes the **cornea** (KAWR nee uh), the clear tissue that covers the front of the eye. The light then passes through a fluid-filled chamber behind the cornea and reaches the pupil. The **pupil** is the opening through which light enters the eye.

You may have noticed that people's pupils change size when they go from a dark room into bright sunshine. In bright light, the pupil becomes smaller. In dim light, the pupil becomes larger. The size of the pupil is adjusted by muscles in the iris. The **iris** is a circular structure that surrounds the pupil and regulates the amount of light entering the eye. The iris also gives the eye its color. If you have brown eyes, your irises are brown.

How Light Is Focused Light that passes through the pupil strikes the lens. The **lens** is a flexible structure that focuses light. The lens of your eye functions something like the lens of a camera, which focuses light on photographic film. Because of the way in which the lens of the eye bends the light rays, the image it produces is upside down and reversed. Muscles that attach to the lens adjust its shape. This adjustment produces an image that is clear and in focus.

TRY THIS

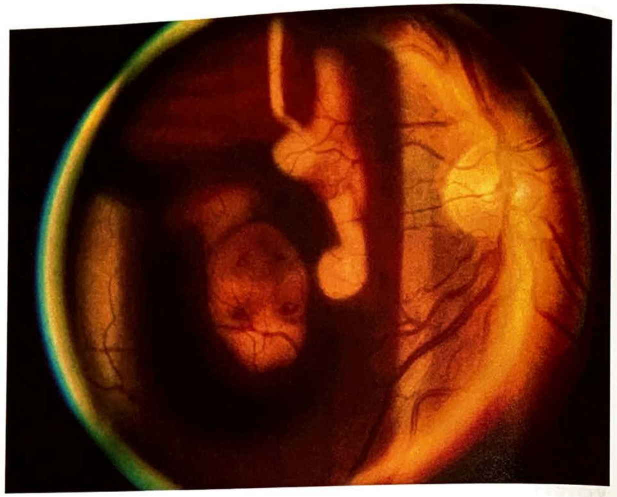
Why Do You Need Two Eyes? ACTIVITY

In this activity, you will investigate how your two eyes work together to allow you to see.

1. With your arms fully extended, hold a plastic drinking straw in one hand and a pipe cleaner in the other.
2. With both eyes open, try to insert the pipe cleaner into the straw.
3. Now close your right eye. Try to insert the pipe cleaner into the straw.
4. Repeat Step 3, but this time close your left eye instead of your right eye.

Inferring How does closing one eye affect your ability to judge distances?

Figure 14 An upside-down image is focused on the retina. *Applying Concepts When you see an object, why does it appear right-side up?*



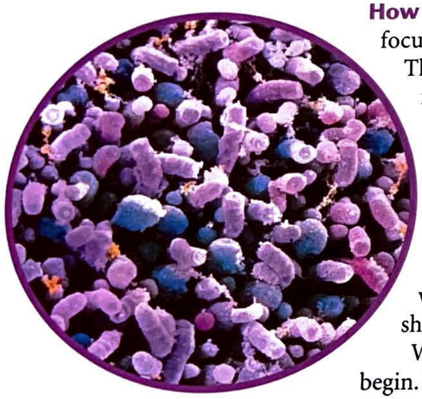


Figure 15 The retina of the eye contains light-sensitive cells. In this photograph, the rods have been colored pink, and the cones have been colored blue.

How You See an Image After passing through the lens, the focused light rays pass through a transparent, jellylike fluid. Then the light rays strike the **retina** (RET 'n uh), the layer of receptor cells that lines the back of the eye. The retina contains about 130 million receptor cells that respond to light. There are two types of receptors, rods and cones. Rod cells work best in dim light and enable you to see black, white, and shades of gray. In contrast, cone cells only work well in bright light and enable you to see colors. This difference between rods and cones explains why you see colors best in bright light, but you see only shadowy gray images in dim light.

When light strikes the rods and cones, nerve impulses begin. These nerve impulses travel to the cerebrum through the optic nerves. One optic nerve comes from the left eye and the other one comes from the right. In the cerebrum, two things happen. The brain turns the reversed image right-side up. In addition, the brain combines the images from each eye to produce a single image.

Correcting Vision Problems

INTEGRATING PHYSICS A lens—whether it is located in your eye, in a camera, or in eyeglasses—is a curved, transparent object that bends light rays as they pass through it. If the lens of the eye does not focus light properly on the retina, vision problems result. The glass or plastic lenses in eyeglasses can help correct such vision problems.

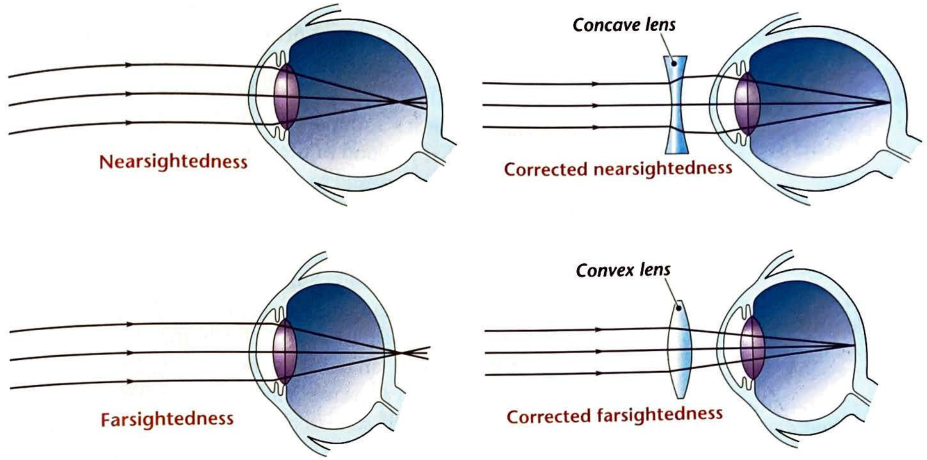


Figure 16 Nearsightedness and farsightedness are conditions in which images do not focus properly on the retina. The diagrams on the left show where the images are focused in both of these conditions. The diagrams on the right show how lenses in eyeglasses can help correct these conditions.

Nearsightedness People with **nearsightedness** can see nearby objects clearly. However, they have trouble seeing objects that are far away. Nearsightedness is caused by an eyeball that is too long. Because of the extra length that light must travel to reach the retina, distant objects do not focus sharply on the retina. Instead, the lens of the eye makes the image come into focus at a point in front of the retina, as shown in Figure 16.

To correct nearsightedness, a person needs to wear eyeglasses with concave lenses. A concave lens is a lens that is thicker at the edges than it is in the center. When light rays pass through a concave lens, they are bent away from the center of the lens. The concave lenses in glasses make light rays spread out before they reach the lens of the eye. Then, when these rays pass through the lens of the eye, they focus on the retina rather than in front of it.

Farsightedness People with **farsightedness** can see distant objects clearly. Nearby objects, however, look blurry. The eyeballs of people with farsightedness are too short. Because of this, the lens of the eye bends light from nearby objects so that the image does not focus properly on the retina. If light could pass through the retina, the image would come into sharp focus at a point behind the retina, as shown in Figure 16.

Convex lenses are used to help correct farsightedness. A convex lens is thicker in the middle than the edges. The convex lens makes the light rays bend toward one another before they reach the eye. Then the lens of the eye bends the rays even more. This bending makes the image focus exactly on the retina.

☑ ***Checkpoint*** *What type of lens is used to correct nearsightedness?*

TRY THIS

Tick! Tick! Tick!

In this activity, you will determine whether one of a person's ears hears better than the other one.

1. Work in teams of three. Hold a ticking watch next to the right ear of one team member.
2. Slowly move the watch away from the ear. Stop moving it at the point where the student can no longer hear the ticking.
3. At that point, have the third team member measure the distance between the watch and the student's right ear.
4. Repeat Steps 1 through 3 to test the student's left ear.

Measuring How did the two distances compare? Do you think this is an accurate way to evaluate someone's hearing? Why or why not?

Hearing

What wakes you up in the morning? Maybe an alarm clock buzzes, or perhaps your parent calls you. On a summer morning, you might hear birds singing. Whatever wakes you up, there's a good chance that it's a sound of some sort. **Your ears are the sense organs that respond to the external stimulus of sound. The ears convert the sound to nerve impulses that your brain interprets.** So when you hear an alarm clock or other morning sound, your brain tells you that it's time to wake up.

How Sound Is Produced Sound is produced by vibrations. INTEGRATING PHYSICS The material that is vibrating, or moving rapidly back and forth, may be almost anything—a guitar string, an insect's wings, or splashing water.

The vibrations create waves. The waves move outward from the source of the sound, something like ripples moving out from a stone dropped in water. The waves consist of moving particles, such as the molecules that make up air. When you hear a friend's voice, for example, sound waves have traveled from your friend's larynx to your ears. In addition to being able to travel through gases such as air, sound waves can also travel through liquids such as water and solids such as wood.

Sound Vibrations and the Ear The structure of the ear functions to receive sound vibrations. As you can see in Figure 18, the ear consists of three parts—the outer ear, middle ear, and inner ear. The outer ear includes the part of the ear that you see. The visible part of the outer ear is shaped like a funnel.

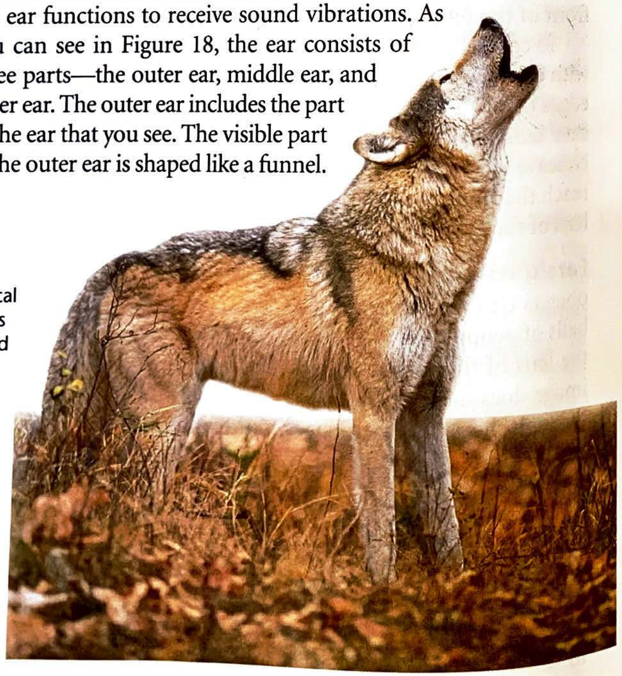


Figure 17 When a wolf howls, its vocal cords vibrate. The vibrating vocal cords produce sound waves. When the sound waves reach a person's ear, the person hears the wolf.

This funnel-like shape enables the outer ear to gather sound waves. The sound waves then travel down the ear canal, which is also part of the outer ear.

At the end of the ear canal, sound waves reach the eardrum. The **eardrum,** which separates the outer ear from the middle ear, is a membrane that vibrates when sound waves strike it. Your eardrum vibrates in much the same way that the surface of a drum vibrates when it is struck. Vibrations from the eardrum pass to the middle ear, which contains the three smallest bones in the body—the hammer, anvil, and stirrup. The names of these bones are based on their shapes. The vibrating eardrum makes the hammer vibrate. The hammer passes the vibrations to the anvil, and the anvil passes them to the stirrup.

How You Hear The stirrup vibrates against a thin membrane that covers the opening of the inner ear. The membrane channels the vibrations into the fluid in the cochlea. The **cochlea** (KAHK le uh) is a snail-shaped tube that is lined with receptors that respond to sound. When the fluid in the cochlea vibrates, it stimulates these receptors. Sensory neurons then send nerve impulses to the cerebrum through the auditory nerve. These impulses are interpreted as sounds that you hear.

☑ ***Checkpoint*** *Where in the ear is the cochlea located?*

Internal Stimuli and Balance

Your ear also controls your sense of balance. Above the cochlea in your inner ear are the **semicircular canals,** which are the structures in the ear that are responsible for your sense of balance.

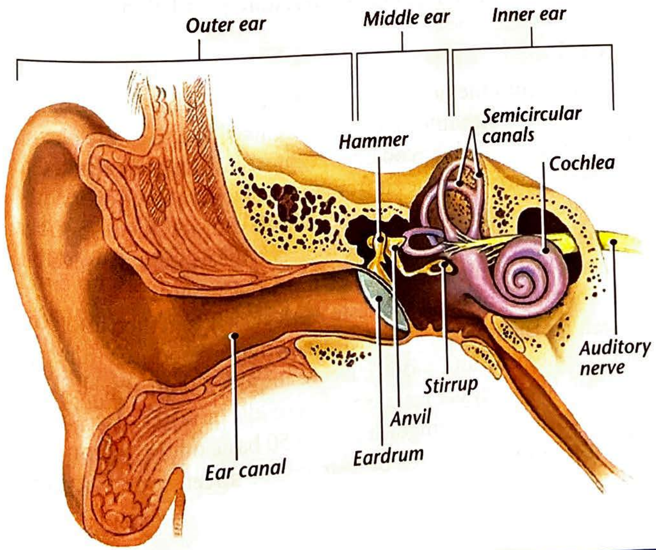


Figure 18 The ear has three regions—the outer ear, the middle ear, and the inner ear. Sound waves enter the outer ear and make structures in the middle ear vibrate. When the vibrations reach the inner ear, nerve impulses travel to the cerebrum through the auditory nerve. *Predicting What would happen if the bones of the middle ear were stuck together and could not move?*

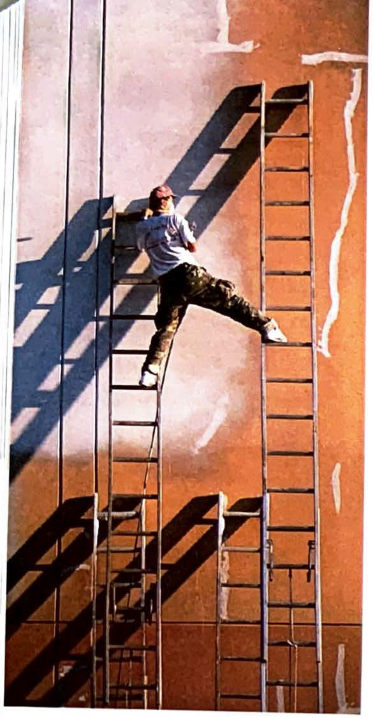


Figure 19 The semicircular canals of the inner ear enable people to keep their balance—even in very tricky situations!

You can see how these structures got their name if you look at Figure 19. These canals, as well as two tiny sacs located behind them, are full of fluid. The canals and sacs are also lined with tiny cells that have hairlike extensions.

When your head moves, the fluid in the semicircular canals is set in motion. The moving fluid makes the cells' hairlike extensions bend. This bending is an internal stimulus that produces nerve impulses in sensory neurons. The impulses travel to the cerebellum. The cerebellum then analyzes the impulses to determine the way your head is moving and the position of your body. If the cerebellum senses that you are losing your balance, it sends impulses to muscles that help you restore your balance.

Sharpen your Skills

Designing Experiments

ACTIVITY

Can people tell one food from another if they can taste the foods but not smell them? Design an experiment to find out. Use these foods: a peeled pear, a peeled apple, and a peeled raw potato. Be sure to control all variables except the one you are testing. Write your hypothesis and a description of your procedure. Show these to your teacher. Do not perform your experiment until your teacher approves your procedure.

Smell and Taste

You walk into the house and smell the aroma of freshly baked cookies. You bite into one and taste its rich chocolate flavor. When you smelled the cookies, receptors in your nose reacted to chemicals carried by the air from the cookies to your nose. When you took a bite of a cookie, taste buds on your tongue responded to chemicals in the food. These food chemicals were dissolved in saliva, which came in contact with your taste buds.

The senses of smell and taste work closely together, and both depend on chemicals. The chemicals trigger responses in receptors in the nose and mouth. Nerve impulses then travel to the brain, where they are interpreted as smells or tastes.

The nose can distinguish at least 50 basic odors. In contrast, there are only four kinds of taste buds—sweet, sour, salty, and bitter. When you eat, however, you experience a much wider variety of tastes. The flavor of food is determined by both the the senses of smell and taste. When you have a cold, your favorite foods may not taste as good as they usually do. That is because a stuffy nose can decrease your ability to smell food.

Figure 20 Blind people use their sense of touch to read. To do this, they run their fingers over words written in Braille. Braille uses raised dots to represent letters and numbers. Here a teacher shows a blind child how to read Braille.

Touch

Unlike vision, hearing, balance, smell, and taste, the sense of touch is not found in one specific place. Instead, the sense of touch is found in all areas of your skin. Your skin is your largest sense organ!

Your skin contains different kinds of touch receptors. Some of these receptors respond to light touch and others to heavy pressure. Still other receptors pick up sensations of pain and temperature change.

The receptors that respond to light touch are in the upper part of the dermis. They tell you when something brushes against your skin. These receptors also let you feel the textures of objects, such as smooth glass and rough sandpaper. Receptors deeper in the dermis pick up the feeling of pressure. Press down hard on the top of your desk, for example, and you will feel pressure in your fingers.

The dermis also contains receptors that respond to temperature and pain. Pain is unpleasant, but it can be one of the body's most important feelings, because it alerts the body to possible danger. Have you ever stepped into a bathtub of very hot water and then immediately pulled your foot out? If so, you can appreciate how pain can trigger an important response in your body.

Section 3 Review

1. What function do the senses perform in the body?
2. Describe the process by which your eyes produce an image of your surroundings. Begin at the point at which light is focused by the lens.
3. How do sound vibrations affect structures in the ear to produce the sensation of hearing?
4. How are the senses of taste and smell similar? How are they different?
5. **Thinking Critically** **Relating Cause and Effect** Infections of the inner ear sometimes make people more likely to lose their balance and fall. Explain why this is so.

Check Your Progress

CHAPTER PROJECT

By now, you should have submitted your plans for your experiment to your teacher. Make any necessary changes in the plan. Prepare all the materials for the fair, including the illusions and questionnaire. Have a data table ready so you can record all responses. (*Hint:* Be sure the people you test cannot see or hear each other's responses. Also, test a large enough number of individuals.)