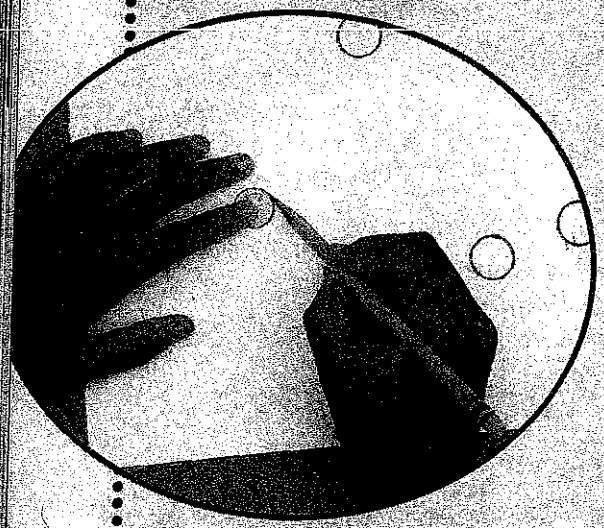
SECTION 1

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. Number the circles from 1 through 12. Write the numbers randomly, in no particular order.
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. What organ system coordinated all the different processes involved in this task?

GUIDE FOR READING

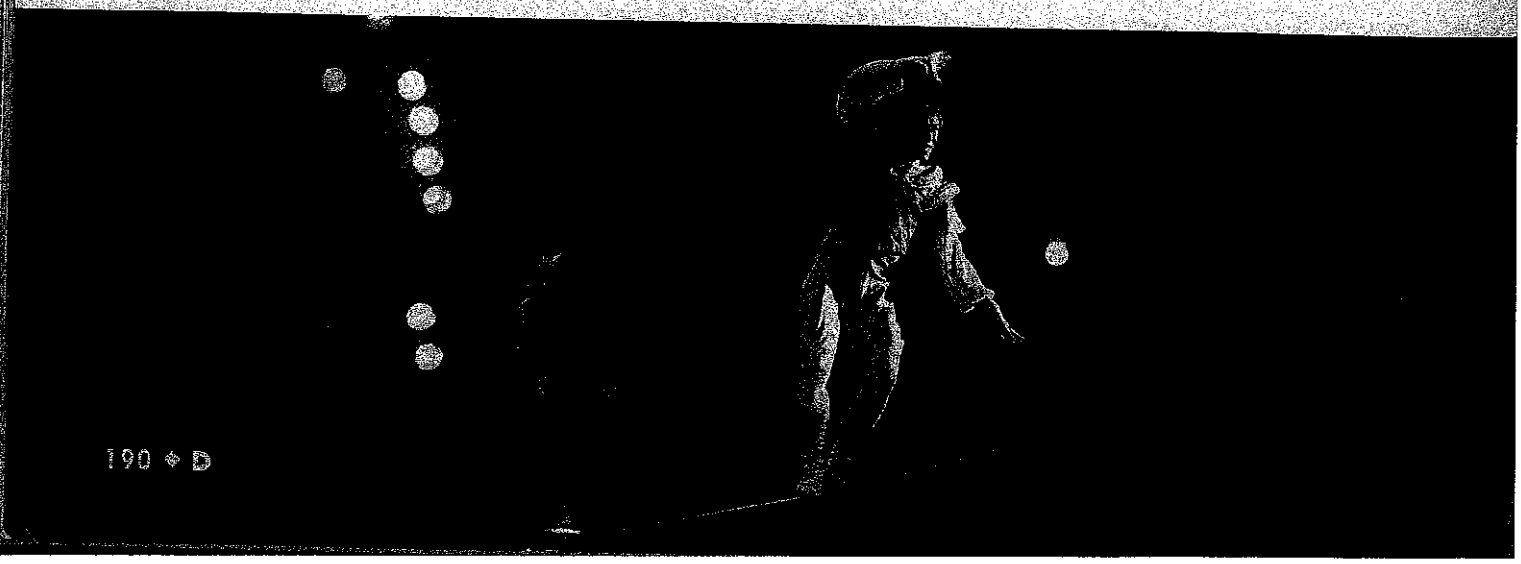
- **What are the functions of the nervous system?**
- **What are the three types of neurons and how do they interact?**

Reading Tip **Before you read, preview *Exploring the Path of a Nerve Impulse* on page 193. List any unfamiliar terms. Then, as you read, write a definition for each term.**

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 too 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.



Jobs of the Nervous System

The Internet lets people gather information from anywhere in the world with the click of a button. 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 maintain homeostasis. Without your nervous system, you could not move, think, feel pain, or taste a spicy taco.

Figure 1 The sparkling water is a 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 Information Any change or signal in the environment that can make an organism react is a **stimulus** (STIM yoo lus) (plural *stimuli*). A zooming soccer ball is a stimulus. 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.

Some nervous system responses, such as kicking a ball, are voluntary, or under your control. However, many processes necessary for life, such as heartbeat rate, are controlled by involuntary actions of the nervous system.

Maintaining Homeostasis 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 homeostasis by supplying your body with nutrients and energy it needs.

Checkpoint What is a stimulus?

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.

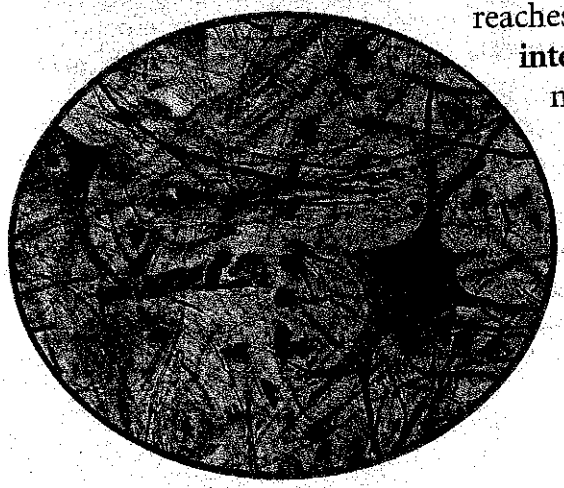
The Structure of a Neuron A neuron has a large cell body that contains the nucleus. The cell body has threadlike extensions. One kind of extension, a **dendrite,** carries impulses toward the cell body. An **axon** carries impulses away from the cell body. Nerve impulses begin in a dendrite, move toward 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?*



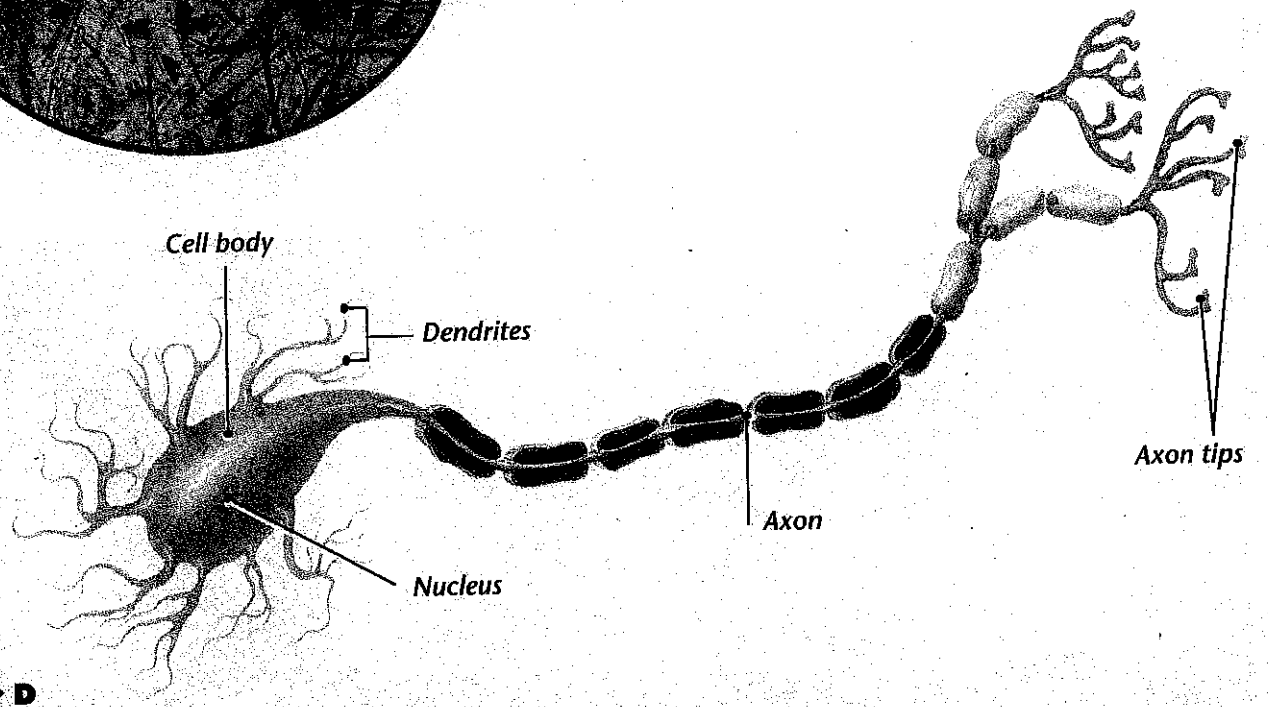
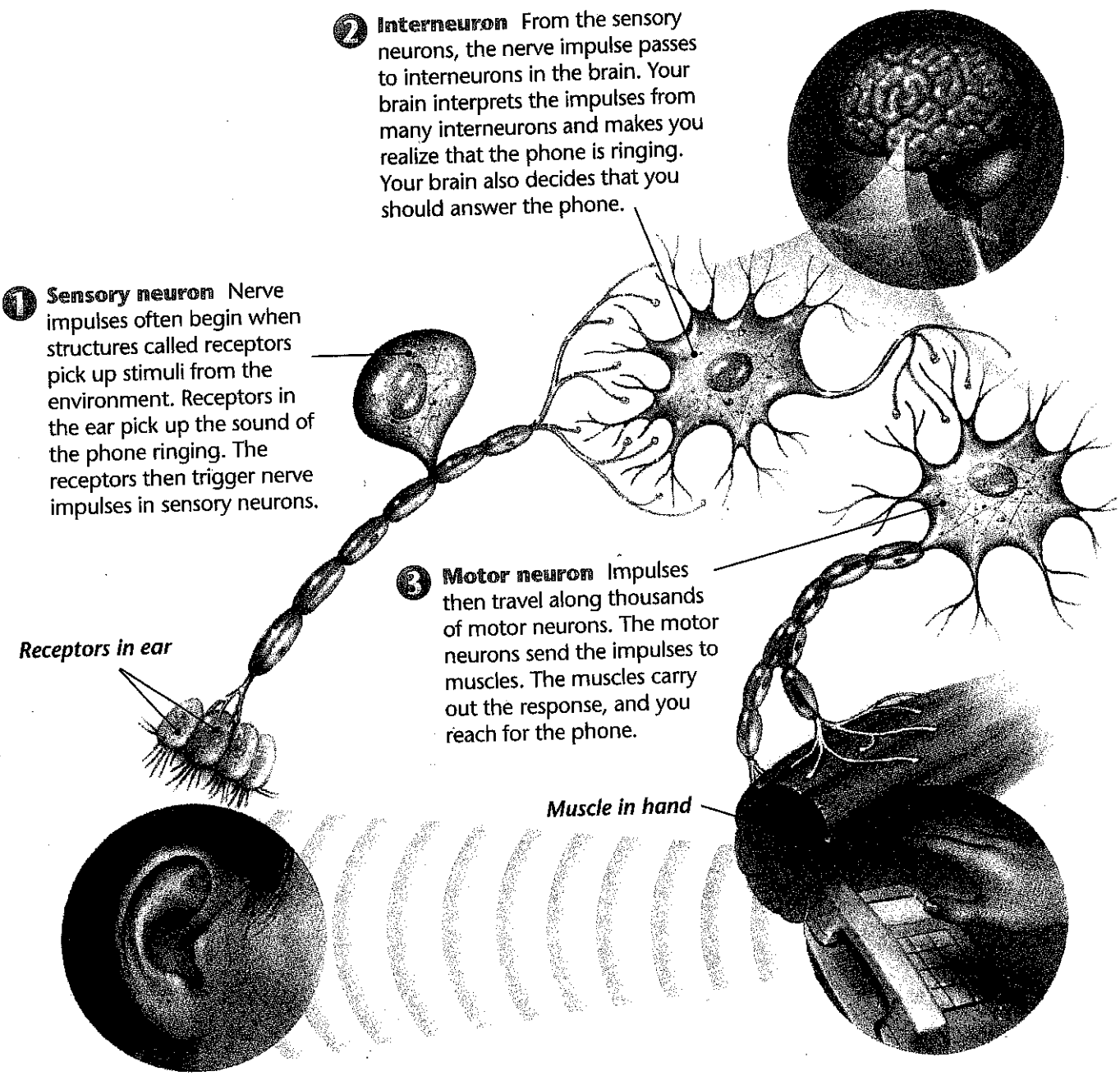


Figure 2 A neuron, or nerve cell, has one axon and many dendrites that extend from the cell body. The dendrites carry a nerve message toward the cell body, and the axon carries the message away from the cell body. *Applying Concepts How many axons can a neuron have?*

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 action.



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.

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.

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.

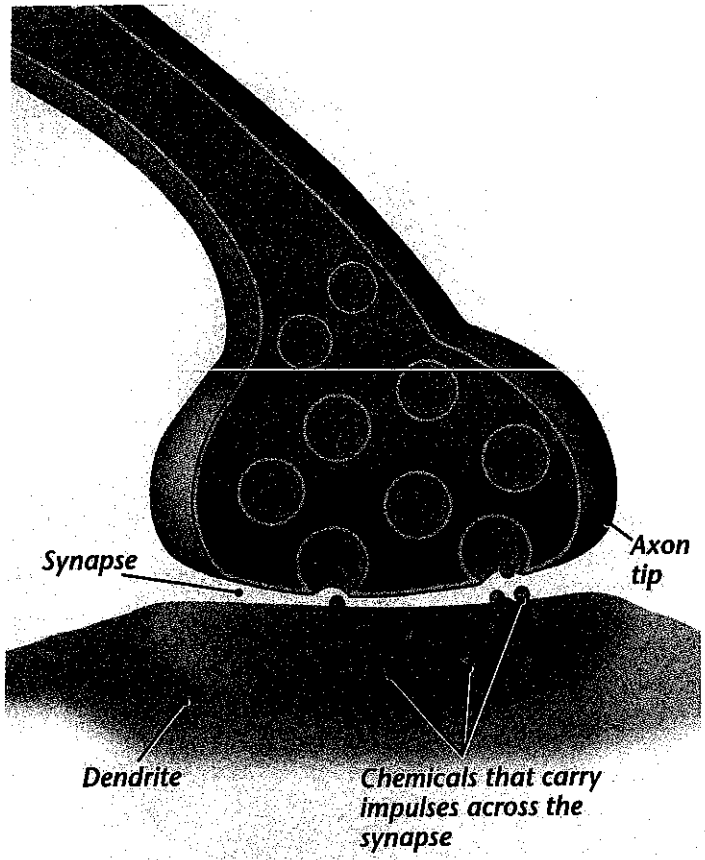


Figure 3 A synapse is the tiny space between the axon of one neuron and the dendrite of another neuron. When a nerve impulse reaches the end of an axon, chemicals are released into the synapse. These chemicals enable the nerve impulse to cross the synapse.

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 illustrates 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 that are found in the nervous system. Describe how they interact to carry nerve impulses.
3. How does a nerve impulse cross a synapse?
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.

Science at Home

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 a stimulus and that the family member's reaction was a response. Discuss other examples of stimuli and responses with your family.

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 functions does the peripheral nervous system perform?**
- **What is a reflex?**

Reading Tip **As you read, make a list of main ideas and supporting details about the central and peripheral nervous systems.**

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.

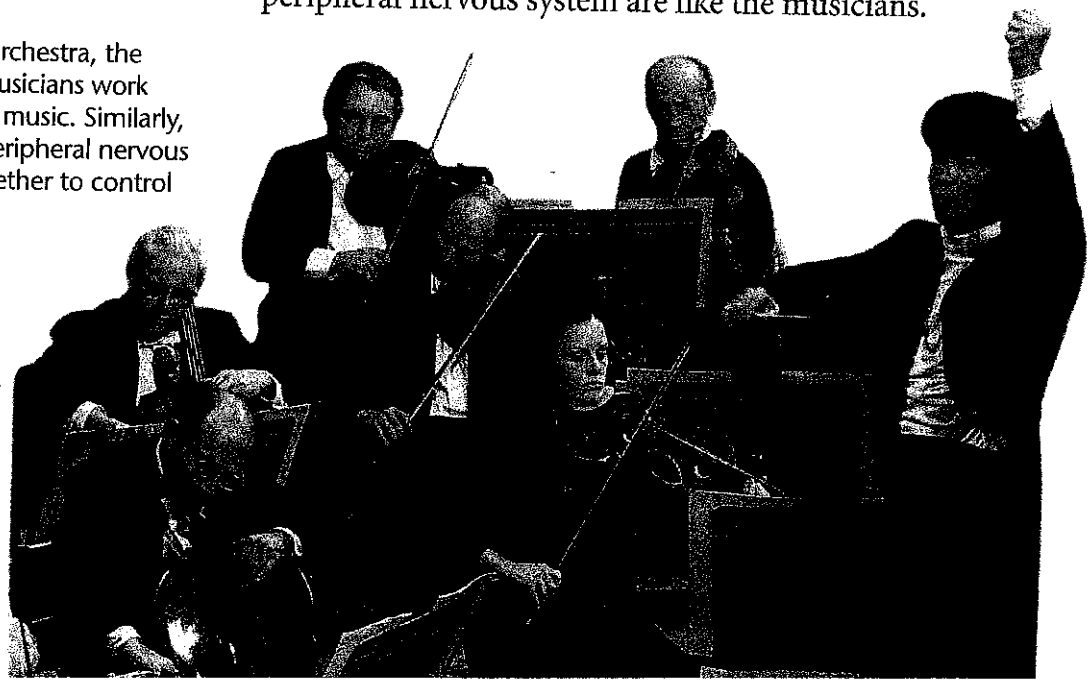


Figure 4 In an orchestra, the conductor and musicians work together to make music. Similarly, the central and peripheral nervous systems work together to control body functions.

The Central Nervous System

You can see 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?

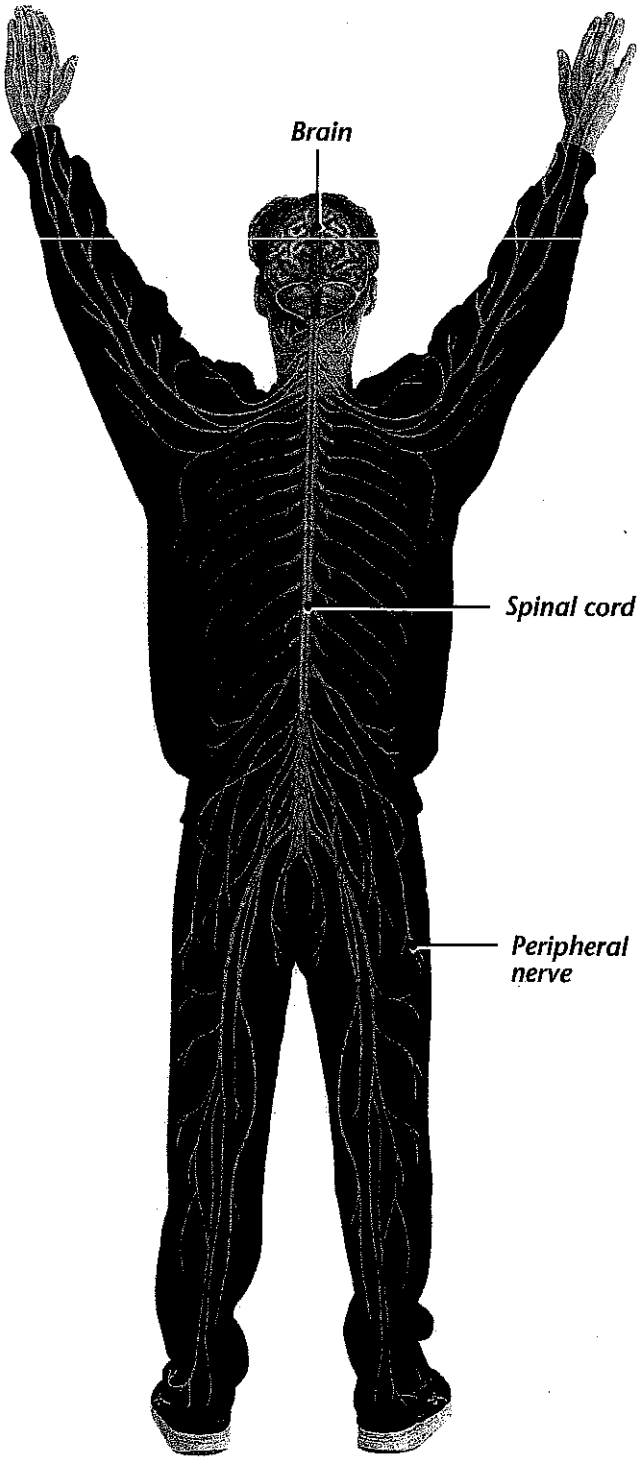
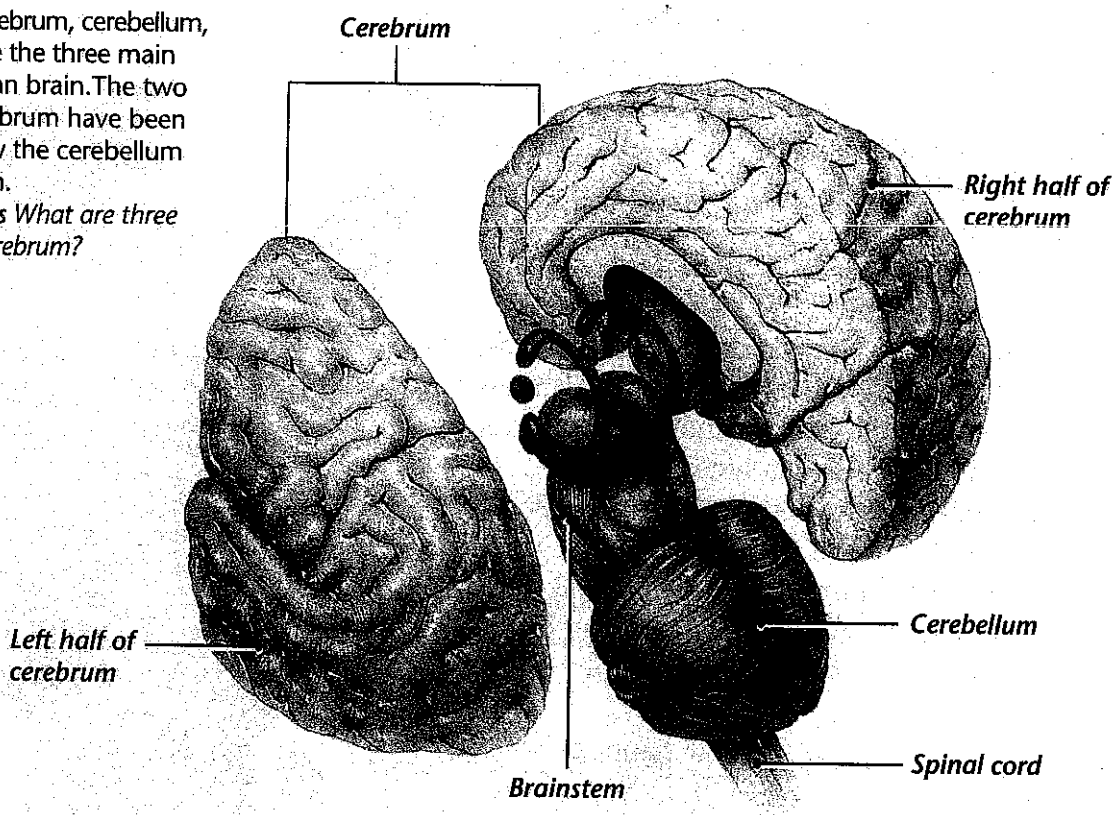


Figure 5 The central nervous system consists of the brain and spinal cord. The peripheral nervous system contains all the nerves that branch out from the brain and spinal cord.

The Brain

Your brain contains about 100 billion neurons, all of which are interneurons. Each of those neurons may receive messages from up to 10,000 other neurons and may send messages 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?



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.

Sharpen your Skills

Controlling Variables

Activity

Are people better able to memorize a list of words in a quiet room or in a room where soft music is playing? First write a hypothesis. Then design an experiment to test your hypothesis. Make sure that all variables are controlled except the one you are testing—music versus quiet. Check your procedure with your teacher. Then perform your experiment. Analyze your results to see whether they support your hypothesis.

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.

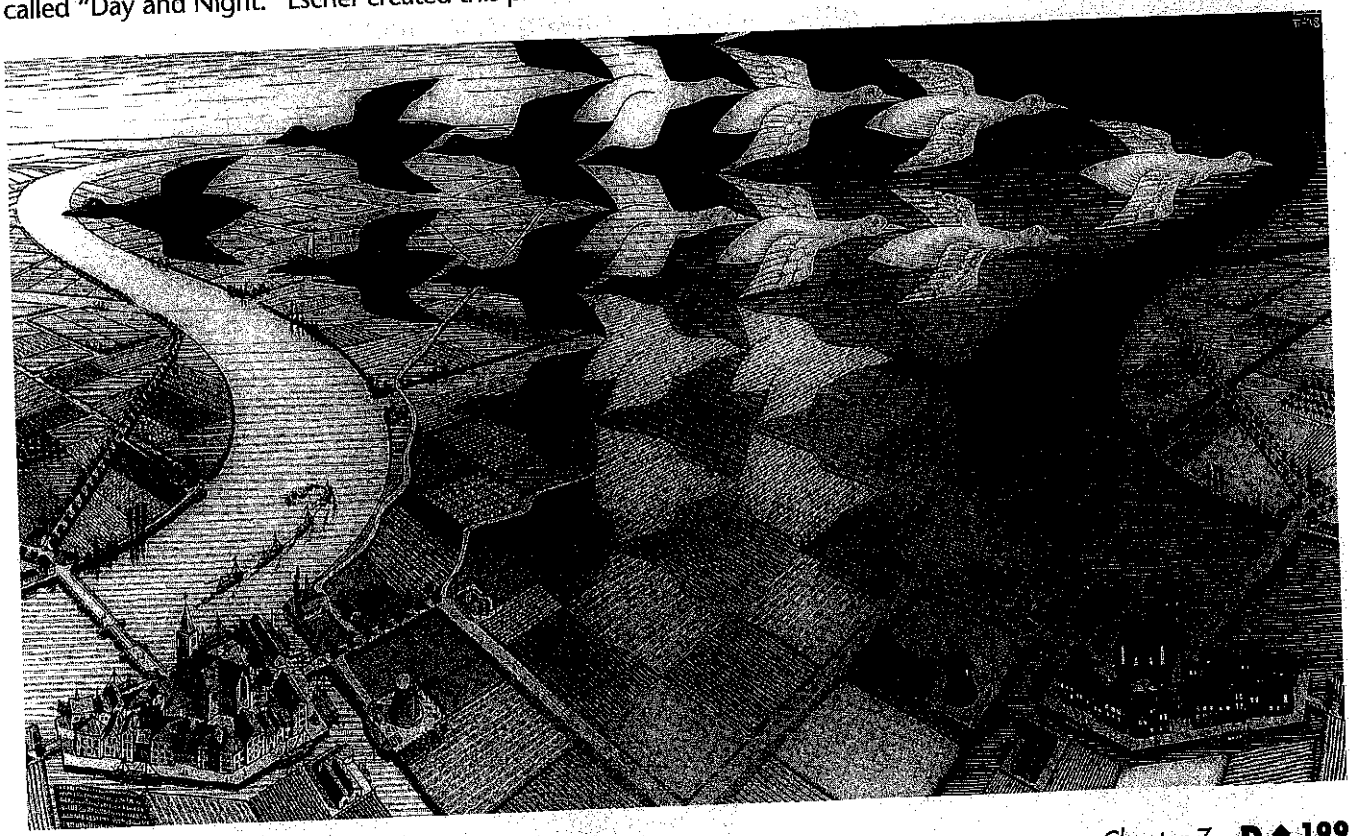
Visual Arts CONNECTION

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



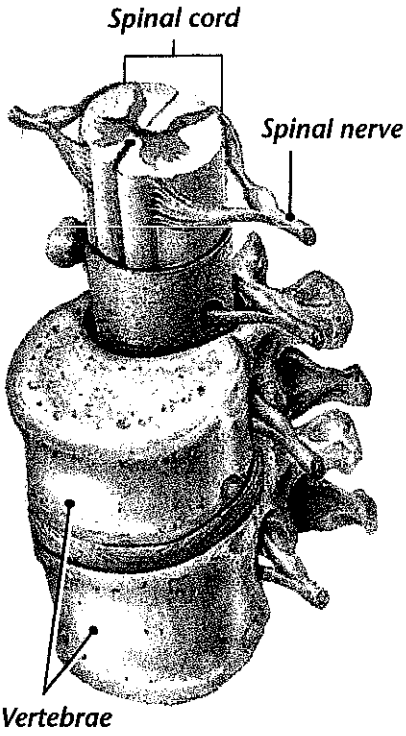


Figure 8 The spinal nerves, which connect to the spinal cord, emerge from spaces between the vertebrae. Each spinal nerve consists of both sensory and motor neurons.

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 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, called 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.

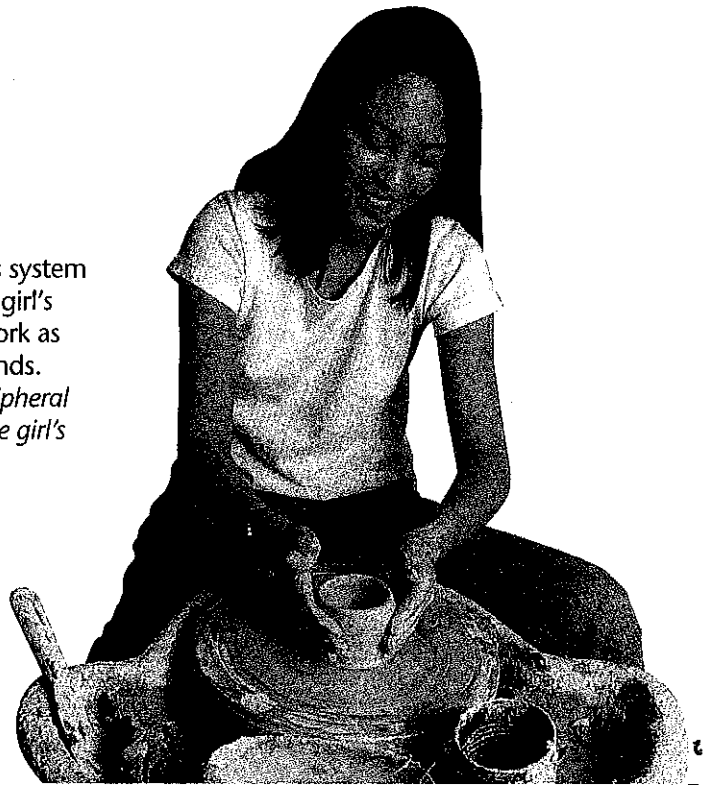


Figure 9 The somatic nervous system controls voluntary actions. The girl's somatic nervous system is at work as she shapes the pot with her hands. *Classifying What part of the peripheral nervous system helps regulate the girl's heartbeat?*

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 saw another example of a reflex.

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.

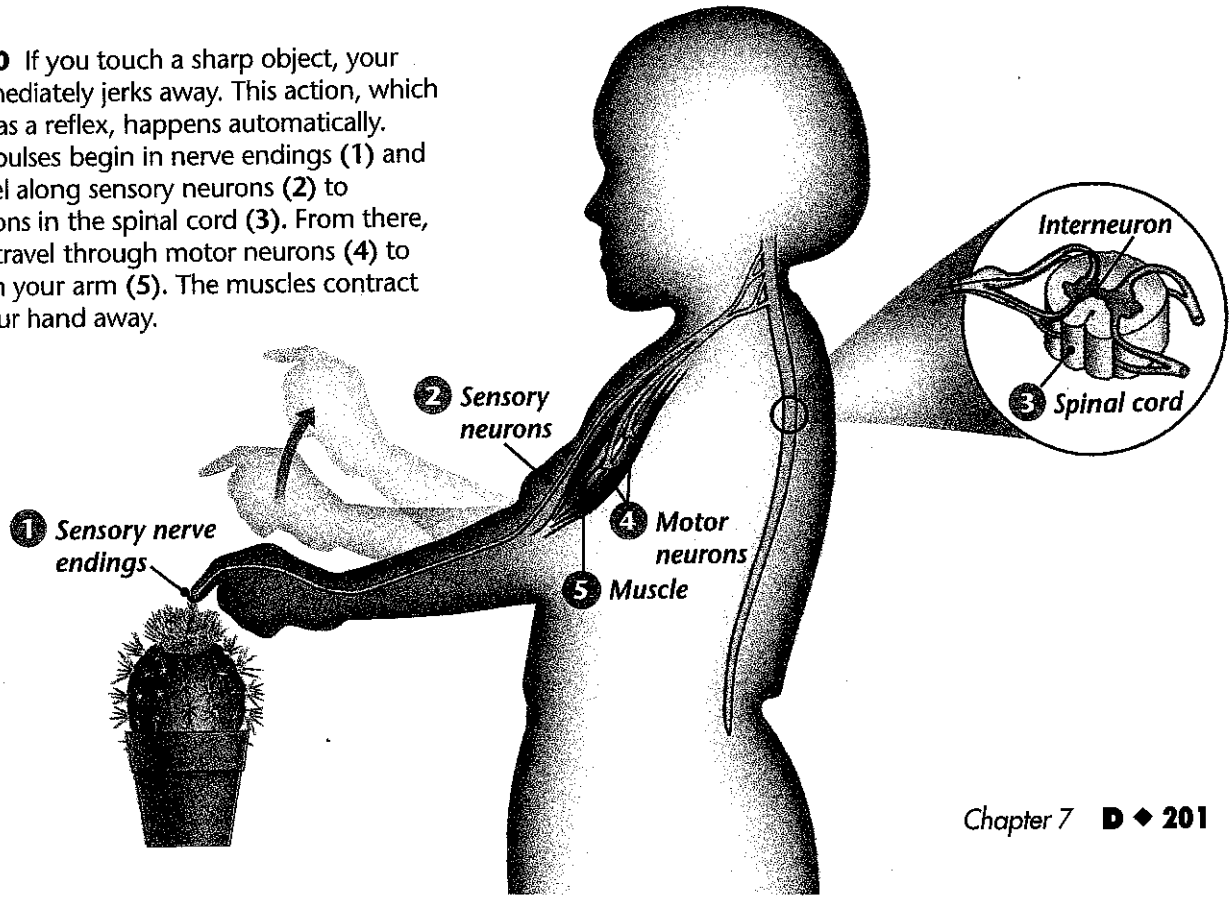


Figure 10 If you touch a sharp object, your hand immediately jerks away. This action, which is known as a reflex, happens automatically. Nerve impulses begin in nerve endings **(1)** and then travel along sensory neurons **(2)** to interneurons in the spinal cord **(3)**. From there, impulses travel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

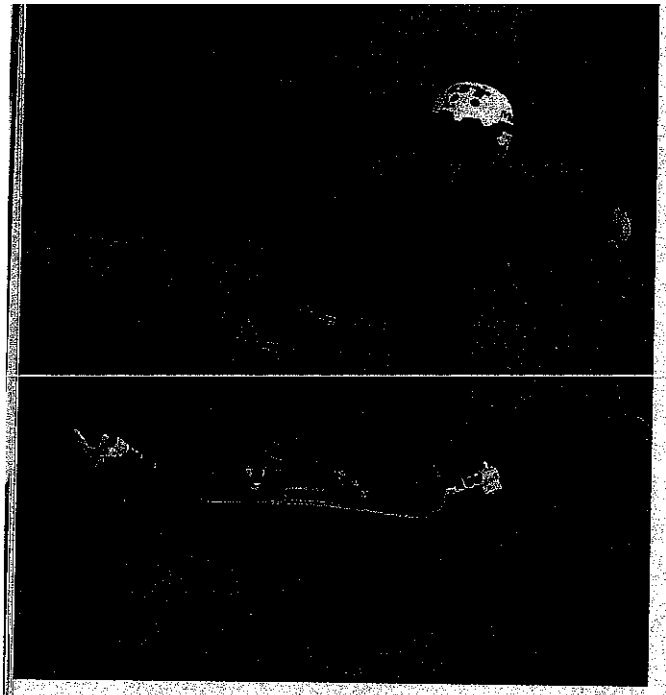


Figure 11 By wearing a helmet, this skateboarder is helping to prevent injury to his brain.

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 are its functions?
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

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.