CHAPTER 12

The Nervous System

Reflecting Questions

- How does the nervous system help us cope with changes inside and outside the body?
- How does the structure and function of the neuron influence the activities of the nervous system?
- How do complex sense organs provide an organism's nervous system with information about the external environment?

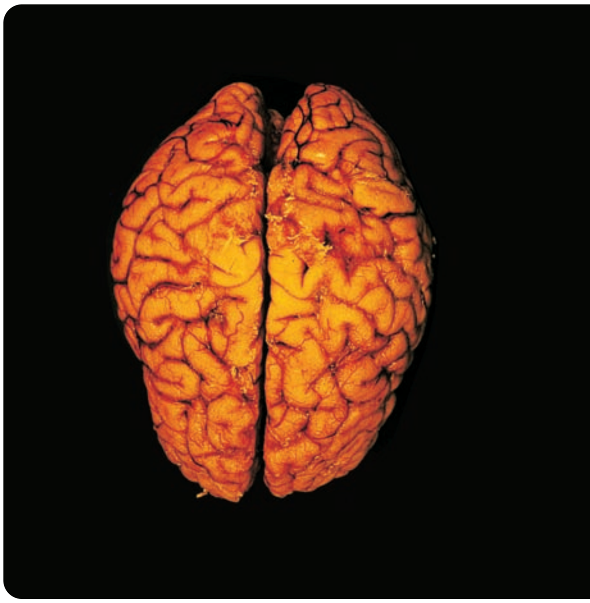
Humans have the most complex nervous system of all organisms on Earth (although some scientists give an honourable mention to certain members of the whale and dolphin family). The complex structure of the human nervous system is the result of millions of years of evolution, from the development of simple nervous systems in animals such as flatworms to the system we will examine in this chapter.

A simple brain is a collection of nerve cells that co-ordinate reactions to a limited number of stimuli. The evolution of the more complex vertebrate brain exhibits a number of trends. First, the ratio of the brain to body mass increases. Second, there is a progressive increase in the relative size of the area of the brain that is involved in higher mental abilities. The higher intellectual abilities, such as the capacity to learn and solve problems, are functions of an area of the brain called the cerebrum. In vertebrates such as fish and reptiles, the brain is small and the cerebrum is only a fraction of the total size of the brain. In more complex species such as the cat and the chimpanzee, the cerebrum is the dominant part of the brain. In humans, the cerebrum (as shown on the right) is so large that it almost covers the rest of the brain.

Over the past two million years of human evolution, the human brain has doubled in size. Newborn humans have a very large head (in relation to body size) when compared to other primates. The head is so large that birth is only possible because of the flexible connections of the bones that make up the skull. The head is compressed as it comes through the birth canal, and it regains its normal shape days after delivery. Some researchers speculate that humans may have reached their maximum brain size, which has been limited by the birth canal.

As you read through this chapter, learn more about the human brain and the nervous system's role in homeostasis.

The progressive enlargement and increasing level of complexity of the cerebrum has contributed most to the overall development of the brain.



Chapter Contents

12.1 The Structure of the Nervous System

OUTCOMES

- **Describe the anatomy and physiology of the nervous system.**
- **Examine neurons and reflex responses.**
- **Explain how the nervous system functions to maintain homeostasis.**

How does the human nervous system help maintain homeostasis? In other words, how does the nervous system cope with changes both inside and outside the body? The nervous system provides a high-speed communication system to and from almost every part of the body. A series of sensory receptors provides information about changes in both the internal and external environment that may affect the body's responses. For example, you have already studied the sensory receptors in the skin that provide information about whether the body is gaining or losing heat. You know that this information is sent to the brain to stimulate the appropriate body response. In Figure 12.1, the basketball players could not focus on the game if they were conscious of all the information being processed by the various parts of their brains. Information about carbon dioxide, water, and glucose levels, as well as blood pressure, are all monitored by the hypothalamus. Other parts of the brain monitor the spatial orientation of the body. The eyes, ears, and nose provide information about the external environment.

Figure 12.1 While this player is concentrating on shooting the ball into the net, his hypothalamus is monitoring his blood pressure as well as carbon dioxide, water, and glucose levels.

The human nervous system, as shown in Figure 12.2, is actually a complex of interconnected systems, with larger systems comprised of subsystems that each have specific structures and functions.

Two major parts comprise the human nervous system. The **central nervous system** (CNS) is made up of the brain and spinal cord. The **peripheral nervous system** (PNS) includes the nerves that lead into and out of the central nervous system (see Figure 12.2).

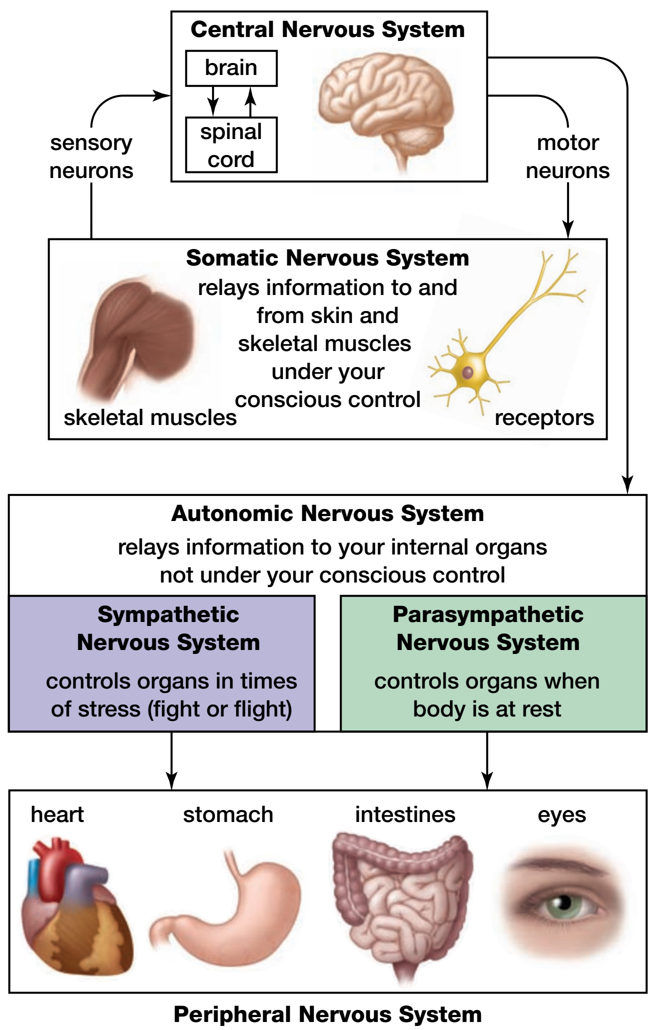


Figure 12.2 The organization of the human nervous system

The Central Nervous System

The central nervous system receives sensory information and initiates motor control. The CNS is well protected by bone, with the skull forming an enclosure around the brain and the vertebrae enclosing the spinal cord. As well, protective membranes called meninges surround the brain and spinal cord. Cerebrospinal fluid fills the spaces within the meninges to create a cushion that further protect the CNS (see Figure 12.3).

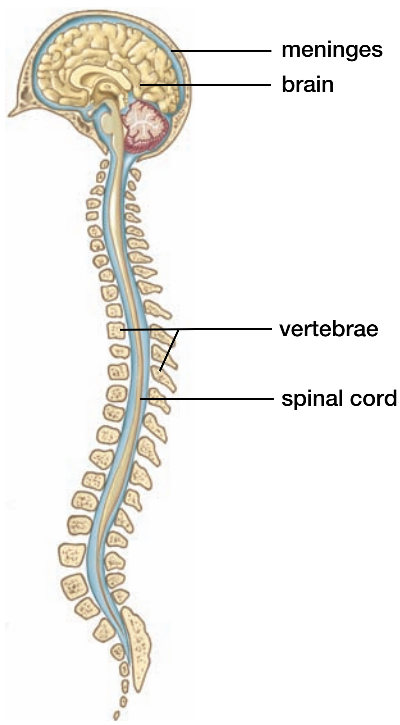


Figure 12.3 The central nervous system (CNS)

The spinal cord extends from the vertebral canal formed by the vertebrae, up through the bottom of the skull, and into the base of the brain. The spinal cord is the vehicle of communication between the brain and the peripheral nervous system (PNS). The spinal nerves coming from the cord pass through openings between the vertebrae and out to the PNS. In cross section, the spinal cord contains a central canal, which is filled with cerebrospinal fluid, grey matter, and white matter. Figure 12.4 shows the spinal cord in detail.

The **grey matter** consists of neural tissue that contains sensory neurons, motor neurons, as well as interneurons and has a brownish-grey color. It is found in the centre of the spinal cord in the shape of the letter H. The grey colour is a result of the cell bodies and short, non-myelinated fibres this tissue contains. You will learn more about these features in the next section.

The **white matter** of the spinal cord is found around the grey matter (see Figure 12.4). Its colour results from the presence of myelinated axons of interneurons, running together in bundles called tracts. Ascending tracts carry information to the brain while descending tracts carry information from the brain. The brain will be examined in detail later in this section.

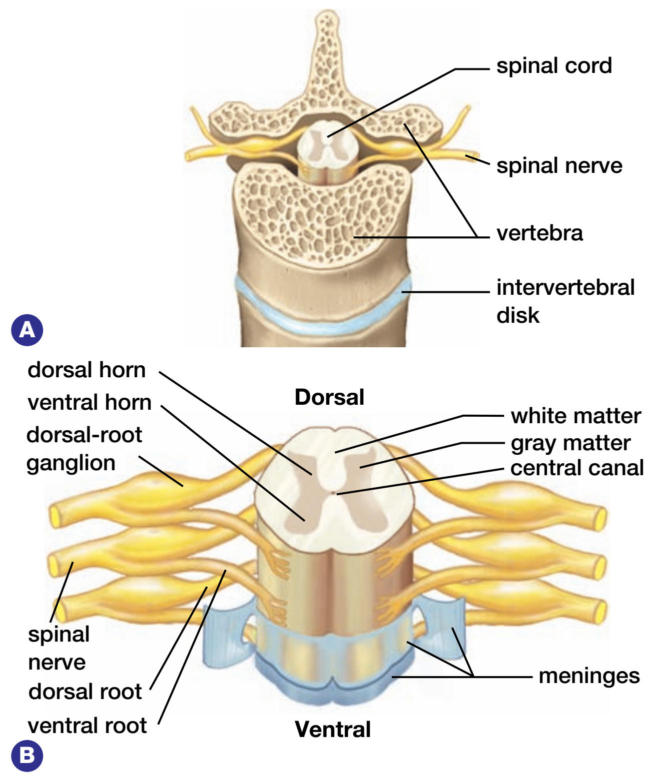


Figure 12.4 (A) The spinal cord passes through the canal within the vertebrae, and the spinal nerves exit to the PNS through spaces between the vertebrae. (B) The spinal cord contains a central canal, grey matter, and white matter. The white matter contains the nerve tracts that communicate between the PNS and the brain.

The Peripheral Nervous System

The peripheral nervous system consists of the **autonomic nervous system** and the **somatic nervous system**. The autonomic nervous system is not consciously controlled. As Figure 12.5 on the next page shows, the autonomic nervous system is made up of the sympathetic and parasympathetic nervous systems, which control a number of organs within the body. The **sympathetic nervous system** sets off the "fight-or-flight" reaction that prepares the body to deal with an immediate threat. When this system is stimulated, heart rate and breathing rate increase. Also, blood sugar is released from the liver to provide the energy required to deal with the perceived threat.

Many perceived threats today do not require the fight-or-flight response. In fact, this response may worsen a situation. For example, some students suffer from test anxiety. In these individuals, the stress of a test produces rapid heart and breathing rates that may interfere with higher levels of brain activity, such as concentration and memory. Learning relaxation techniques can often help people deal with stressful situations. (You will learn more about the "fight-or-flight" response in Chapter 13.)

The **parasympathetic nervous system** has an effect opposite to that of the sympathetic nervous system. When a threat has passed, the nerves of this system slow heart rate and breathing rate and reverse the effects of the sympathetic nervous system response.

The somatic nervous system is made up of sensory nerves that carry impulses from the body's sense organs to the central nervous system. This system also consists of motor nerves that transmit commands from the central nervous system to the muscles. This combination of sensory and motor nerves deals primarily with the external world and the changes in it. The somatic nervous system, to some degree, is under your conscious control. The information from your eyes and ears is processed by the brain and correlated with information you already have. You then make a decision that may or may not involve the movement of muscles.

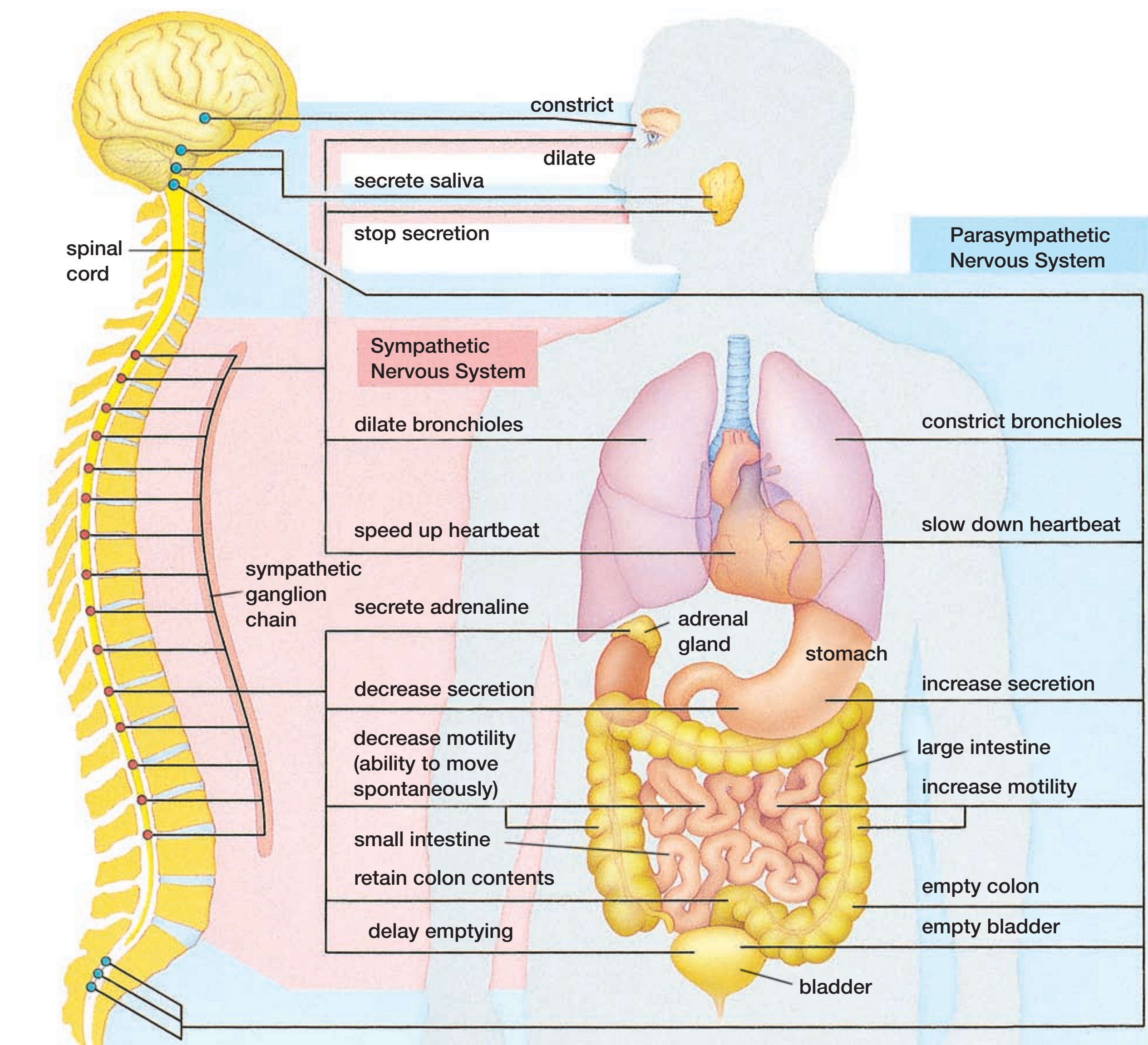


Figure 12.5 The ganglia of sympathetic nerves are located near the spine. The ganglia of parasympathetic nerves are located far from the spine, near the organs they affect. As you can see, a nerve pathway runs from both of the systems to every organ indicated, except the adrenal gland.

Other functions of this system are more subtle. Decision making can be time-consuming, so in some cases the system is designed in such a way that a certain action sets off a specific reaction. This reaction is known as a **reflex**. An example is an eye blink when something moves close to your eye. Such reflexes do not require a conscious decision. Indeed, sometimes we are not even aware of their occurrence.

Neurons and Reflex Responses

The structural and functional unit of the nervous system is the **neuron**. The central and peripheral nervous systems are both composed of a series of interconnected neurons. The PNS consists of **nerves**, which are numerous neurons held together by connective tissue. The CNS is also made up of neurons; in fact, 90 percent of the body's neurons are found in the CNS. A **reflex arc** is the nerve pathway that leads from stimulus to reflex action.

A neuron consists of three parts: the cell body, dendrites, and an axon, as shown in Figure 12.6. The **cell body** has a large, centrally located nucleus with a large nucleolus. The cytoplasm contains numerous mitochondria and lysosomes, along with a Golgi complex and rough endoplasmic reticulum. Neurons are capable of surviving for over 100 years, since most do not undergo cell division after adolescence.

Dendrites are the primary site for receiving signals from other neurons. The number of dendrites can range from one to thousands, depending on the neuron's function. The **axon** is a long, cylindrical extension of the cell body that can range from 1 mm to 1 m in length. When the neuron receives a sufficiently strong stimulus, the axon transmits impulses or waves of depolarization along its length. At the end of the axon are specialized structures that release chemicals. These chemicals stimulate neighbouring neurons or muscle cells. The various functions of the neuron will be discussed in more detail shortly.

Neurons can be separated into three classes: sensory neurons, motor neurons, and interneurons. A sensory neuron takes information from a sensory receptor, such as a pain receptor, to the CNS, while a motor neuron takes information from the CNS to an effector, such as a muscle fiber or a gland. The interneuron receives information both from other interneurons and from sensory neurons, and it exchanges information among neurons in the CNS.

The three major types of neurons can be illustrated in a simple reflex. For example, if you touch something hot, what happens first? Do you pull your hand back or are you aware of the pain first? The hand usually moves first. Pulling your hand back is a reflex that involves your spinal cord rather than your brain. In the reflex arc shown in Figure 12.7 on the next page, the heat triggers nerve endings in the skin of the hand. These are dendrites of a *sensory neuron*, which requires a strong stimulus to activate it. The impulse travels along this neuron, up the arm, and into the spinal cord. In the spinal cord the signal is passed on to interneurons. An *interneuron* is a nerve cell that acts as a link between a sensory neuron and a motor neuron. Found only in the CNS, a motor neuron is stimulated and transmits an impulse along its axon. When stimulated, the *motor neuron* triggers the contraction of the muscles in your arm, pulling your hand away. While this is happening, other interneurons in the spinal cord transmit a message to the brain, making you aware of what has just happened. This type of reflex is involuntary and can be triggered without input from the brain. (Section 12.3 features an activity exploring a reflex in the eye.)

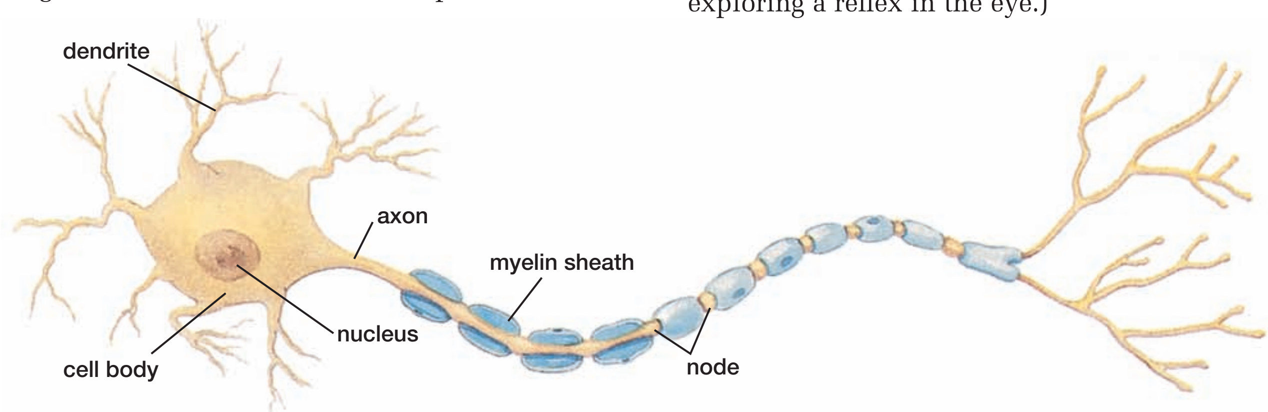


Figure 12.6 A typical neuron is composed of dendrites, a cell body, and an axon. Impulses are transmitted from the dendrites to the cell body. The axon carries impulses away from the cell body to the dendrites of the next neuron.

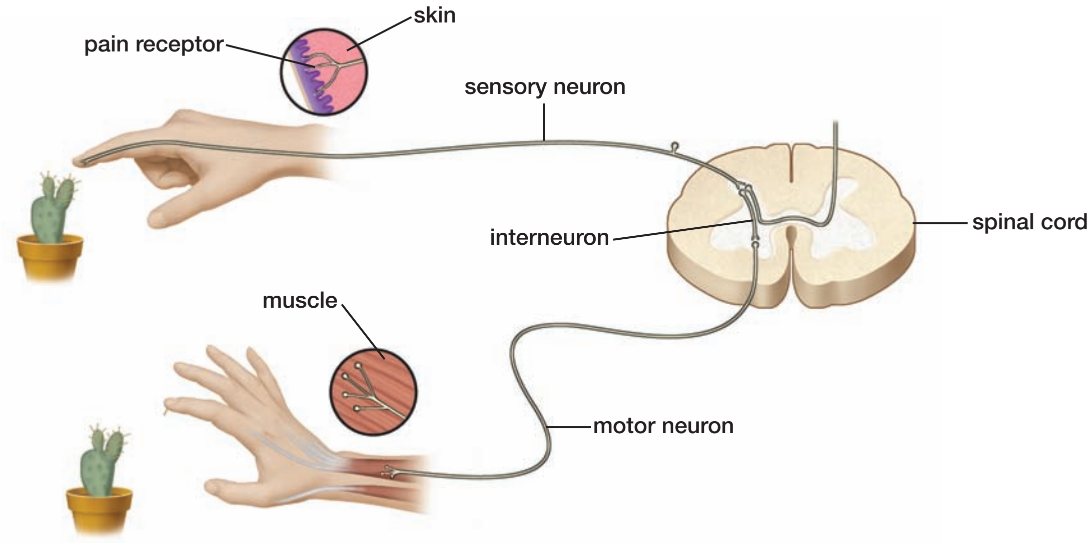


Figure 12.7 Reflex responses are carried out at the level of the spinal cord without assistance from the brain. The impulse travels directly to the spinal cord from the affected body part, crosses to a small interneuron, and then moves to a motor neuron that transmits the impulse to a muscle. The muscle contracts. The brain becomes aware of the reflex only after it occurs.

Investigation 12 • A

SKILL FOCUS

- Performing and recording
- Analyzing and interpreting
- Conducting research

The Nervous System and Reflex Responses

The structural and functional unit of the nervous system is the neuron. Nerves, which are numerous neurons held together by connective tissue, make up the PNS. Reflex actions occur when specific stimulus results in a particular reaction. The nerve pathway between a stimulus and the reflex action is called reflex arc.

Pre-lab Question

- What is the advantage of a reflex response?

Problem

Does the location of a stimulus affect the strength of a reflex response?

Prediction

Predict how specifically located a stimulus must be to produce a reflex response.

Materials

rubber reflex hammer

Procedure

1. Prepare a table to collect data for all three parts of this investigation.
2. Be consistent in the strength of the reflex-hammer strike applied. The strike does not need to be hard and should not cause the subject pain.

A. Knee-jerk Reflex

1. Have the subject sit comfortably in a chair, with his or her legs crossed. Ensure that the upper leg is relaxed.
2. Locate the patella (knee cap) and feel immediately below it for the large central tendon.

WEB LINK

www.mcgrawhill.ca/links/atlbiology
To learn more about reflex arcs, go to the web site above.

The Brain and Homeostasis

A neurologist once compared brain research to the following scenario. Aliens from outer space land on the roof of a hockey arena. They drill holes in the roof of the building and send down microphones. Some microphones pick up sounds in the crowd, some pick up sounds in dressing rooms, some pick up sounds near the popcorn stand, and some pick up sounds of the game itself. From this information the aliens try to figure out the rules of hockey. Scientists today have many pieces of information about what happens in the various parts of the brain, but they are striving for a complete and thorough understanding of precisely how the brain functions.

The brain co-ordinates homeostasis within the body. The brain processes the information that is transmitted through the senses so the body can deal with changes in the external and internal environment. The human brain makes up only 2 percent of the body's weight. However, at any given time it contains 15 percent of the body's blood supply and consumes 20 percent of the body's oxygen and glucose. Obviously, the brain is a high-energy organ. It contains about 100 billion neurons, which is roughly equal to the number of stars in our galaxy.

However, the complexity of the brain is not just a function of the large number of cells. The brain's complexity is also due to the variety of cells involved; to the brain's unique internal hormone system; and to complex interconnections between the various parts of the brain.

There is still much to learn about how complex operations of the brain, such as memory and

3. Using the reflex hammer, strike the tendon. Describe any motion in the leg.
4. Using the same procedure, strike different areas around the tendon. Record the location of the strikes, and the resulting motion in the leg.

B. Achilles Reflex

1. Have the subject remove a shoe and kneel on a chair with his or her foot hanging over the edge of the chair.
2. With your hand, push the subject's toes gently towards the chair. Using the reflex hammer, gently strike the Achilles tendon. Describe any motion in the foot.
3. Using the same procedure, strike different areas around the tendon. Record the location of the strikes, and the resulting motion in the foot.

C. Babinski Reflex

1. With the shoe still removed, have the subject prop his or her foot on the chair.
2. Have the subject look in another direction, away from the foot. Gently draw the handle of the hammer across the sole of the foot from the heel towards the toes. Describe any motion in the foot.
3. Using the same procedure, draw the handle of the reflex hammer across the foot in another direction. Record the direction of the handle draw, and the resulting motion of the foot.

Post-Lab Questions

1. Why did you vary the region where the stimulus was applied?
2. Was this a controlled experiment? Explain your answer.
3. Did the reflex occur each time you performed the stimulus, or did the specific location of the stimulus affect the reaction? Support your answer with the data you collected.

Conclude and Apply

4. What is the advantage of having reflex reactions?
5. Why would the knee-jerk reflex be essential for walking?
6. Diagram the reflex arc for the Achilles reflex. Make sure you fully label your diagram.

Exploring Further

7. Do research to find our how the Babinski reflex differs in adults and infants. Propose an explanation for these differences.
8. Newborns exhibit several reflexes that gradually disappear. Describe one of these reflexes and explain the advantage of this reflex.

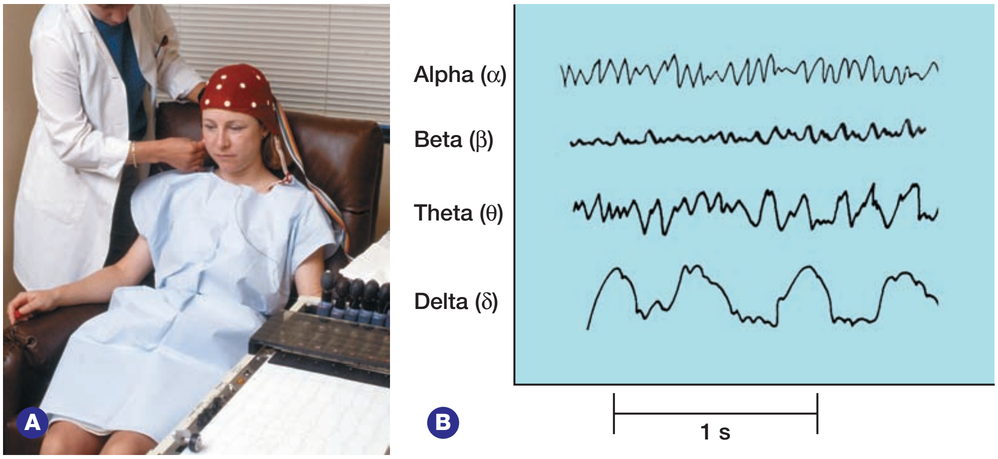


Figure 12.8 The electroencephalogram (EEG). (A) An EEG is recorded from an array of electrodes attached to the forehead and scalp. (B) The printout of brain waves help doctors diagnose certain diseases.

decision making, are carried out. Early knowledge of brain function came from studying the brains of people with brain diseases or injury. Brain damage causes symptoms such as the loss of particular body functions or changes in behaviour. Researchers assumed that any abnormalities in the structure of the patient's brain must have been the source of the symptom. They believed that the area of the brain that was abnormal must control whatever body function was changed by the disorder or damage.

In general, early researchers were reluctant to probe healthy human brains for ethical reasons. This limited many areas of research to work with rats or monkeys. However, technological innovation has resulted in many new, benign ways of probing the structure and function of the human brain. For example, the electroencephalograph (EEG) was invented in 1924 by Austrian psychiatrist Dr. Hans Borger. This device measures the electrical activity of the functioning brain and produces a printout that allows doctors to diagnose disorders, such as epilepsy and to locate brain tumours. Figure 12.8 illustrates an EEG reading. Such readings have been used to study brain activity during sleep to help doctors diagnose and understand sleep disorders.

Another method of research is direct electrical stimulation of parts of the brain during surgery. This type of stimulation has been used to map the functions of the various areas of the brain. The brain has no pain receptors, so brain surgery can be carried out without anesthesia while the patient is fully awake. In the 1950s, Canadian neurosurgeon Dr. Wilder Penfield, shown in Figure 12.9, pioneered this method of mapping the functions of the brain. He won a Nobel Prize for his work. Dr. Penfield stimulated the temporal lobe of one patient, who then "heard" the voices of her mother and brothers. With similar brain stimulation, another patient "heard" a concert she had attended in the past.

Figure 12.9 Canadian neurosurgeon Dr. Wilder Penfield pioneered the mapping of the functions of the brain.

Modern advances in scanning technology now allow researchers to observe changes in activity in specific areas of the brain. Scanning techniques can be used to show which parts of the brain are involved in activities such as speaking or listening. Computerized tomography (CAT) scans, positron emission tomography (PET) scans, and magnetic resonance imaging (MRI) continually enhance our knowledge of both healthy and diseased brains. CAT scans take a series of cross-sectional X-rays to create a computer-generated, three-dimensional image of a part of the body. Figure 12.10 shows how PET scans identify which areas of the brain are most active when the subject performs certain tasks. MRI scans use a combination of large magnets, radio frequencies, and computers to produce detailed images of the brain and other structures in the body.

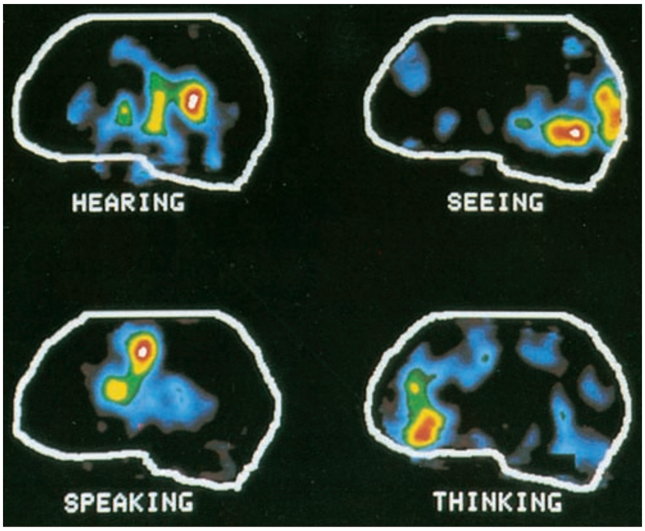


Figure 12.10 As these PET scans show, different areas of the brain are active when we hear a spoken word, see and read that same word silently, speak the word aloud, and think of and say a word related to the first.

The Brain

Research based on scanning technologies has produced information about the functions of each part of the brain. The **medulla oblongata**, attached to the spinal cord at the base of the brain, has a number of major functions, each of which is related to a particular structure. The cardiac centre controls heart rate and the force of the heart's contractions. The vasomotor centre adjusts blood pressure by controlling the diameter of blood vessels, and the respiratory centre controls the rate and depth of breathing. The medulla oblongata also contains reflex centres for vomiting, coughing, hiccupping, and swallowing. Any damage to this part of the brain is usually fatal.

The **cerebellum**, shown in Figure 12.11, controls muscle co-ordination. Although the cerebellum makes up only 10 percent of the volume of the brain, it contains 50 percent of the brain's neurons. If you stand in one place, specific muscles are contracted while others are relaxed. As groups of muscle fibres become fatigued, others are contracted to compensate. The position of the head, the limbs, and other parts of the body all affect decisions as to which muscles should be involved. This series of decisions is complex and, like other forms of muscle co-ordination, develops over time. Have you ever watched a young child just learning to

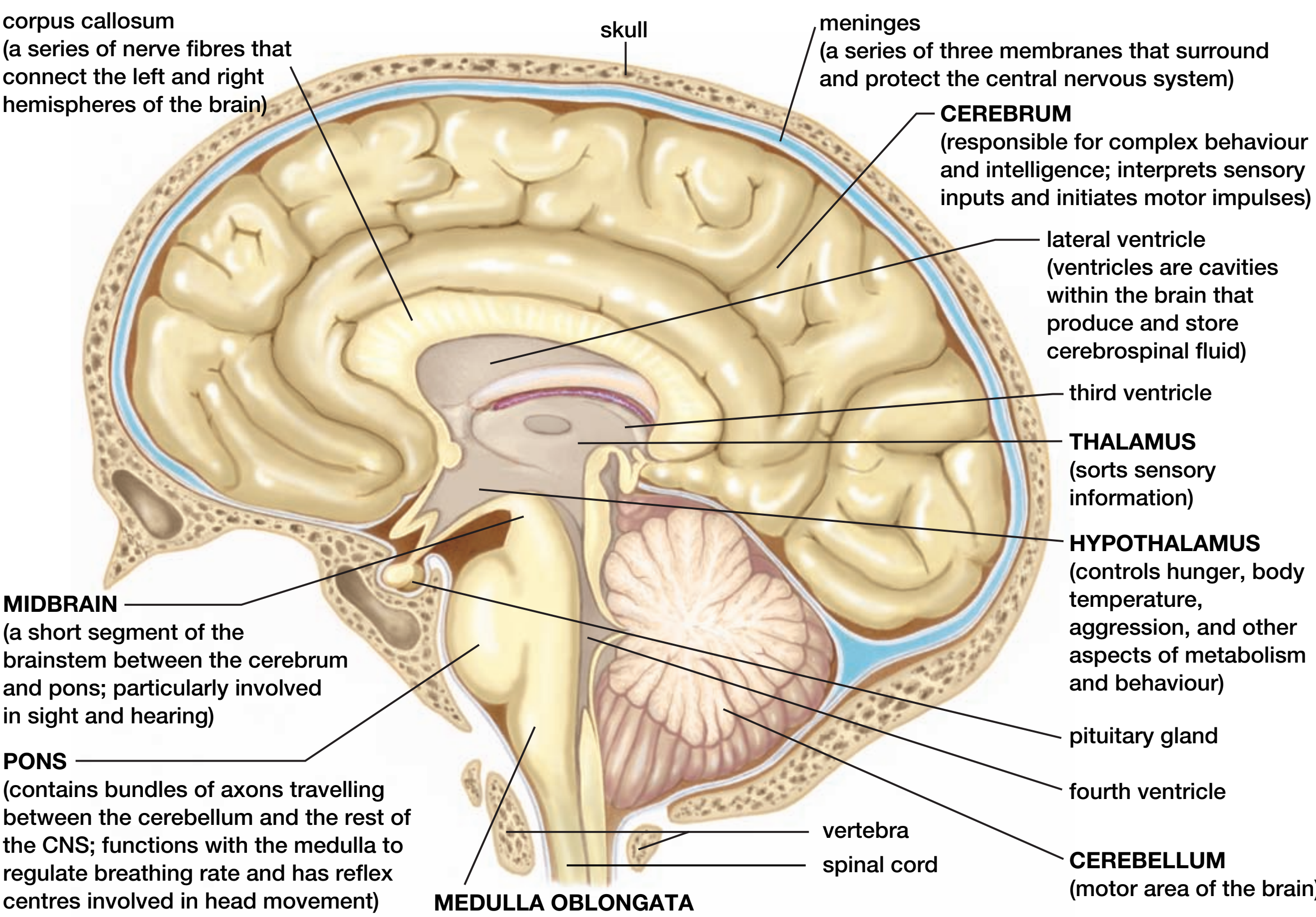


Figure 12.11 An overview of the structure and major functions of the brain

stand or walk? The child works hard to keep her balance. However, older children and adults do not even think about maintaining balance because the cerebellum takes over. Although we consciously decide to stand, walk, or run, we do not have to consciously control all the separate muscle actions involved.

Indeed, most of the physical skills that we learn are slowly taken over by the cerebellum. The difference between a beginner and a more accomplished player of any game may be related to the degree to which the basics have been taken over by the cerebellum and are no longer consciously controlled. For instance, do you think an experienced hockey player concentrates on the plays of the game or on his or her skating?

The **thalamus** is a sensory relay centre. It receives sensations of touch, pain, heat, and cold, as well as information from the muscles. If the sensations are mild, the thalamus relays the information to the appropriate part of the cerebrum (the conscious part of the brain that will be discussed shortly). However, if the sensations are strong, the thalamus triggers a more immediate reaction while, at the same time, transferring the sensations to the homeostatic control centre — the hypothalamus.

The **hypothalamus** — to be studied in detail in Chapter 13 — is an incredibly complex and important bundle of tissues that acts as the main control centre for the autonomic nervous system. The hypothalamus enables the body to respond to external threats by sending impulses to various internal organs via the sympathetic nervous system. It re-establishes homeostasis after the threat has passed by stimulating the parasympathetic nerves.

The **cerebrum** is the part of the brain in which all the information from our senses is sorted and interpreted. Voluntary muscles that control movement and speech are stimulated from this part of the brain. Memories are stored and decisions are made in this region as well. The cerebrum is what makes humans different from any other animal on the planet. It is the centre of human consciousness.

As shown in the photograph on page 390, the cerebrum is divided into two halves, called the left and right hemispheres. The surface of each half is covered with convolutions that increase the cerebrum's surface area.

The **cerebral cortex**, the thin layer that covers each hemisphere of the brain, contains over one billion cells. It is this layer that enables us to experience sensation, voluntary movement, and all the thought processes we associate with consciousness. The surface of the cerebral cortex

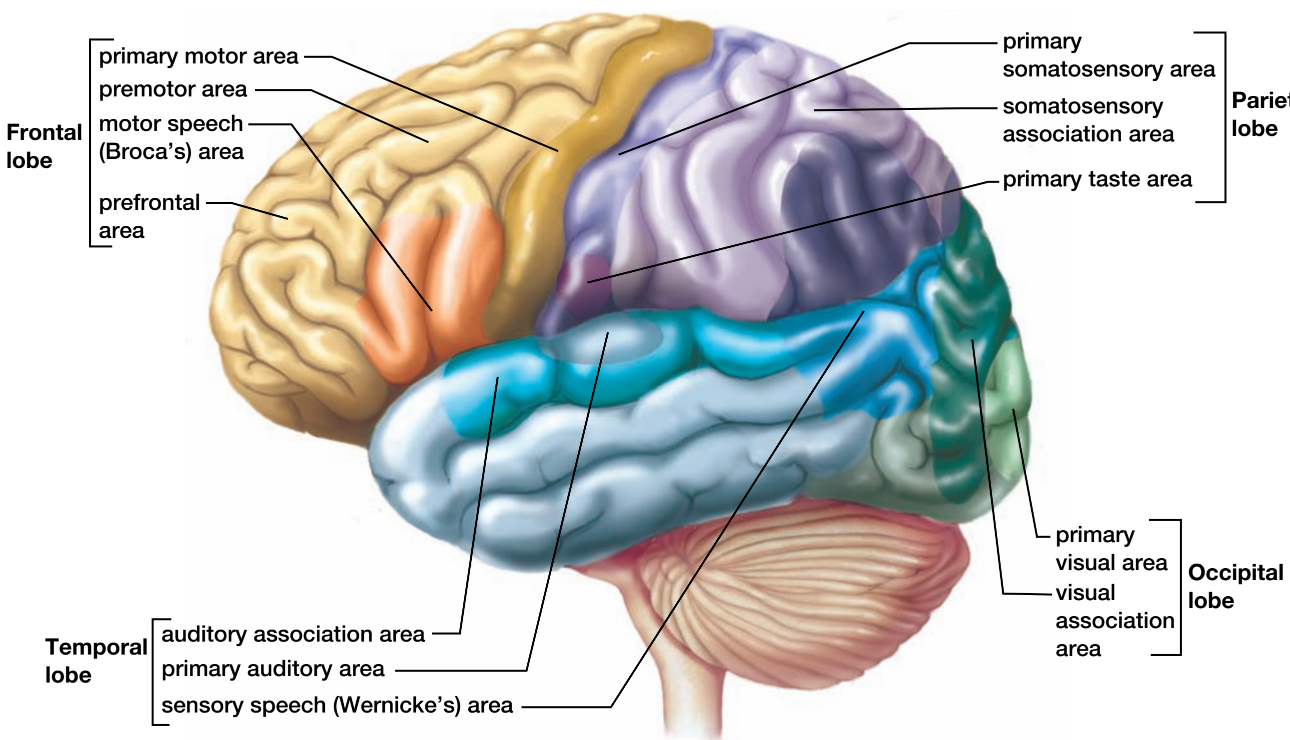


Figure 12.12 The cortex of the cerebrum is divided into four lobes: frontal, parietal, temporal, and occipital. The frontal lobe has motor areas and an association area called the prefrontal area. The other lobes have sensory areas and also association areas.

is made up of grey matter, composed primarily of cell bodies and dendrites packed closely together for maximum interaction. The two hemispheres are joined by the **corpus callosum**, a layer of white matter made up of axons. The corpus callosum transfers impulses from one hemisphere to the other.

Figure 12.12 shows that the cerebrum is also divided into four lobes, each associated with different functions. The frontal lobe is involved in the control of muscles (motor areas) and the integration of information from other parts of the brain to help us reason. This area allows us to think critically and plan our actions. The parietal lobe receives sensory information from the skin and skeletal muscles, and is associated with our sense of taste. The occipital lobe receives information from our eyes, and the temporal lobe receives information from our ears.

In the next section, you will examine more closely the structure and function of the neurons in your body, as well as the high-speed communication network of which they are a part. You will see how chemical substances stimulate neurons to trigger the impulses that enable you to think, move, and respond to stimuli. In the final section of this chapter, you will study sensory receptors associated with sight, hearing, and touch.

WEB LINK

www.mcgrawhill.ca/links/atlbiology
Memory is an important cognitive function. What do you do to help remember important information for your next class test? To access procedures for memory tests, go to the web site above, and click on **Web Links**.

SECTION REVIEW

1. Identify the two major parts of the human nervous system.
2. How is the autonomic system different from the somatic system?
3. Which parts of your nervous system are you using to complete this homework assignment? Make a diagram of yourself and label the parts of your nervous system that are working.
4. What is a reflex arc? How is it useful to an organism like you?
5. A sudden interruption in the blood supply to the brain (known as a stroke) can cause serious brain damage. Investigate how a stroke can affect a person's ability to speak naturally and clearly and to comprehend what others are saying (in other words, to communicate effectively). Present your findings in a brief report to the class.
6. What factors contribute to the complexity of the brain?
7. Explain how the EEG, MRI, and PET scans help us to understand brain function.
8. How have studies of people with brain disorders helped us understand brain function? Explain your answer.
9. Prions are proteins that can cause other proteins to change shape and lose normal function. Bovine spongiform encephalitis (BSE), also known as Mad Cow Disease, is caused by prion infection. BSE prions attack proteins in the brain, which eventually leads to deterioration of brain tissue. You are interested in conducting research about prions.
   (a) Identify some safety issues that need to be addressed before you start.
   (b) How could PET scans be helpful to monitor the progress of this disease in an infected person?
   (c) How could animal tests be useful?
10. Describe how damage to the CNS will have a different impact than damage to the PNS. As medical researchers study the effects of damage to both types of nervous systems, consider the use of implanting new stem cells or transplanting whole neurons to reverse damage to nerve tissue. Which strategy might be most effective for each system? Explain your thinking.
11. Copy and complete the following chart.

Brain Structure	Location	Functions
Pons		
Midbrain		
Corpus callosum		
Cerebellum		
Cerebrum		

12. Discuss a situation in which you may have experienced the symptoms of a fight-or-flight reflex. How long did it take for your heart rate and breathing rate to return to normal? Compare your fight-or-flight experience with that of others in your class. Discuss the apparent differences, if any, in the way males and females experience the fight-or-flight reflex.

12.2 How the Neuron Works

OUTCOMES

- **Describe the function of neurons.**
- **Explain the role of neurotransmitters in the central nervous system.**
- **Describe how neurons respond to a stimulus.**

A neuron is formed by the same process of cell division as occurs in other cells. A neuron has a single nucleus, numerous mitochondria, ribosomes, lysosomes, and other organelles. However, neurons also have very specialized structures that make them different from other cells and that enable them to perform their unique functions.

As mentioned previously, a neuron is composed of dendrites, a cell body, and an axon. The axon sends a wave of depolarization along its length, which is part of the high-speed network that sends impulses from one part of the body to another. The wave of depolarization is primarily the movement of two positive ions (Na^+ and K^+) from one side of the axon's cell membrane to the other.

The Neuron at Rest

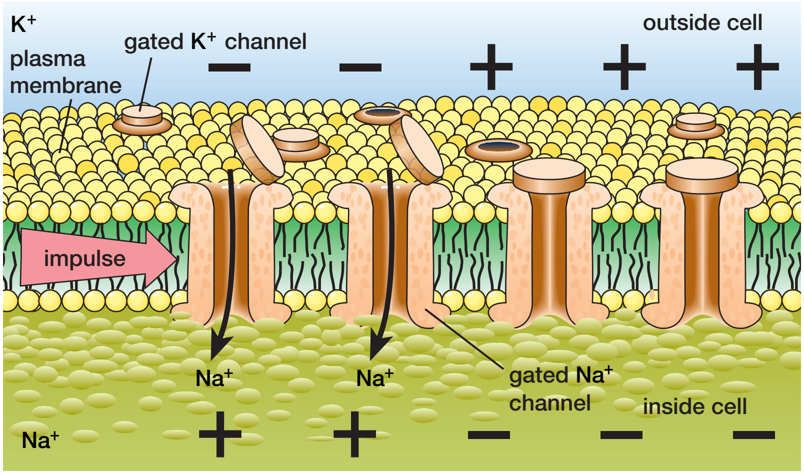
When a neuron is at rest, the outside of the membrane of the neuron is positively charged compared to the inside. This is the result of the uneven distribution of positively charged ions (cations) and negatively charged ions (anions). Outside the cell there are high concentrations of sodium ions (Na^+) and lower concentrations of potassium ions (K^+). Chloride (Cl^-) is the dominant anion exterior to the cell. Inside the cell there is a high concentration of K^+, a lower concentration of Na^+, and the dominant anions are negatively charged proteins, amino acids, phosphates, and sulfates. The membrane has specialized channels or gates for the movement of Na^+, K^+, and Cl^-, but the larger anions (such as proteins and amino acids) are trapped within the cell. As shown in Figure 12.13 on the following page, the movement of Na^+ and K^+ is critical to the wave of depolarization. At rest, the membrane is 50 times more permeable to K^+ than to Na^+. That is, while Na^+ is moving into the cell, there is more K^+ diffusing out of the cell. As this happens, the inside of the cell becomes increasingly negatively charged because the larger anions are trapped inside. Although the increasing negative charge within the cell attracts both the Na^+ and K^+, this force is offset by the Na^+/K^+ pump, which is found in the cell membrane. The Na^+/K^+ pump uses active transport to pull three Na^+ cations from the inside of the cell to the outside. In exchange, two K^+ cations are pulled from outside to inside the cell, thereby increasing the difference in charge. The final result is a relatively negative charge inside the cell compared to the outside. This charge (due to the unequal distribution of cations and anions) can be measured using tiny micro-electrodes placed inside and outside the membrane. At rest, the difference in charge is approximately –70 mV. This difference is referred to as the **resting potential**.

Unlike other cells, nerve cells have only an aerobic metabolism, so they need a constant supply of oxygen and use just glucose to metabolize. The mitochondria in the neuron use oxygen and glucose to produce ATP, which releases energy during its breakdown into ADP. This energy fuels the active transport of Na^+/K^+ across the cell membrane.

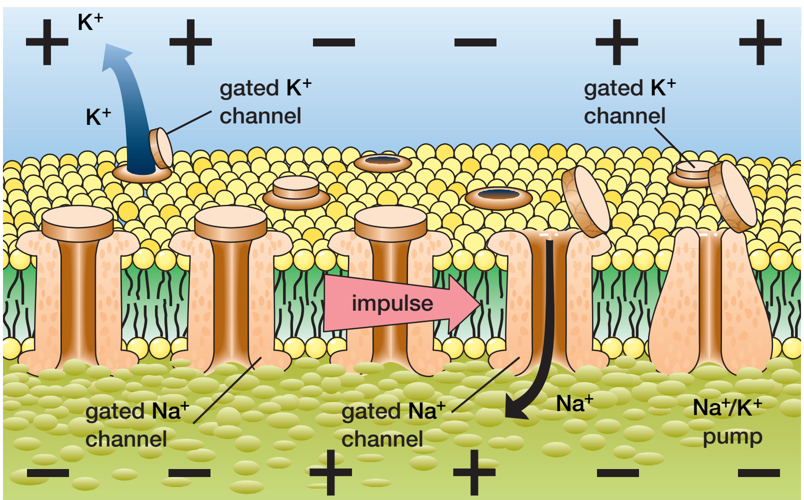
The All-or-none Principle

Sensory neurons can be stimulated by chemicals, light, heat, or the mechanical distortion of their membrane. Motor neurons and the neurons of the central nervous system are usually stimulated by **neurotransmitters**, which are chemicals secreted by other neurons. Neurons can also be stimulated experimentally using an electrical current. If the neuron is given a mild electrical stimulus, there is a brief and small change in the charge of the cell membrane near the point of stimulation. The axon itself does not send a wave of depolarization along its length. However, if the electrical stimulus is strong enough (that is, if it reaches the threshold of stimulus), a wave of depolarization will sweep along the surface of the axon.

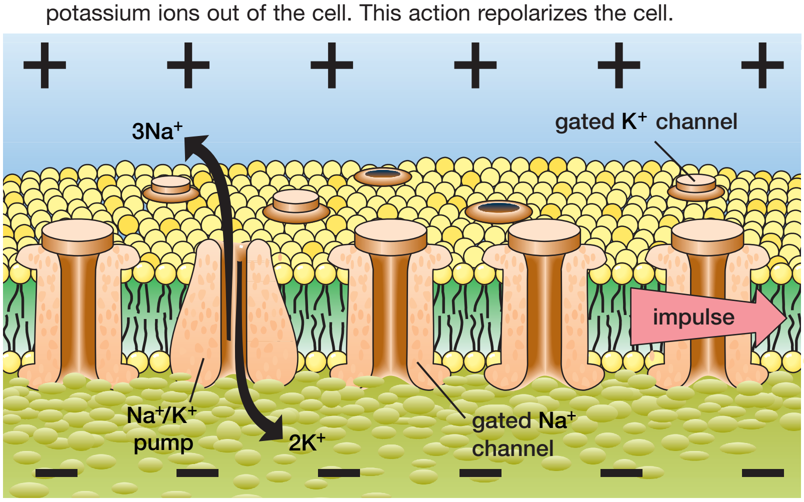
An axon is governed by the all-or-none principle. If an axon is stimulated sufficiently (above the threshold), the axon will trigger an impulse down the length of the axon. The strength of the response



A Gated sodium ion channels open, allowing sodium ions to enter and make the inside of the cell positively charged and the outside negatively charged.



B As the impulse passes, gated sodium ion channels close, stopping the influx of sodium ions. Gated potassium ion channels open, letting potassium ions out of the cell. This action repolarizes the cell.



C As gated potassium ion channels close, the Na^+/K^+ pump restores the ion distribution.

Figure 12.13 The membrane of a neuron contains open as well as gated channels that allow movement of sodium ions (Na^+) and potassium ions (K^+) into and out of the cell. The gated channels open and close as a wave of depolarization moves down the axon of a neuron.

is uniform along the entire length of the axon. Also the strength of response in a single neuron is independent of the strength of the stimulus. An axon cannot send a mild or strong response; it can only respond or not respond. The threshold of stimulus is like the trigger of a gun. Once the pressure on the trigger is strong enough, the bullet is on its way — pulling harder on the trigger has no effect on the speed of the bullet.

Depolarization

As mentioned above, when a neuron is sufficiently stimulated, a wave of depolarization is triggered. When this occurs, the gates of the K^+ channels close and the gates of the Na^+ channels open (see Figure 12.13). Sodium ions move into the axon. This input of positively charged ions neutralizes the negative charge in the axon. This change in charge is called the **action potential**. The depolarization of one part of the axon causes the gates of the neighbouring Na^+ channels to open, and this depolarization continues along the length of the axon. Note that action potentials can occur in the dendrites and in the cell body as well.

Repolarization

Any specific region of the axon is only depolarized for a split second. Almost immediately after the sodium channels have opened to cause depolarization, the gates of the K^+ channels re-open and potassium ions move out. The Na^+ channels close at the same time. This process, combined with rapid active transport of Na^+ out of the axon by the Na^+/K^+ pump, re-establishes the polarity of that region of the axon. The speed with which this process occurs allows an axon to send many impulses along its length every second, if sufficiently stimulated. The brief time between the triggering of an impulse along an axon and when it is available for the next impulse is called the **refractory period**. For many neurons, the refractory period is approximately 0.001 s.

One advantageous effect of a wave of depolarization is that an impulse can move along the entire length of a neuron and the strength of the signal does not dissipate. The signal moves at about 2 m/s. However, in some cases it is important that a wave of depolarization travel faster than this. For a wave of depolarization travelling along a neuron to the small intestine, speed is not a priority. But if an object is moving rapidly toward your eye, hundredths or even thousandths of a second may count. The speed of a wave of depolarization is increased by the addition of a fatty layer called the **myelin sheath**. As shown in Figure 12.14, this layer is formed by **Schwann cells** lined up along the length of the axon.

WEB LINK

www.mcgrawhill.ca/links/atlbiology
To learn more about channel behaviour in a neuron, go to the web site above and click on **Electronic Learning Partner**.

BIO FACT

In the PNS, the myelin sheath is made up of Schwann cells. In the CNS, the myelin sheath is made up of cells called oligodendrocytes.

Between each Schwann cell is a gap called the **node of Ranvier**, where the membrane of the axon is exposed. A nerve impulse that travels along a myelinated neuron is able to jump from one node of Ranvier to the next. This ability speeds up the wave of depolarization to 120 m/s. Myelinated nerve fibres are found in the central nervous system and in the peripheral nervous system, wherever speed is an important part of the function of a neuron.

The Schwann cells perform another important function. As mature cells, most neurons are incapable of reproducing themselves. This means that damage to the nervous system either by accident or disease cannot follow the same healing process that occurs in other parts of the body. However, neurons that have a neurolemma (the outer layer of the Schwann cells) are capable of regenerating themselves if the damage is not too severe. If a neuron is cut, the severed end of the axon grows a number of extensions or sprouts, and the original axon grows a regeneration tube from its neurolemma. If one of the sprouts from the severed section connects with the regeneration tube, the axon can re-form itself. Even if the muscle tissue that the axon was attached to has atrophied, the muscle will regrow when stimulated by the repaired axon.

Damaged neurons in the CNS cannot regenerate, but if an area of the brain itself is damaged, its functions can often be taken over by other parts of the brain. With extensive rehabilitation, the patient may be able to recover. Damage to the spinal cord is usually permanent, however, and can lead to paralysis, as was the case for actor Christopher Reeve, shown in Figure 12.15.

The lack of oxygen to a portion of the brain as a result of stroke causes that portion of the brain to die. Treatment for thrombolytic stroke involves the use of clot-busting drugs, which are described in detail in Chapter 9. A major drawback is that the medicine must be taken within a short interval (approximately three hours) after the stroke occurs.

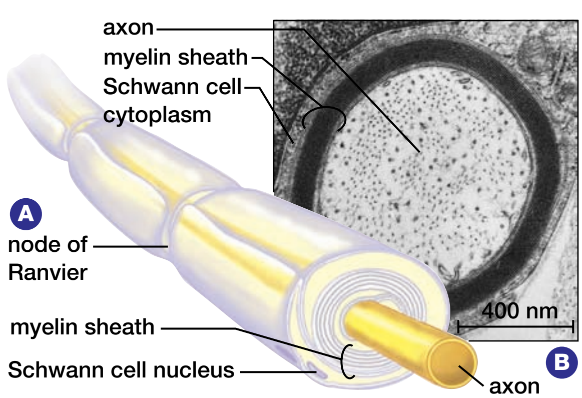


Figure 12.14 (A) A myelin sheath forms when Schwann cells wrap themselves around a nerve fibre. (B) Electron micrograph of a cross section of an axon surrounded by a myelin sheath.

Figure 12.15 Because of a spinal cord injury incurred in an equestrian accident in 1995, actor Christopher Reeve is confined to a wheelchair. He actively campaigns for funding on behalf of spinal cord research.

Another problem is that some patients experience life-threatening bleeding in the brain. Aspirin may also be prescribed for an individual showing symptoms of a stroke. Aspirin reduces the stickiness of the platelets, so it decreases the chances of a clot forming. It is important to realize that some strokes are caused by aneurysms, where a blood vessel breaks in the brain, and in these cases, when the blood is thinned as with aspirin, the bleeding can become worse. There is no evidence that taking aspirin daily will prevent strokes.

The repair of brain and spinal injuries is a major area of medical research. One recent study has identified a gene that inhibits spinal regeneration. This gene, designated Nogo, produces a protein that prevents neurons of the CNS from regenerating. It is believed that this protein is produced to prevent wild, uncontrollable growth of tissue. Researchers hope this discovery will lead to drug therapies that will enable damaged CNS tissue to regenerate. Research on mice at the University of Toronto is also showing promise in repairing spinal cord injuries. In addition, Peter Erikson from Göteborg University in Sweden and his co-worker Fred Gage found as many as 200 new neurons per cubic millimetre of tissue in the brains of some patients who had recently died of cancer. This discovery involved using a specialized drug used to trace the formation of new cells. The scientists estimate that up to 1000 new neurons may be created each day, even in the brains of people in their 50s and 70s. These new neurons apparently arise not by mitosis of mature neurons but from a reserve of embryonic stem cells. These cells are found in some parts of the brain and do not form into specialized cells during the development of the brain. Similar stem cells are found in bone marrow and are responsible for the formation of the wide variety of blood cells found in the body.

The Synapse

Neurons do not touch one another; there are tiny gaps between them. These gaps are called **synapses**. The neuron that carries the wave of depolarization toward the synapse is called the **presynaptic neuron**. The neuron that receives the stimulus is called the **postsynaptic neuron**. When a wave of depolarization reaches the end of a presynaptic axon, it triggers the opening of special calcium ion gates. The calcium triggers the release by exocytosis of neurotransmitter molecules. The neurotransmitter is then released from specialized vacuoles called **synaptic vesicles**, which are produced in the bulb-like ends of the axon. The neurotransmitter diffuses into the gap between the axon and dendrites of neighbouring postsynaptic neurons, as shown in Figure 12.16. The dendrites

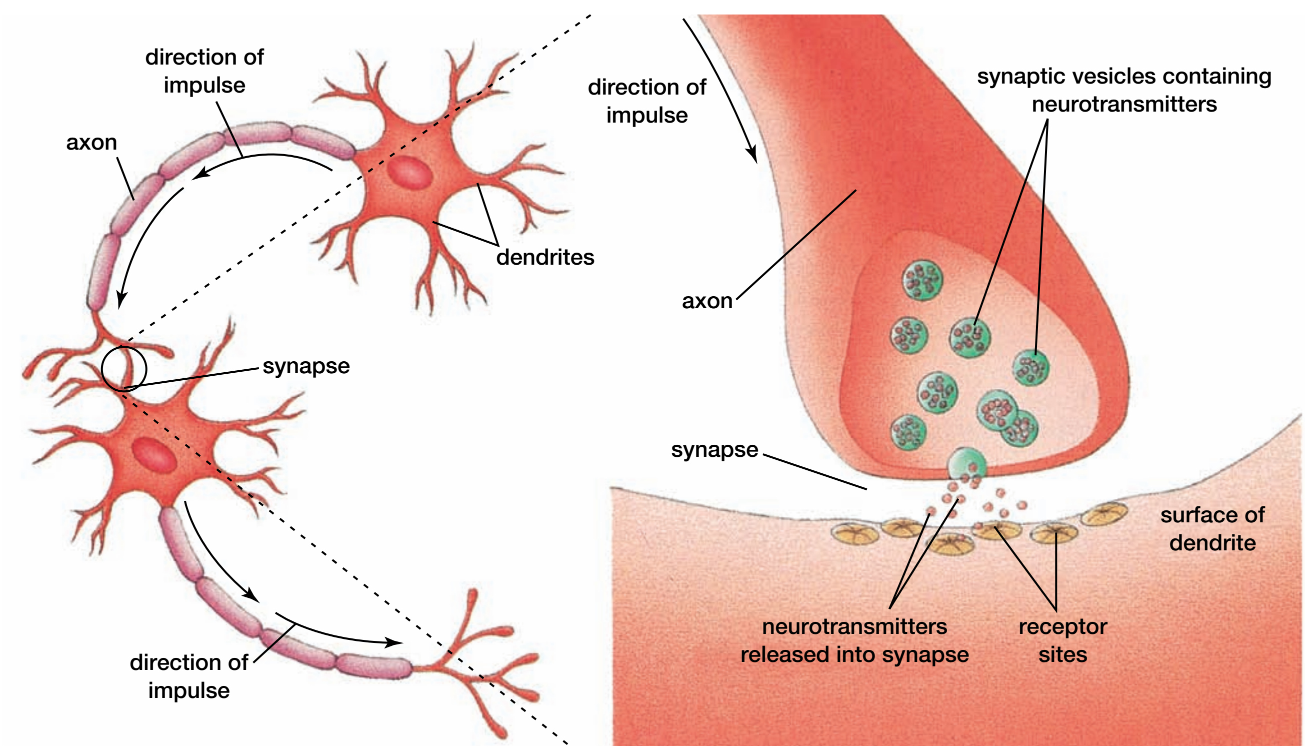


Figure 12.16 At a synapse, neurotransmitters pour into specific sites on nearby dendrites.

have specialized receptor sites and the neurotransmitter attaches to these receptors and excites or inhibits the neuron. The **excitatory response** involves the opening of sodium gates, which triggers a wave of depolarization. The **inhibitory response** makes the post-synaptic neuron more negative on the inside in order to raise the threshold of stimulus. This process is usually accomplished by opening chloride channels to increase the concentration of these negative ions in the neuron.

WEB LINK

www.mcgrawhill.ca/links/atlbiology
To learn more about how the synapse works, go to the web site above and click on **Electronic Learning Partner**.

Neurotransmitters can also stimulate or inhibit cells that are not neurons. This applies particularly to muscles, where the neurotransmitter from the neuron triggers the contraction of the muscle. Also, the adrenal gland is composed of modified neurons of the sympathetic nervous system that release the neurotransmitters adrenaline and noradrenaline into the blood as hormones. They have a variety of effects that will be discussed in Chapter 13.

The neurotransmitter that enters the synapse and attaches to the postsynaptic receptors is broken down almost immediately by an enzyme released from the presynaptic neuron. For example, the enzyme **cholinesterase** breaks down the neurotransmitter **acetylcholine**. Acetylcholine is the primary neurotransmitter of both the somatic nervous system and the parasympathetic nervous system. Acetylcholine can have excitatory or inhibitory effects. This neurotransmitter stimulates skeletal muscles but inhibits cardiac muscles. **Noradrenaline**, also called norepinephrine, is the primary neurotransmitter of the sympathetic nervous system.

As is evident from the above discussion, the neurons of the brain involve a wide variety of neurotransmitters that have numerous functions. **Glutamate** is a neurotransmitter of the cerebral cortex that accounts for 75 percent of all excitatory transmissions in the brain. Gamma aminobutyric acid (**GABA**) is the most common inhibitory neurotransmitter of the brain. Many of the brain's neurotransmitters have multiple functions. **Dopamine** elevates mood and controls skeletal muscles, while **seratonin** is involved in alertness, sleepiness, thermoregulation, and mood. Drugs have been developed to stimulate or inhibit specific neurotransmitters. For example, Valium™ increases the level of the neurotransmitter GABA to alleviate anxiety. Prozac™, an antidepressant, enhances the action of seratonin.

Disorders of the Nervous System

The nervous system controls or affects every action and thought that we have. Any problem or malfunction in the system therefore has enormous consequences for physical and mental well-being. Several disorders of the nervous system are well studied, but research to develop preventative strategies and treatments is ongoing.

Multiple sclerosis (MS) is a progressive disorder affecting the nerve cells in the brain and spinal cord. The myelin sheath that surrounds the nerve cells becomes inflamed or damaged, and this disrupts the nerve impulses that are normally produced. The disruption of nerve signals causes a variety of symptoms, including blurred or double vision; slurred speech; loss of coordination; muscle weakness; a feeling of tingling, numbness, or constriction in the arms or legs; and, occasionally, seizures. MS attacks may occur in episodes during which the symptoms become worse, alternating with periods in which the symptoms improve. Some individuals have a long history of MS attacks before symptoms become progressively and consistently worse. For others, however, the progress of the disorder is rapid and severe.

MS is now believed to be an autoimmune disorder, in which the immune system mistakenly attacks the myelin sheaths of the body's own nerve cells. There is no cure for MS at present, but the disorder can be treated using medications that suppress the autoimmune reaction. Autoimmune disorders were discussed in detail in Chapter 11. In addition, such symptoms as seizures and fatigue are treated separately with drugs specific to the particular symptom.

Alzheimer's disease is another familiar disorder of the nervous system. Alzheimer's is a form of dementia, which is an impairment of the brain's intellectual functions such as memory and orientation. The brain gradually deteriorates, causing memory loss, confusion, and impaired judgment. Alzheimer's results from deposits of a protein called amyloid that distort the communication paths between brain cells. At the same time, levels of acetylcholine begin to drop, causing further breakdown of communication.

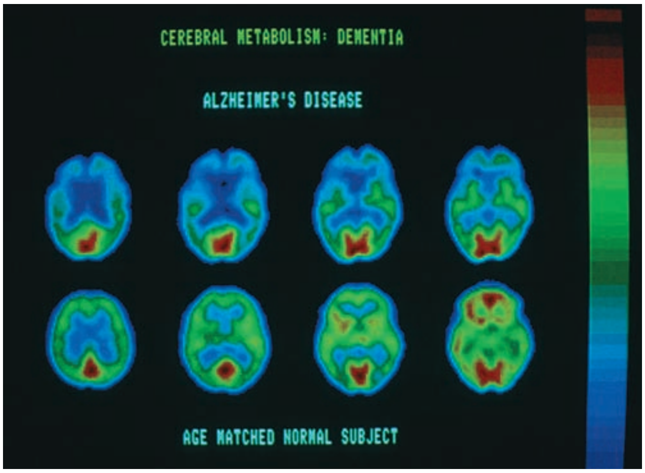


Figure 12.17 Brain scan of an Alzheimer's patient (top) versus brain scan of a healthy person (bottom).

Alzheimer symptoms begin as impairment of recent memories as well as difficulty learning and retaining new information. Gradually, older memories are lost, and patients may not recognize familiar faces and may not be able to carry out simple tasks. Individuals with Alzheimer's disease may also suffer personality changes — becoming irritable, anxious, delusional, and even aggressive. Currently, there is no means of preventing the disease, and treatment options are limited. Certain drugs, called cholinesterase inhibitors, work to increase the brain's level of acetylcholine and thus may improve intellectual function for up to nine months. Unfortunately, Alzheimer's is an irreversible illness and mental function declines over a period of three to 20 years prior to death.

Parkinson's disease is a chronic movement disorder caused by the gradual death of the neurons that produce dopamine. Dopamine is a chemical that acts to carry messages between the areas of the brain controlling body movements. The symptoms of Parkinson's begin as slight tremors and stiffness in limbs on one side of the body. As the disease progresses, the tremor spreads to both sides of the body and the limbs become rigid, body movements slow, and a characteristic abnormal gait develops. Parkinson's is a chronic, progressive disease. Usually, by the time the first symptoms appear, 70 to 80 percent of the brain cells that produce dopamine have already been lost.

At this time, there is no cure for Parkinson's disease, but the symptoms can be treated individually. Most treatments involve medications that boost dopamine levels or mimic the effect of dopamine on target brain cells. Unfortunately, long-term use of the most effective drugs can lead to mental impairment and other complications, so physicians often limit their use. Surgical treatment may be attempted if the individual does not respond to drug therapy. Existing surgical treatments include creating small lesions or implanting electrodes in the specific brain regions that are overactive in Parkinson's disease. These surgical treatments are not completely effective, and research is continuing.

Meningitis is a different type of nervous system disorder in that it is caused by a viral or bacterial infection of the meninges, the three membranes that cover and protect the brain and spinal cord. Viral meningitis is relatively common, especially in children, and usually clears after seven to ten days. If not treated immediately, the more serious bacterial meningitis is fatal. The symptoms of meningitis include headache, fever, and a stiff neck. Other common symptoms include light sensitivity, vomiting, and drowsiness.

Meningitis is diagnosed by testing the cerebrospinal fluid that surrounds the spinal cord for the presence of bacteria or indications of immune system activity. This procedure is called a spinal tap, or lumbar puncture (see Figure 12.18). Prevention of meningitis involves reducing the risk of catching viruses or bacteria from others. Hand washing is particularly important. Vaccines are available for some of the bacteria that cause meningitis, but there is no vaccine for viral meningitis. The prognosis for viral meningitis is excellent, but bacterial meningitis can have more serious, long-term effects. Fatality rates are approximately ten percent, and many survivors suffer from complications such as hearing impairment.

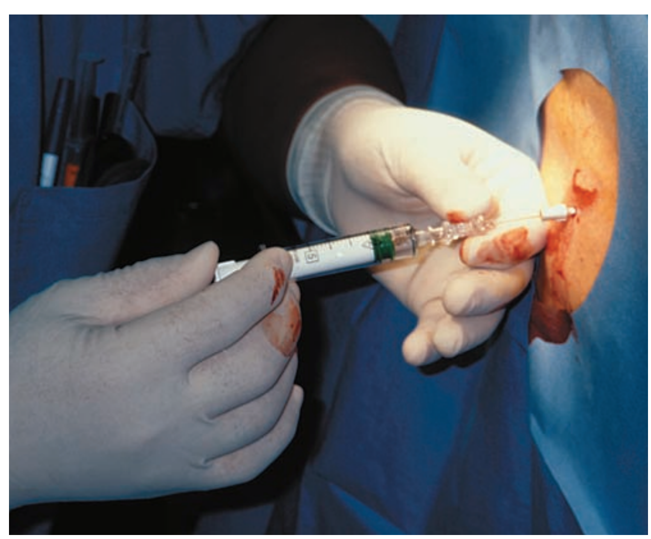


Figure 12.18 A spinal tap collects cerebrospinal fluid for testing.

A less common disorder of the nervous system is Huntington's disease, or Huntington's chorea. *Chorea*, which is the Greek word for "dance," describes the jerky movements made by people suffering from the disorder. Huntington's is a fatal autosomal dominant disorder in which the nerve cells in certain parts of the brain degenerate. This degeneration causes progressive decreases in mental and emotional abilities and loss of control over major muscle movements. Each child of a parent with Huntington's disease has a 50 percent chance of inheriting the disorder. Genetic screening is now available to assess for individuals' chances of passing the disorder to their children.

At present, there is no cure for Huntington's disease and no way of slowing its progression. Symptoms, which include memory loss, dementia, involuntary twitching, clumsiness, chorea, and personality changes, typically appear in mid-life. These symptoms progress in severity until death — usually a period of 15 years.

Given the importance of the nervous system in the homeostasis of the body, drugs are able to strongly affect the system. Drugs can be categorized as nervous system depressants or stimulants. Depressants slow down the CNS so that an individual may feel relaxed and feel less pain, but will also experience reduced coordination and judgment. Depressant drugs include alcohol, opiates such as heroin and morphine, and minor tranquilizers such as Valium™. Stimulants speed up the CNS, and individuals may feel increased energy and confidence, but experience paranoia. Stimulant drugs include caffeine, cocaine, MDMD (ecstasy), and nicotine. Ecstasy has been found to affect the neurotransmitters that produce feelings of euphoria and well-being. Research has shown that after two weeks of use, ecstasy can deplete up to 90 percent of the brain's serotonin supply, and long-term use of ecstasy may lead to permanent changes in neurotransmitter concentrations in the CNS.

Anaesthetic drugs also affect the CNS. There are two main types of anaesthetics: general and local. Local anaesthetics numb a small area of the body by blocking the passage of nerve impulses from the skin to the brain. They do so by disrupting the sodium channels needed to generate the action potential. General anaesthetics are needed during major surgeries so that the patient is unconscious and feels no pain. There is no common way that general anaesthetics work. Gases, such as ether, alter brain function by disrupting proteins in the cell membranes. Barbiturates enhance the activity of neurotransmitters such as GABA and so reduce the activity of brain cells. There is disagreement among scientists about how these general anaesthetics work because there is still much debate about conscious brain function.

SECTION REVIEW

1. Make a diagram of a neuron and label it.
2. Referring to your diagram from Question 1, show where each of these ions is concentrated for a neuron at rest: Na^+, K^+, Cl^-, and other ions.
3. The phospholipid bilayer is not very permeable to ions. How can ions diffuse into or out of a nerve cell?
4. Explain what is meant by resting potential. What is the approximate measure of resting potential?
5. An axon is governed by the all-or-none principle. What does this mean?
6. What is an action potential? How is it started?
7. Use diagrams to show the relative concentration of ions during depolarization and repolarization.
8. How can some neurons grow new axons after injury?
9. Make a diagram with labels to explain how the presynaptic axon responds to the action potential. Show that the dendrite of the next neuron responds if there are *not* enough neurotransmitters to meet the threshold.
10. What is the role of an enzyme like cholinesterase?
11. Much of what is known about the activity of motor neurons is based on research of the axon of the giant squid. This large cell extends from the head to the tail of the squid. The table shows how the external environment of the neuron can be changed, without changing the internal environment of the cell.

    (a) Copy and complete the table.

Solutes in the water outside the cell	Nerve impulse conducted?	Proposed explanation
Na^+ only		
K^+ only		
Cl^-		

    (b) Suggest three other possible solutions you could use to alter the external environment of the neuron.

12.3 The Sense Organs

OUTCOMES

- **Describe how sensory receptors in the eye and ear help to maintain homeostasis.**
- **Compile data about sensory reception and interpret graphs.**
- **Conduct research to investigate feedback mechanisms.**

Sight, hearing, taste, smell, and touch are all ways in which your body gathers information about the outside world. This information is essential to maintaining homeostasis and responding to changes in the world around you. Homestatic mechanisms inside your body regulate your blood sugar level, temperature, and blood pressure.

Imagine lying in a warm bath that has enough Epsom™ salts in the water to keep you afloat without exerting yourself. The room you are in is completely dark and soundproof. You are in a sensory deprivation tank. These tanks are used to induce relaxation and stress reduction.

Your brain is in the same kind of chamber, but it is continually stimulated with messages from the outside world through the sense organs. However, the flow of information ceases if there is damage to the sense organs or to the nerves that connect them to the brain. Researchers are exploring the effects of sensory deprivation on the body and mind to determine how loss of sensation changes the brain and its functions.

Experiencing even partial sensory deprivation for long periods can have negative effects. Early experiments in the 1950s showed that students sitting in darkened rooms deprived of sensation became restless and moody. In time, they became disoriented and experienced difficulty concentrating. After a while, some began to hallucinate. Even after the experiment, some students experienced sensory distortions and abnormal EEGs, although they suffered no long-term negative effects.

Current research from the National Academy of Child Development shows that deprivation of all five senses can result in partial loss of memory, lowered intelligence, and personality changes. However, research has also revealed that people adversely affected by a loss of sight or hearing can be helped by enriching their sensory environment. Animals deprived of one sense at birth will show changes in brain structure as the area that controlled the lost sense shrinks and other areas enlarge to compensate. This provides experimental evidence in support of the common observation that a visually impaired person's other senses become heightened due to the loss of sight. Evidence bears out that children who do not receive sufficient sensory stimulation from birth to age three may develop problems in terms of intellectual ability and personality disorders. However, it is possible to decrease the impact of this deprivation by providing children with an enriched environment after age three.

All of this evidence highlights the importance of the senses — not only to our perception of the world, but also to our mental health.

The Human Eye

Humans are visual organisms; we receive much of the information about the external world through our eyes. The eyes are protected by eyelashes, eyelids, eyebrows, and ridges of bone in the skull. Our ancestors were probably vertical clingers and leapers — animals that moved through the trees and required three-dimensional vision to judge distances. This vision was achieved by having two eyes at the front of the face. Binocular vision became increasingly important as humans learned to manipulate the outside world through the use of tools.

As shown in Figure 12.19, the eye is composed of three layers — the sclera, the choroid layer, and the retina. The **sclera** is the thick, white, outer layer that gives the eye its shape. At the front of the eye the sclera bulges outward and becomes clear to form the **cornea**. The cornea is covered by a thin, transparent membrane — the **conjunctiva** — that is continually kept moist by fluid from the tear glands. The fluid is drained off through small ducts that lead to the nasal cavities.

The middle layer is the coloured **choroid layer**, which absorbs light and prevents internal reflection. The light absorbed by the choroid layer is that which has not been absorbed by the sclera. At the front of the eye, the choroid becomes the **iris**, which opens and closes to control the size of the **pupil**.

Behind the iris, the choroid thickens and forms the ciliary body, which contains muscles to control the shape of the **lens**. The clear, flexible lens changes as you look at objects close up or far away. The lens is attached to suspensory ligaments that are, in turn, attached to the ciliary muscles.

The inner layer of the eye, the **retina**, is composed of two types of photoreceptors — **rods**

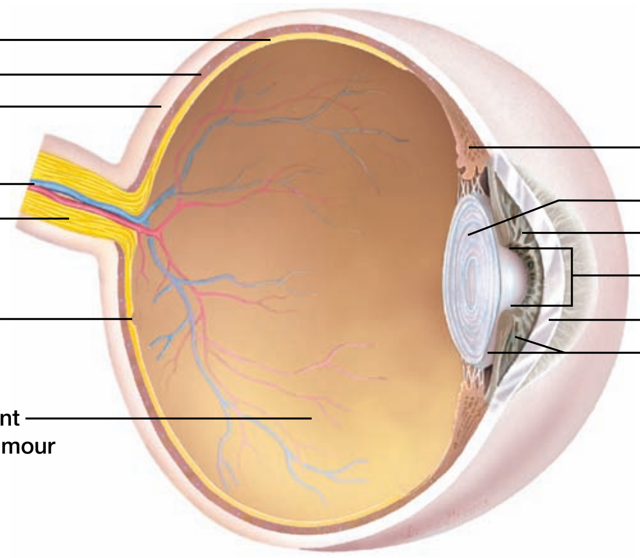


Figure 12.19 Notice that the sclera, the outer layer of the eye, becomes the cornea and that the choroid, the middle layer, is continuous with the ciliary body and the iris. The retina, the inner layer of the eye, contains the photoreceptors for vision; the fovea centralis is the region where vision is most acute.

Investigation 12 • B

SKILL FOCUS
- Predicting
- Performing and recording
- Analyzing and interpreting
- Conducting research

The Effect of Light on Pupil Size

The size of the pupil is controlled by ciliary muscles of the iris. The size of the pupil changes with the amount of light. This reaction is called the **pupillary reflex**.

Pre-lab Question

- What is the advantage of the pupillary reflex?

Problem

Does the colour of light affect the speed of the pupillary reflex?

Prediction

Predict whether the colour of light affects the speed of the pupillary reflex and, if it does, which colour will have the greatest effect.

Materials

stop watch
flashlight
pieces of coloured cellophane (red, yellow, green, blue) large enough to cover the flashlight lens

and **cones**. Rods are more sensitive to light than cones, but they are unable to distinguish colours. Cones require more light to stimulate them, but they are able to detect red, green, and blue.

The eye has two chambers divided by the lens. The anterior chamber between the cornea and the lens is filled with the fluid aqueous humour. The cornea and anterior chamber act as a pre-lens to initiate the process of focussing an image on the retina before it encounters the lens. The lens completes the process. The posterior chamber, behind the lens, is filled with a clear gel (vitreous humour) that helps maintain the shape of the eyeball.

BIO FACT

Lysozyme, an enzyme that destroys bacteria by dissolving their cell membranes, was discovered in the fluid from the tear glands by Canadian bacteriologist Alexander Fleming in 1922. Fleming also discovered penicillin in 1925.

How the Eye Functions

As light enters the eye, the pupil dilates if there is insufficient light or constricts if there is too much. The pupil also constricts when you focus on something close, to reduce the distortion that occurs around the outside field of view.

The shape of the lens changes in response to your distance from the object being viewed. Figure 12.20 on the next page illustrates that if you are looking at something far away, the ciliary muscles relax. The suspensory ligaments, which are attached to the ciliary muscles, become taut and the lens flattens. When you focus on something close, the ciliary muscles contract, pulling forward and releasing the tension on the suspensory ligaments. The lens then becomes more rounded. This adjustment is called **accommodation**.

BIO FACT

Some evidence shows that the pupil of the eye dilates when the person is interested in what he or she is viewing.

The image is focussed on the retina, which is composed of three layers — the ganglion cell layer, the bipolar cell layer, and the rod and cone cell layer (see Figure 12.21 on the next page). Bipolar cells synapse with rods or cones and transmit impulses to the ganglion cells. The ganglion cells join together

Procedure

1. This is a controlled experiment. The more variables you control, the more reliable your data will be.
2. To be consistent, select one member of each lab group to be the subject of the experiment, and allow at least 2 min between trials. Another member of the lab group should hold the flashlight, and a third should be in charge of observing the subject's eye and timing the pupillary reflex.
3. Prepare a data table.
4. The subject covers one eye with his or her hand for 1 min and then removes the hand. Time how long it takes for the pupil to constrict until it stops constricting. Repeat this step three times.
5. Repeat step 4 using the flashlight covered with one colour of cellophane to shine at the subject's eye after the eye is uncovered. Record your results. **CAUTION:** Do not shine the uncovered flashlight into the subject's eye.
6. Alternate colours of cellophane until you have completed three trials with each colour.
7. Graph your results. Be sure to use the format that will best illustrate your data.

Post-lab Questions

1. Why did you alternate colours during the experiment?
2. Would the experiment be more valid if you used more that one subject? Explain.
3. What are the advantages and disadvantages of doing this experiment in one session?
4. What is the purpose of taking the first set of readings in normal room lighting?

Conclude and Apply

5. Based on your data, does the colour of light affect the pupillary reflex?

Exploring Further

6. What other factors might affect the speed of the pupillary reflex?
7. What controls the pupillary reflex?

and form the optic nerve as they exit the eye. The retina is composed of approximately 150 million rod cells and 6 billion cone cells. Both function using a purple pigment called **rhodopsin**. When light strikes this pigment, rhodopsin breaks down into two proteins — retinal (which is formed from vitamin A) and opsin (which releases the energy required to stimulate a bipolar cell). The two proteins are then rejoined in a process that requires energy from ATP.

Rods are very sensitive to light and are therefore ideal for night vision. However, rods cannot distinguish colours, resulting in images that are primarily made up of shades of grey. Cones require more light to be stimulated. They exist in three forms, which are characterized by slight changes in the structure of opsin. The three kinds of cones are sensitive to red, green, or blue wavelengths of light. Each cone is connected to a separate bipolar cell, which enables the brain to form a very detailed image from the information it receives. Many rods (sometimes as many as 100) can be attached to a single bipolar cell. This is why night vision is blurry and indistinct.

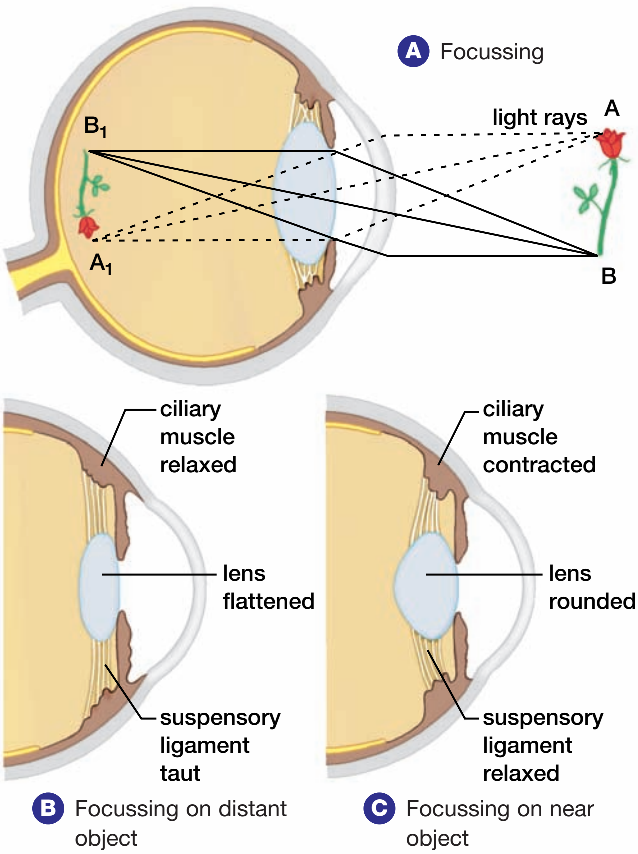


Figure 12.20 (A) Light rays from each point on an object are bent by the cornea and the lens in such a way that an inverted and reversed image of the object forms on the retina. (B) When focussing on a distant object, the lens is flat because the ciliary muscle is relaxed and the suspensory ligament is taut. (C) When focussing on a near object, the lens accommodates. It becomes rounded because the ciliary muscle contracts, thus causing the suspensory ligament to relax.

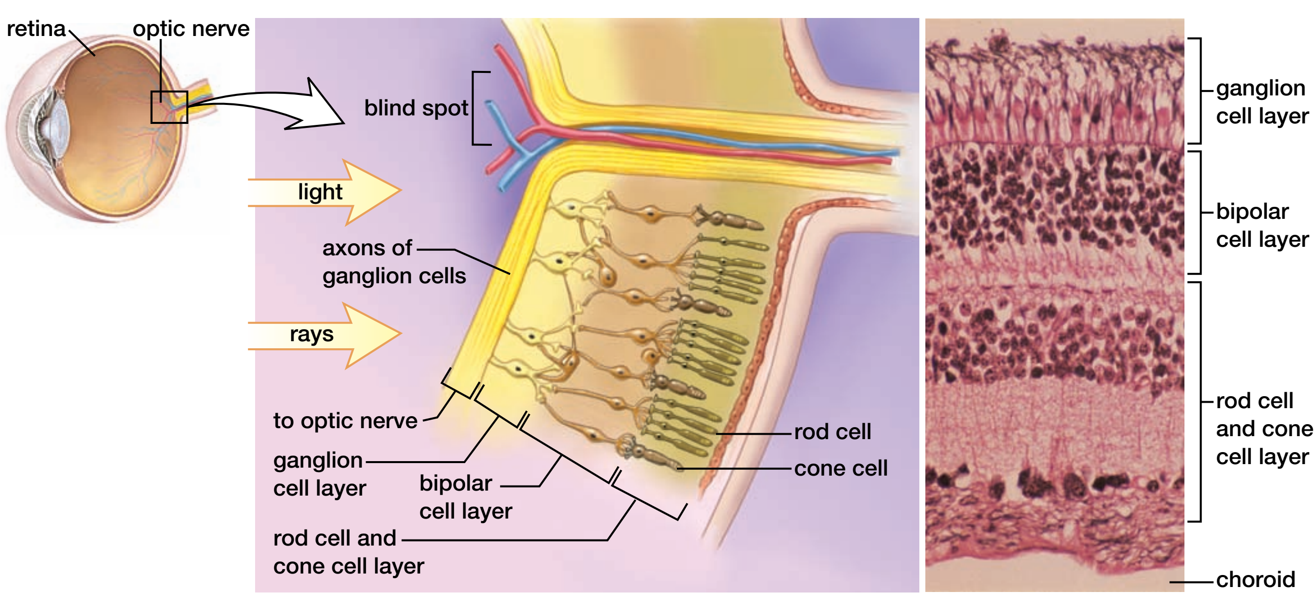


Figure 12.21 The retina is the inner layer of the eye. Rod cells and cone cells located at the back of the retina synapse with bipolar cells, which synapse with ganglion cells. Integration of signals occurs at these synapses; therefore, much processing occurs in bipolar and ganglion cells. Further, notice that many rod cells share one bipolar cell but cone cells do not. Each cone synapses with only one ganglion cell. Cone cells, therefore, distinguish more detail than do rod cells.

Cones are not evenly distributed on the retina. They are concentrated in an area called the **fovea centralis**, which is located directly behind the centre of the lens. When we are doing something that requires fine detail, we move the object directly in front of our eyes to focus the image onto the fovea, since this area produces the most distinct image.

Disorders of the Visual System

Cataracts are cloudy or opaque areas on the lens that increase over time and eventually cause blindness. They tend to occur in older people or they can result from exposure to sunlight. Today cataracts can be treated by surgically replacing the damaged lens with an artificial lens. **Glaucoma** is caused by a buildup of aqueous humour between the lens and the cornea. This fluid is produced continuously and has its own drainage system. If this system is blocked, the fluid builds up and creates pressure that can destroy the nerve fibres responsible for peripheral vision. The damage cannot be repaired, but it can be curbed with drugs or surgery. Therefore, it is important that our eyes be checked regularly by a doctor.

Near-sightedness (**myopia**) is a condition in which the person has difficulty seeing things that are far away. It is usually caused by the eyeball being too long or the ciliary muscle system being too strong. Far-sightedness (**hyperopia**) is a condition in which a person has difficulty seeing things close up. It is caused by the eyeball being too short or the ciliary muscle system being too weak to focus the image of nearby objects onto the retina. An **astigmatism** is an abnormality in the shape of the cornea or lens that results in uneven focus. In these cases, the image of the object can be focussed in front of the retina using corrective lenses, as shown in Figure 12.22 on the next page.

In some cases, surgery known as laser refractive correction can correct myopia, hyperopia, and astigmatism. There are two main laser surgery procedures: photorefractive keratectomy (PRK) and laser in situ keratomileusis (LASIK). PRK is an outpatient procedure performed with local anaesthetic eye drops. The laser beam reshapes the cornea by cutting microscopic amounts of tissue from the cornea's outer surface. The procedure takes only a few minutes and recovery is quick.

LASIK surgery is a more complex procedure performed for all degrees of nearsightedness. A knife is used to cut a flap of corneal tissue, then a laser removes the tissue underneath, and the corneal flap is replaced. Unlike the PRK procedure, which is controlled by the laser's computer, LASIK depends on the surgeon's skill. Both of these procedures have high success rates; in some cases, however, eyesight may actually diminish after surgery.

If the cornea is seriously impaired, usually by disease, a corneal transplant can be performed. In this procedure, the diseased cornea is replaced with a donor cornea, which like livers and kidneys, comes from individuals who have died and donated their corneas. Corneas, however, do not need to be type-matched to the same extent as a kidney or liver. Recovery is long but most patients do well. Vision improves gradually over the course of six to 12 months, and success rates vary depending on the original problem. Recurrence of most diseases in the donor cornea is unusual.

WEB LINK

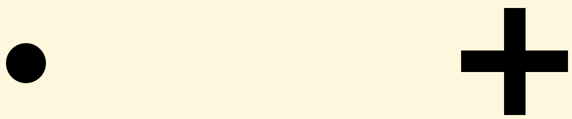
www.mcgrawhill.ca/links/atlbiology

People who are colour-blind are unable to distinguish some or all colours of the visible light spectrum. This condition, a sex-linked genetic trait, affects about 8 percent of males and 0.4 percent of females. To access a set of "Ishihara charts" (a test for colourblindness) that can be used to test your own colour vision, go to the web site above, and click on **Web Links**.

MINI LAB

Finding Your Blind Spot

The ganglion cells exit the eye through the optic nerve. There are no rods or cones here, so no image can be formed from light that hits this area.



Hold the text approximately 30 cm from your eyes. Close your right eye and stare at the cross with your left eye. Slowly move the text toward you until the circle disappears. At this point, the image of the circle is on the blind spot.

Analyze

Why are we not aware of this hole in our field of vision? Hypothesize how the brain compensates for this lack of information.

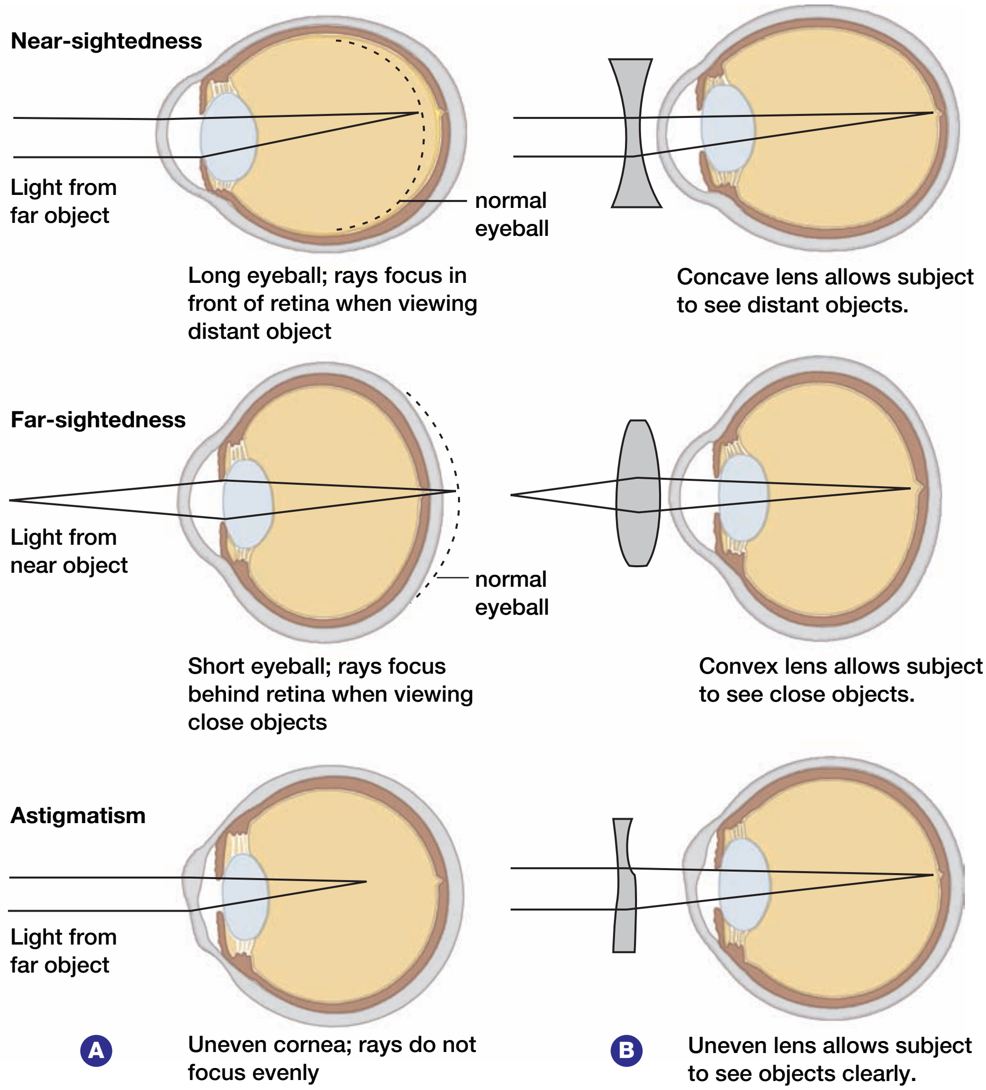


Figure 12.22 (A) The cornea and the lens bring light rays (shown here as lines) into focus, but sometimes they are unable to compensate for the shape of the eyeball or for an irregular curvature of the cornea. (B) In these instances, corrective lenses can allow the individual to see normally.

The Human Ear

The ear contains mechanoreceptors that translate the movement of air into a series of nerve impulses that the brain is able to interpret as sound. The ear is divided into three separate sections: the outer, middle, and inner ear, as shown in Figure 12.23. The **outer ear** consists of the pinna and the auditory canal. The auditory canal contains tiny hairs and sweat glands, some of which are modified to secrete earwax that protects the ear from foreign particles.

The **middle ear** begins at the **tympanic membrane**, or eardrum, and ends at two small openings called the **round window** and the **oval window**. Between the tympanic membrane and the oval window are the three smallest bones: the **malleus**, **incus**, and **stapes**. Together, these bones comprise the **ossicles**. Between the middle ear and the nasopharynx is the auditory tube, or **eustachian tube**. This tube allows air pressure to equalize, and in situations such as in airplanes or elevators, yawning can cause the air to move through the eustachian tubes and the ear will "pop."

The **inner ear** consists of three sections: the **cochlea**, which is involved in hearing, and the **vestibule** and **semicircular canals**, which are involved in balance and equilibrium. The inner ear is filled with fluid, unlike the outer and middle ear, which contain air.

Hearing actually begins when sound waves enter the auditory canal. Sound waves, which travel by vibrations of air molecules, cause the tympanic membrane to vibrate. These vibrations pass across the tympanic membrane to the malleus, which in turn causes the incus and finally the stapes to move.

The stapes passes the vibration to the membrane of the oval window, which passes it through to the fluid within the cochlea.

The cochlea contains three canals: the **vestibular canal**, the **cochlear canal**, and the **tympanic canal**, all of which are visible if the cochlea is uncoiled as shown in Figure 12.24 on the next page. The vestibular canal joins the tympanic canal and leads to the round window. The lower wall of the cochlear canal is formed from the **basilar membrane**. The basilar membrane has tiny hair cells along its length that connect above with the **tectorial membrane**. The hair cells in the cochlear canal combine to form the **spiral organ**, or the organ of Corti, and synapse with fibres from the cochlear, or auditory, nerve.

Disorders of the Auditory System

There are two main types of deafness: nerve deafness and conduction deafness. Nerve deafness is caused by damage to the hair cells in the spiral organ. In nerve deafness, hearing loss is usually uneven, with some frequencies being more affected than others. Nerve deafness is typically found with aging and cannot usually be reversed. Conduction deafness is caused by damage to the outer or middle ear that affects the transmission of sound waves to the inner ear. Conduction deafness does not usually cause a total loss of hearing because sound waves can also be transmitted through the skull bones to the inner ear. This type of hearing loss can frequently be improved with the use of hearing aids.

There are several different categories of hearing aids: conventional, programmable, and digital aids. Conventional hearing aids have a microphone that gathers sound, an amplifier to increase the volume of the sound, and a receiver that transmits the sound to the inner ear. The volume is user adjustable. Programmable hearing aids have an analog circuit that a healthcare professional can specifically program to an individual's needs. This type of hearing aid also has automatic volume control. The digital hearing aid is a technological advance that processes sound digitally. Individuals differ in the levels of hearing loss at different frequencies, so different frequencies require different levels of amplification. The digital hearing aid can shape amplifications across various pitches and frequencies according to individual needs.

Many children suffer from fluid build-up behind the eardrums, which then causes chronic middle ear infections. Fluid builds up because the angle that the eustachian tube enters the middle ear is shallow in children, and does not allow proper drainage. A common solution is tympanostomy tube surgery, or eustachian tube implants. Tiny plastic tubes are placed in a slit in the eardrum, relieving the pressure from the built-up fluid, and allowing it to drain. The surgery is simple, and complications are rare. In most cases, the tubes are pushed out of the ear by the eardrum as it heals, usually after six months to two years.

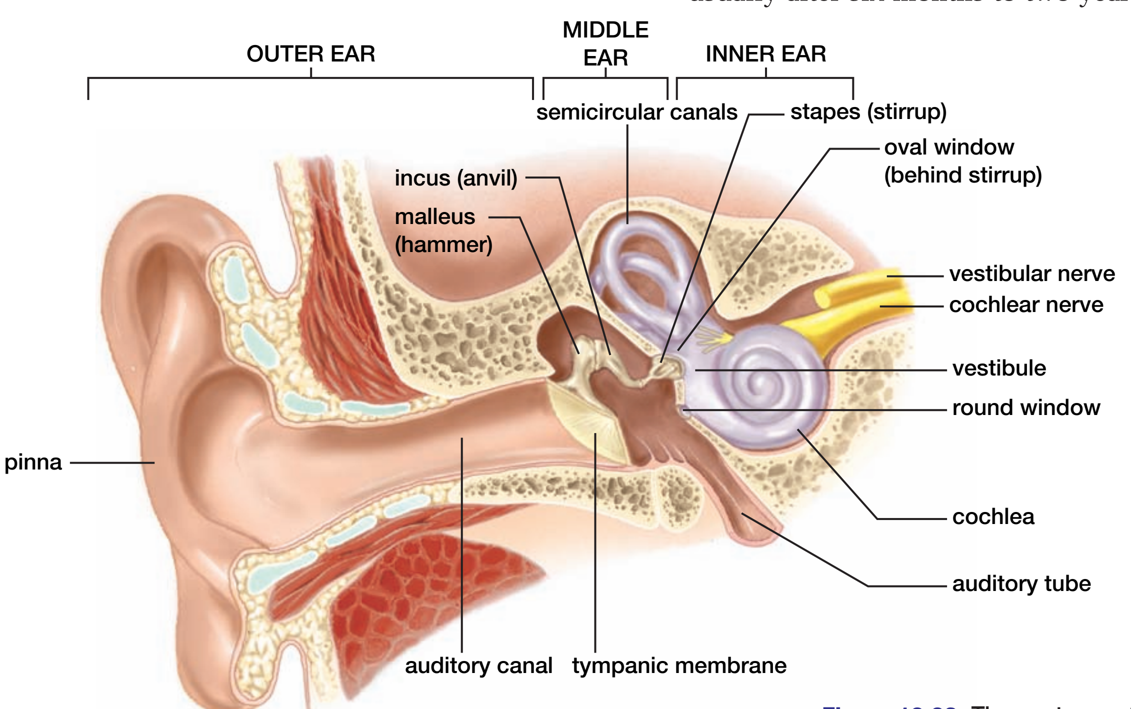


Figure 12.23 The anatomy of the human ear

Other considerations, primarily ethical ones, influence the choice of medical treatment of auditory and visual impairments. In some instances, hearing-impaired individuals are unwilling to intervene medically to improve their hearing because they feel that doing so would exclude them from the deaf community that communicates in American Sign Language (ASL). Medically improving the hearing of a hearing-impaired person can be traumatic if he or she then feels outside the usual community while still being treated as hearing-impaired by the larger, hearing community.

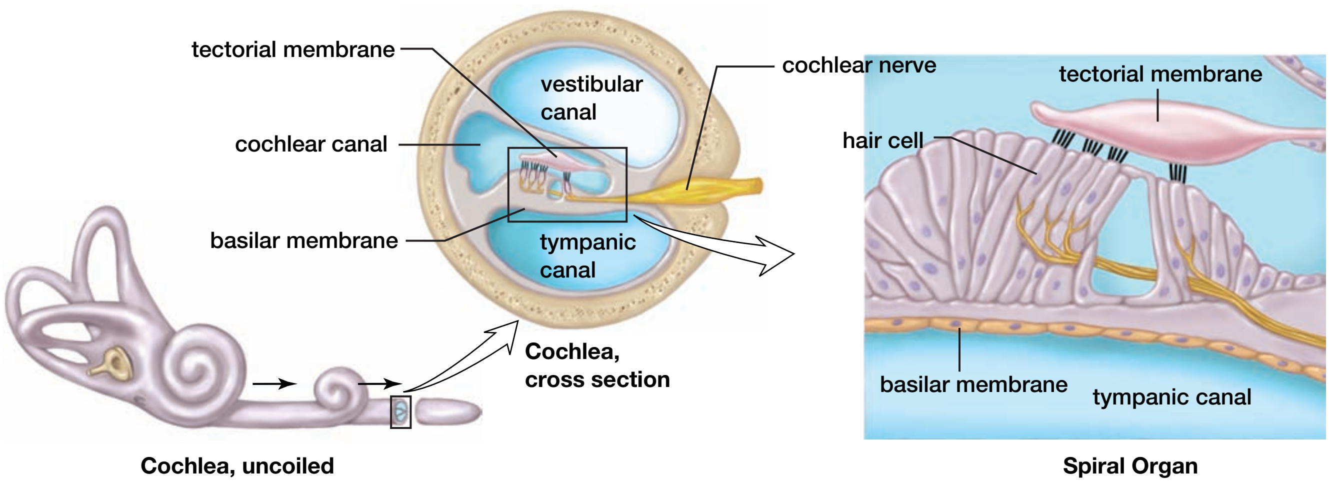


Figure 12.24 The cochlea and the spiral organ. Hearing occurs when pressure waves move from the vestibular canal to the tympanic canal, making the basilar membrane vibrate. This bends the hair cells between the basilar and tectorial membrane causing a nerve impulse to travel along the cochlear nerve to the brain, resulting in hearing.

SECTION REVIEW

1. How is sensory information important to you?
2. List three parts of your body that relay sensory information to the brain.
3. Draw a diagram of the eye. Use a coloured marker to highlight those parts of the eye that are part of the nervous system. Use a differently coloured marker to highlight the part of the eye that is mostly muscle. Use a third coloured marker to highlight the parts of the eye that are vascular (tissue supplied by blood).
4. Describe the path of light through each part of the eye, from the outermost structure to the retina.
5. Explain why there is a blind spot in one portion of the retina.
6. Identify those parts of the eye that are responsible for allowing light in.
7. Identify those parts of the eye that are responsible for keeping light out.
8. Draw a feedback loop showing how the eye responds to low levels of light.
9. Distinguish between rod cells and cone cells and identify the advantage of each.
10. List three disorders of the visual system.
11. If a tree fell in the forest and nobody was nearby, would it make a sound? Explain your reasoning.
12. Describe how your eye focusses on details of close images, such as the words on this page. Make a sketch that shows how the lens of the eye changes shape as you focus on near and distant objects.
13. If you wear eyeglasses or contact lenses, investigate the type and strength of the corrective lenses you are using. Find out if the prescription for each eye is the same or different. If possible (and if your teacher judges it appropriate to do so), compare the corrective lenses you use to those used by your classmates. What type of corrective lenses are most common in your class? Discuss and debate the pros and cons of wearing eyeglasses versus contact lenses.
14. A severe impact to the head can cause blindness. Understanding the mechanisms of sight involve study of brain activity as well as study of the eye. How can research into the neurology of vision be used to develop safe helmets?
15. Trace the path a pressure wave follows in order for you to hear a sound. Start at your pinna.

Chapter Summary

Briefly explain each of the following points.

- An essential function of the nervous system is maintaining homeostasis in the body. (12.1)
- The human nervous system is composed of two parts, the central nervous system and the peripheral nervous system. (12.1)
- The fight-or-flight response to dangerous situations illustrates how the sympathetic nervous system regulates many essential physiological processes in the body. (12.1)
- The nervous system is composed largely of neurons, which are specialized body cells. (12.1)
- Reflex arcs are constructed to produce quick responses to certain stimuli without input from the brain. (12.1)
- The medulla oblongata is the region of the brain that is the primary control centre of the autonomic nervous system. (12.1)
- The cerebrum is the centre of human consciousness. (12.1)
- A nerve impulse is actually composed of a wave of electrical depolarization that travels down the cell membrane of a neuron. (12.2)
- The polarity of cell membranes of neurons is a result of unequal concentrations of positive ions on either side of the membrane. (12.2)
- The action of neurotransmitters determines the direction of nerve impulses travelling in the nervous system. (12.2)
- The all-or-none principle determines whether a particular stimulus will initiate a new nerve impulse in a stimulated neuron. (12.2)
- Even though all nerve impulses are essentially the same, the brain can still distinguish between weak and strong sensory stimuli, and between stimuli originating from different types of sensory structures and locations in the body. (12.1, 12.2)
- Schwann cells can repair some types of damage to nerve tissue. (12.2)
- A healthy eye is capable of focussing on and forming sharp images of both near and distant objects. (12.3)
- In bright light, we see clearly in colour. In low light, our colour vision is diminished. (12.3)
- The human ear is a multifaceted sensory structure that is sensitive to sound waves of various frequencies and that helps us maintain equilibrium. (12.3)

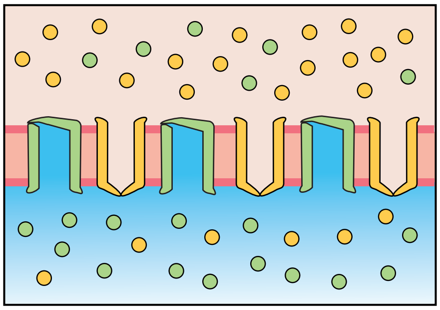
Language of Biology

Write a sentence using each of the following words or terms. Use any six terms in a concept map to show your understanding of how they are related.

- central nervous system
- peripheral nervous system
- grey matter
- white matter
- autonomic nervous system
- somatic nervous system
- sympathetic nervous system
- parasympathetic nervous system
- reflex
- neuron
- nerve
- reflex arc
- cell body
- dendrite
- axon
- medulla oblongata
- cerebellum
- thalamus
- hypothalamus
- cerebrum
- cerebral cortex
- corpus callosum
- resting potential
- neurotransmitters
- action potential
- refractory period
- myelin sheath
- Schwann cell
- node of Ranvier
- synapse
- presynaptic neuron
- postsynaptic neuron
- synaptic vesicle
- excitatory response
- inhibitory response
- cholinesterase
- acetylcholine
- noradrenaline
- glutamate
- GABA
- dopamine
- seratonin
- multiple sclerosis (MS)
- Alzheimer's disease
- Parkinson's disease
- meningitis
- sclera
- cornea
- conjunctiva
- choroid layer
- iris
- pupil
- lens
- retina
- rod
- cone
- accommodation
- rhodopsin
- fovea centralis
- cataract
- glaucoma
- myopia
- hyperopia
- astigmatism
- outer ear
- middle ear
- tympanic membrane
- round window
- oval window
- malleus
- incus
- stapes
- ossicles
- eustachian tube
- inner ear
- cochlea
- vestibule
- semicircular canals
- vestibular canal
- cochlear canal
- tympanic canal
- basilar membrane
- tectorial membrane
- spiral organ

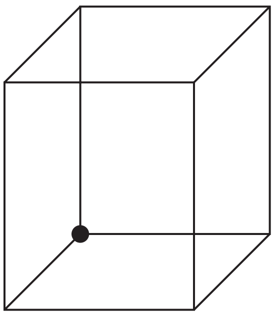
UNDERSTANDING CONCEPTS

1. Compare the structure and function of sensory neurons and motor neurons.
2. Describe the role of the Na^+/K^+ pump in restoring resting potential of a nerve cell membrane following a nerve impulse.
3. Explain how nerve impulses travel faster along axons covered by a myelin sheath than they do along non-myelinated neurons.
4. Compare how the parasympathetic and sympathetic nervous systems affect heart function.
5. Explain why the brain consumes more glucose and oxygen than any other body organ.
6. Is the medulla oblongata part of the somatic nervous system, part of the autonomic nervous system, or does it function as part of both systems? Explain your answer.
7. Some injuries to the body involve a severing of the spinal cord. Explain why all sensations and control of motor functions are lost in the parts of the body below the location of the injury.
8. The diagram on the right illustrates the distribution of sodium and potassium ions on either side of a nerve cell membrane at rest. Reproduce this diagram in your notebook and label the following: Na^+, K^+, gated Na^+ channel, gated K^+ channel, nerve cell membrane, outside neuron, inside neuron.
9. Describe how the nervous system functions when you perform the following activities.
   (a) Your hand grasps an apple and raises it to your mouth.
   (b) You take a bite out of the apple and swallow it.
10. Explain how light energy is transformed into nerve impulses in the retina.
11. Describe how your eyes adjust when you move from a brightly lit environment to a dimly lit area.
12. There are many forms of epilepsy, a disease in which spontaneous electrical discharges occur in the brain. Different types of epileptic seizures produce different symptoms, including unusual colours, sounds, or other types of sensations. What do these variations in symptoms tell you about the parts of the brain affected by each type of epilepsy?



INQUIRY

13. Observe the optical illusion in the following figure. Draw what you see. Compare your observations to those of others in your class. What do these kinds of illusions tell us about how our brains interpret visual stimuli? Do people have identical or different perceptions of the world around them? Discuss possible factors that influence a person's perception of a particular experience.



14. Design an experiment to test if caffeine has an effect on a person's ability to perceive different colours of light. Make a chart to record your data. Propose a control for your experiment. What variables will you include in your control? What kind of data would you expect to find? Justify your response.
15. Acupuncture is increasingly being used as a drug-free therapy for pain.
   (a) How could you determine the effect of acupuncture on alertness?
   (b) What kind of drugs would be inappropriate to take while under acupuncture therapy? Explain.
16. A breathalizer test can be used to determine how much alcohol is in a person's body. This test, however, gives no information about a person's neurological function. Design two

tests to determine if alcohol affects the somatic system or the autonomic nervous system.

17. The motor neuron produces an action potential or impulse as an all-or-none response to stimulus. Muscles respond to this impulse, and contract as an all-or-nothing action. The presynaptic axon is highly branched at the neuro-muscular synapse. If some of the presynaptic branches are damaged, will the muscle contract? Describe a procedure that would help you to answer this question.

COMMUNICATING

18. **(a)** Use wire to make a model of a neuron. Complete the circuit using dry cells, a switch, and a light bulb.
 (b) Record your circuit in your notebook. If the wire is a neuron, what do the other parts of the circuit represent?
 (c) Identify one neuronal disorder. Model this disorder using your circuit.

19. Find pictures of the brain of a fish, a turtle, and a bird. Make rough diagrams showing the major parts of the brain for each organism. What differences in proportion of the brain parts do you see among the organisms. Suggest an explanation for the differences you see.

20. Medication can be used to treat many disorders, including mood disorders. What is the impact of mood-disorder medication on systems in the body other than the nervous system? Use Internet resources to research a specific mood disorder. Make a chart to list the advantages and disadvantages of mood-disorder therapy.

21. A rarely performed treatment for epilepsy involves severing of the corpus callosum. This surgical procedure stops the flow of information from one side of the brain to the other. A more common therapy for epilepsy involves the use of drugs to block certain nerve impulses. Use diagrams to show how each method can limit the transmission of information in the brain.

22. Imagine you have been hired as a fundraiser for a neurological disorders research centre. Create an informational pamphlet that could be distributed to raise awareness of a particular one neurological disorder. Include information on symptoms, prevention, treatment, and current research.

MAKING CONNECTIONS

23. Both alcohol and caffeine affect the neurological system. Although alcohol is a controlled substance, caffeine is not. Develop an argument to make caffeine (coffee and other caffeinated beverages) a controlled substance.

24. Acupuncture and acupressure can be effective treatments to reduce pain. Traditional acupuncture involves the use of needles. Acupressure involves the use of pressure at specific points on the body. Both acupuncture and acupressure are not as well accepted as prescription therapy. Identify points to support more research into acupuncture and acupressure therapy. Identify cautions to further research into each therapy.

25. Some people increase their risk for stroke by eating a poor diet, smoking, and having little or no exercise. Develop a plan to educate people about maintaining a healthy lifestyle. How might a healthy lifestyle contribute to a healthy nervous system?

26. Your class has raised $200 to donate to charity and has narrowed the choice down to supporting Alzheimer research, Multiple Sclerosis research, or research into alcoholism. You and two classmates will debate the merits of donating the money to each group. After the debate the class will select which charity to support. Select one group and prepare for the class debate.

27. Prepare arguments for and against the idea of medically intervening to improve the hearing of a child with conduction deafness. Assume that the child's parents are also hearing-impaired.

28. What can you do to prevent damage to your hearing from extremely loud or persistent noises in your environment? Is the school presently doing enough to protect student hearing? What types of policies could be adopted to help protect students from hearing loss while attending noisy school functions, such as school dances?