20 The Body's Control Mechanisms

CHAPTER 20

Chapter Outline

Key Concepts	Applications
Understand the ionic events that take place at the nerve cell membrane.	• Describe how nerve cells carry information from one place to another.
Describe the events that take place at the synapse.	• Recognize that many nervous disorders are caused by incorrect amounts of specific neurotransmitters. • Understand why an impulse can go only in one direction across a synapse.
Understand that specific functions are located in particular parts of the brain.	• Understand why damage to a particular part of the brain affects a specific sensory or motor ability. • Recognize that different portions of the brain have different kinds of neurotransmitters.
Understand that cardiac, skeletal, and smooth muscle have different abilities and respond to stimuli differently.	• Understand why some muscles behave differently than others.
Understand that hormones produced by endocrine glands function by attaching to receptor sites on cells.	• Recognize that a specific hormone will only affect certain tissues with the correct receptors. • Recognize that hormones can have long-term effects such as growth.
Understand that sense organs respond to changes in the environment and are connected to nerve cells.	• Appreciate that each kind of sense organ responds to a specific change in its surroundings. • Explain why nerve damage can impair sensory ability.

20.1 Integration of Input

A large, multicellular organism, which consists of many different kinds of systems, must have some way of integrating various functions so that it can survive. The various systems must be coordinated to maintain a reasonably constant internal environment. Recall from chapter 18 that this condition of maintaining a constant internal environment is called **homeostasis.** To allow for homeostasis there must be constant monitoring and modification of the way specific parts of the organism function. If the organism does not respond appropriately, it will die. There are many kinds of sense organs located within organs and on the surfaces that respond to specific kinds of stimuli. A **stimulus** is any change in the environment that the organism can detect. Some stimuli, like light or sound, are typically external to the organism; others, like the pain generated by an infection, are internal. The reaction of the organism to a stimulus is known as a **response** (figure 20.1).

The nervous and endocrine systems are the major systems of the body that integrate stimuli and generate appropriate responses necessary to maintain homeostasis. The **nervous system** consists of a network of cells with fibrous extensions that carry information along very specific pathways from one part of the body to another. The **endocrine system** consists of a number of glands that communicate with one another and with other tissues through chemicals distributed throughout the organism. **Glands** are organs that manufacture specific molecules that are either secreted into surrounding tissue, where they are picked up by the circulatory system, or are secreted through ducts into the cavity of an organ or to the body surface. **Endocrine glands** have no ducts and secrete their products into the circulatory system. The molecules produced by endocrine glands are called hormones. A **hormone** is a specific molecule released by one organ that is transported to another organ where it triggers a change in the other organ's activity. Other glands, such as the digestive glands and sweat glands, empty their contents through ducts. These kinds of glands are called **exocrine glands.**

Although the functions of the nervous and endocrine systems can overlap and be interrelated, these two systems have quite different methods of action. The nervous system functions very much like a computer. A message is sent along established pathways from a specific initiating point to a specific end point, and the transmission is very rapid. The endocrine system functions in a manner analogous to a radio broadcast system. Radio stations send their signals in all directions, but only those radio receivers that are tuned to the correct frequency can receive the message. Messenger molecules (hormones) are typically distributed throughout the body by the circulatory system, but only those cells that have the proper receptor sites can receive and respond to the molecules.

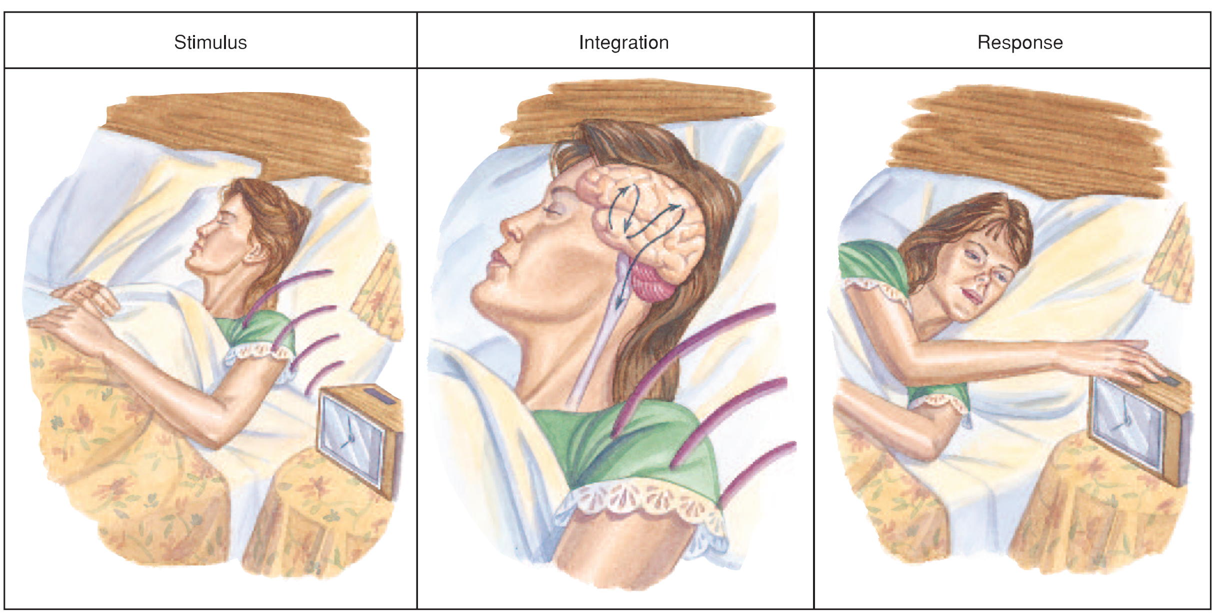


Figure 20.1

Stimulus and Response
A stimulus is any detectable change in the surroundings of an organism. When an organism receives a stimulus, it processes the information and may ignore the stimulus or generate a response to it.

The Structure of the Nervous System

The basic unit of the nervous system is a specialized cell called a **neuron,** or **nerve cell.** A typical neuron consists of a central body called the **soma,** or *cell body,* which contains the nucleus and several long, protoplasmic extensions called nerve fibers. There are two kinds of fibers: **axons,** which carry information away from the cell body, and **dendrites,** which carry information toward the cell body (figure 20.2). Most nerve cells have one axon and several dendrites.

Neurons are arranged into two major systems. The **central nervous system,** which consists of the brain and spinal cord, is surrounded by the skull and the vertebrae of the spinal column. It receives input from sense organs, interprets information, and generates responses. The **peripheral nervous system** is located outside the skull and spinal column and consists of bundles of long axons and dendrites called **nerves.** There are two different sets of neurons in the peripheral nervous system. **Motor neurons** carry messages from the central nervous system to muscles and glands, and **sensory neurons** carry input from sense organs to the central nervous system. Motor neurons typically have one long axon that runs from the spinal cord to a muscle or gland; sensory neurons have long dendrites that carry input from the sense organs to the central nervous system.

The Nature of the Nerve Impulse

Because most nerve cells have long fibrous extensions, it is possible for information to be passed along the nerve cell from one end to the other. The message that travels along a neuron is known as a **nerve impulse.** A nerve impulse is not like an electric current but involves a specific sequence of chemical events involving activities at the cell membrane.

Because all cell membranes are differentially permeable, it is difficult for some ions to pass through the membrane and the combination of ions inside the membrane is different from that on the outside. Cell membranes also contain proteins that actively transport specific ions from one side of the membrane to the other. Active transport involves the cell's use of adenosine triphosphate (ATP) to move materials from one side of the cell membrane to the other. Because ATP is required this is an ability that cells lose when they die. One of the ions that is actively transported from cells is the sodium ion (Na^+). At the same time sodium ions are being transported out of cells, potassium ions (K^+) are being transported into the normal resting cells. However, there are more sodium ions transported out than potassium ions transported in.

Because a normal resting cell has more positively charged Na^+ ions on the outside of the cell than on the inside, a small but measurable voltage exists across the membrane of the cell. (**Voltage** is a measure of the electrical charge difference that exists between two points or objects.) The voltage difference between the inside and outside of a cell membrane is about 70 millivolts (0.07 volt). The two sides of the cell membrane are, therefore, polarized in the same sense that a battery is polarized, with a positive and negative pole. A resting neuron has its positive pole on the outside of the cell membrane and its negative pole on the inside of the membrane (figure 20.3).

When a cell is stimulated at a specific point on the cell membrane, the cell membrane changes its permeability and lets sodium ions (Na^+) pass through it from the outside to

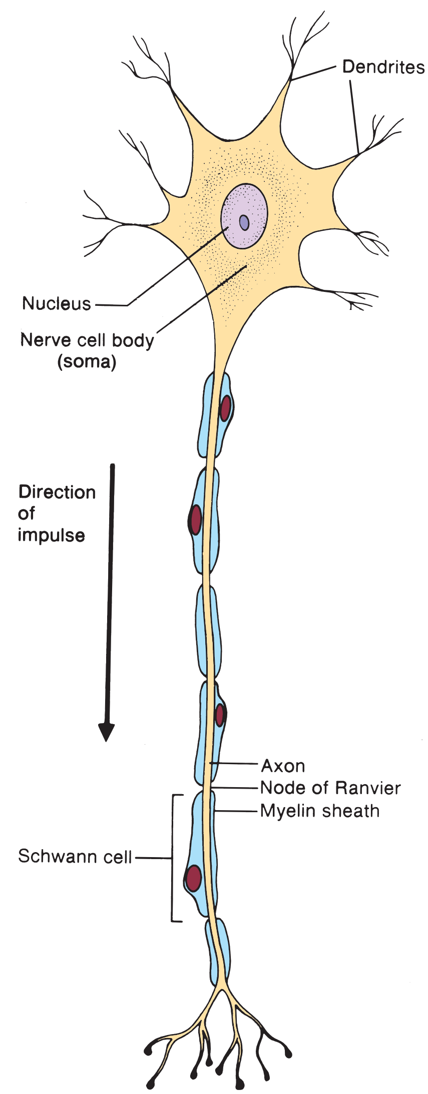
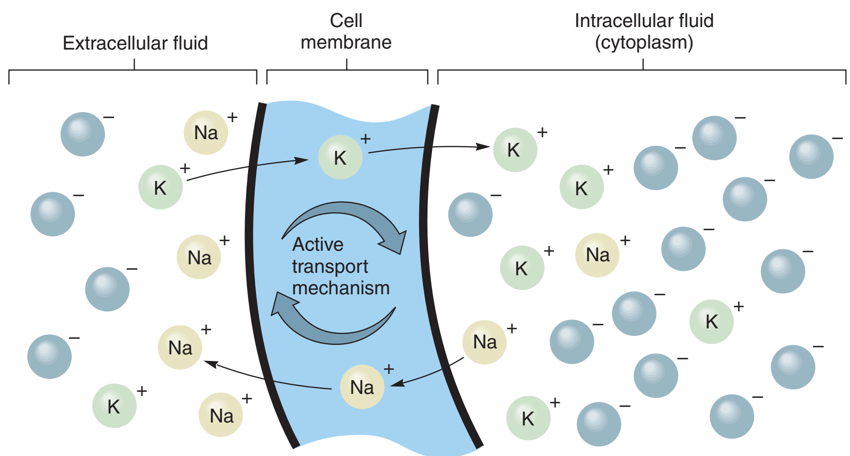


Figure 20.2

The Structure of a Nerve Cell
Nerve cells consist of a nerve cell body that contains the nucleus and several fibrous extensions. The shorter, more numerous fibers that carry impulses to the nerve cell body are dendrites. The long fiber that carries the impulse away from the cell body is the axon.

Figure 20.3

The Polarization of Cell Membranes
All cells, including nerve cells, have an active transport mechanism that pumps Na^+ out of cells and simultaneously pumps K^+ into them. The end result is that there are more Na^+ ions outside the cell and more K^+ ions inside the cell. In addition, negative ions such as Cl^- are more numerous inside the cell. Consequently, the outside of the cell is positive (+) compared to the inside, which is negative (–).



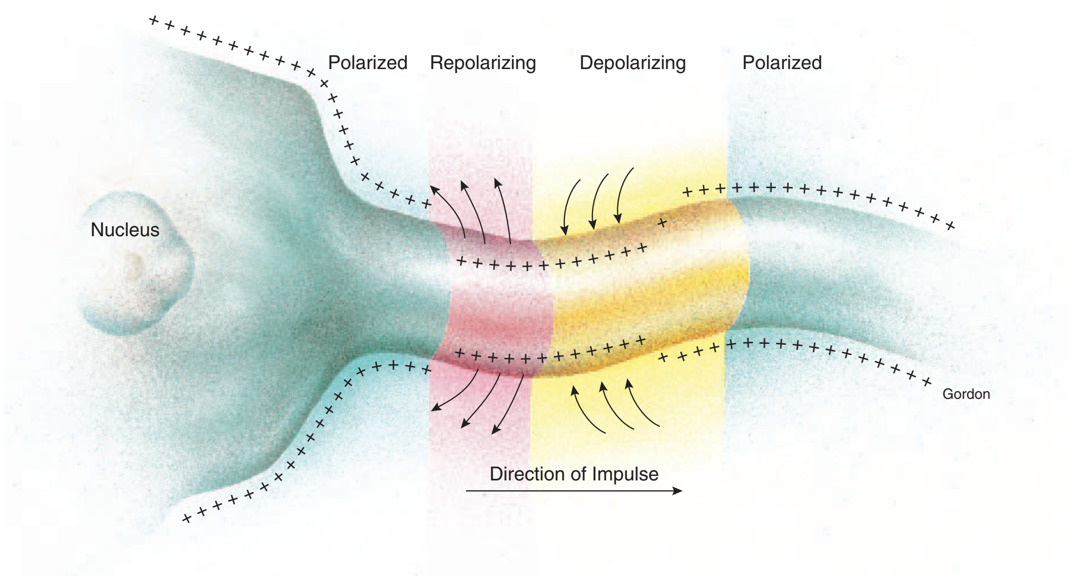


Figure 20.4

A Nerve Impulse
When a nerve cell is stimulated, a small portion of the cell membrane depolarizes as Na^+ flows into the cell through the membrane. This encourages the depolarization of an adjacent portion of the membrane, and it depolarizes a short time later. In this way a wave of depolarization passes down the length of the nerve cell. Shortly after a portion of the membrane is depolarized, the ionic balance is re-established. It is repolarized and ready to be stimulated again.

the inside. The membrane is thus **depolarized;** it loses its difference in charge as sodium ions diffuse into the cell from the outside. Sodium ions diffuse into the cell because, initially, they are in greater concentration outside the cell than inside. When the membrane becomes more permeable, they are able to diffuse into the cell, toward the area of lower concentration. The depolarization of one point on the cell membrane causes the adjacent portion of the cell membrane to change its permeability as well, and it also depolarizes. Thus a wave of depolarization passes along the length of the neuron from one end to the other (figure 20.4). The depolarization and passage of an impulse along any portion of the neuron is a momentary event. As soon as a section of the membrane has been depolarized, potassium ions diffuse out of the cell. This re-establishes the original polarized state and the membrane is said to be *repolarized*. Subsequently, the

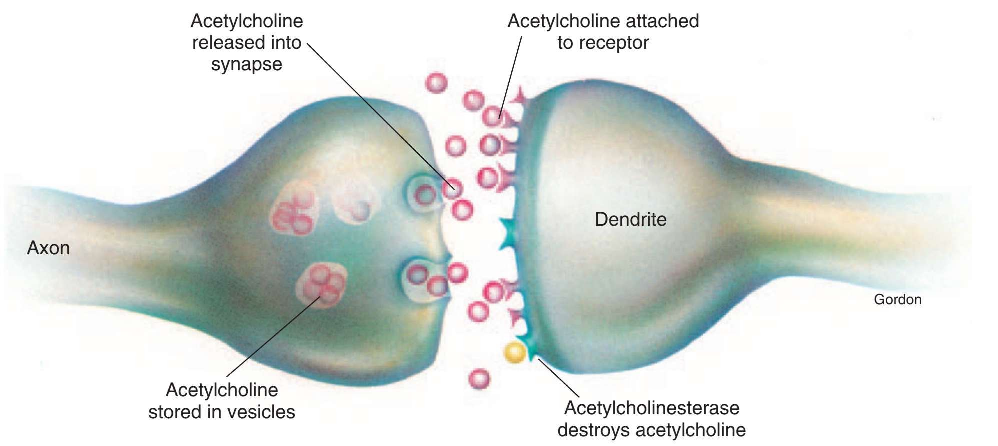


Figure 20.5

Events at the Synapse
When a nerve impulse reaches the end of an axon, it releases a neurotransmitter into the synapse. In this illustration, the neurotransmitter is acetylcholine. When acetylcholine is released into the synapse, acetylcholine molecules diffuse across the synapse and bind to receptors on the dendrite, initiating an impulse in the next neuron. Acetylcholinesterase is an enzyme that destroys acetylcholine, preventing continuous stimulation of the dendrite.

continuous active transport of sodium ions out of the cell and potassium ions into the cell restores the original concentration of ions on both sides of the cell membrane. When the nerve impulse reaches the end of the axon, it stimulates the release of a molecule that stimulates depolarization of the next neuron in the chain.

Activities at the Synapse

Between the fibers of adjacent neurons in a chain is a space called the **synapse.** Many chemical events occur in the synapse that are important in the function of the nervous system. When a neuron is stimulated, an impulse passes along its length from one end to the other. When the impulse reaches a synapse, a molecule called a **neurotransmitter** is released into the synapse from the axon. It diffuses across the synapse and binds to specific receptor sites on the dendrite of the next neuron. When enough neurotransmitter molecules have been bound to the second neuron, an impulse is initiated in it as well. Several kinds of neurotransmitters are produced by specific neurons. These include dopamine, epinephrine, acetylcholine, and several other molecules. The first neurotransmitter identified was **acetylcholine.** Acetylcholine molecules are manufactured in the soma and migrate down the axon where they are stored until needed (figure 20.5).

As long as a neurotransmitter is bound to its receptor it continues to stimulate the nerve cell. Thus if acetylcholine continues to occupy receptors, the neuron continues to be stimulated again and again. An enzyme called **acetylcholinesterase** destroys acetylcholine and prevents this from happening. (The breakdown products of the acetylcholine can be used to remanufacture new acetylcholine molecules.) The destruction of acetylcholine allows the second neuron in the chain to return to normal. Thus it will be ready to accept another burst of acetylcholine from the first neuron a short time later. Neurons must also constantly manufacture new acetylcholine molecules or they will exhaust their supply and be unable to conduct an impulse across a synapse.

Certain drugs, such as curare and strychnine, interfere with activities at the synapse. Curare blocks the synapse and causes paralysis, whereas strychnine causes nerve cells to be continually stimulated. Many of the modern insecticides are also nerve poisons and are therefore quite hazardous.

Because of the way the synapse works, impulses can go in only one direction: Only axons secrete acetylcholine, and only dendrites have receptors. This explains why there are sensory and motor neurons to carry messages to and from the central nervous system.

The nervous system is organized in a fashion similar to a computer. Information from various input devices (sense organs) is delivered to the central processing unit (brain) by way of wires (sensory nerves). The information is interpreted in the central processing unit. Eventually messages can be sent by way of cables (motor nerves) to drive external machinery (muscles and glands). This concept allows us to understand how the functions of various portions of the nervous system have been identified. It is possible to electrically stimulate specific portions of the nervous system or to damage certain parts of the nervous system in experimental animals and determine the functions of different parts of the brain and other parts of the nervous system. For example, because peripheral nerves carry bundles of both sensory and motor fibers, damage to a nerve may result in both a lack of feeling because sensory messages cannot get through and an inability to move because the motor nerves are damaged.

The Organization of the Central Nervous System

Major functions of specific portions of the brain have been identified. Certain parts of the brain are involved in controlling fundamental functions such as breathing and heart rate. Others are involved in generating emotions, whereas others decode sensory input, or coordinate motor activity. The human brain also has considerable capacity to store information and create new responses to environmental stimuli.

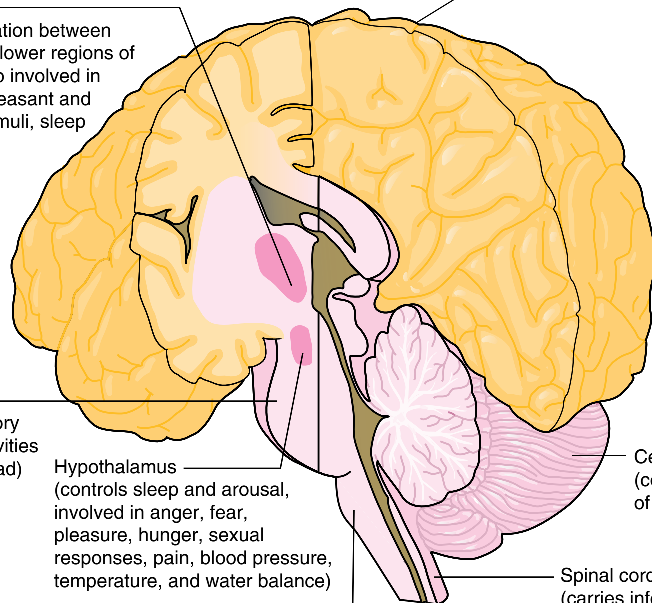


Figure 20.6

Functions of the More Primitive Brain Regions
The brain is organized into several levels of function. The more primitive regions of the brain connected to the spinal cord monitor and manage many essential functions automatically. Some of the major functions are shown in this drawing.

The brain consists of several regions each of which has specific functions. The functions of the brain can be roughly divided into three major levels: automatic activities, basic decision making and emotions, and thinking and reasoning. If we begin with the spinal cord and work our way forward we will proceed from the more fundamental, automatic activities of the brain to the more complex thinking portions of the brain. The **spinal cord** is a collection of nerve fibers surrounded by the vertebrae that conveys information to and from the brain. At the base of the brain where the spinal cord enters the skull is a portion of the brain known as the **medulla oblongata.** This region of the brain controls fundamental activities such as blood pressure, breathing, and heart rate. Most of the fibers of the spinal cord cross from one side of the body to the other in the medulla oblongata. This is why the left side of the brain affects the right side of the body.

The **cerebellum** is a large bulge at the base of the brain that is connected to the medulla oblongata. The primary function of the cerebellum is coordination of muscle activity. It receives information from sense organs such as the portions of the ear that involve balance, the eyes, and pressure sensors in muscles and tendons. This information is used to make adjustments to the strength and order of contraction of muscles necessary to move in a coordinated fashion.

The **pons** is connected to the anterior end of the medulla oblongata. It also connects to the cerebellum and to higher levels of the brain. It is involved in controlling many sensory and motor functions of the sense organs of the head and face.

If we continue forward the pons is connected to a portion of the brain that forms two bulblike structures that ultimately connect to the cerebrum. Although these portions of the brain still control many automatic activities, there are many activities that involve much more integration of information and some level of "decision making" occurs in this region. The primary regions are the **thalamus** and the **hypothalamus.** The thalamus relays information between the cerebrum and lower portions of the brain. It also provides some level of awareness in that it determines pleasant and unpleasant stimuli and is involved in sleep and arousal. The hypothalamus is also involved in sleep and arousal and is important in emotions such as anger, fear, pleasure, hunger, sexual response, and pain. Several other more automatic functions are regulated in this region, such as body temperature, blood pressure, and water balance. The hypothalamus also is connected to the pituitary gland and influences the manufacture and release of its hormones. Figure 20.6 shows the relationship of the various more primitive parts of the brain.

The **cerebrum** is the largest portion of the brain in humans. The two hemispheres of the cerebrum cover all other portions of the brain except the cerebellum. The cerebrum is the thinking part of the brain. The surface of the cerebrum has been extensively mapped so that we know the location of many functions. Abilities such as memory, language, control of movement, interpretation of sensory input, and thought are associated with specific areas of the cerebrum. Figure 20.7 shows a diagram of the cerebrum and the locations of specific functions.

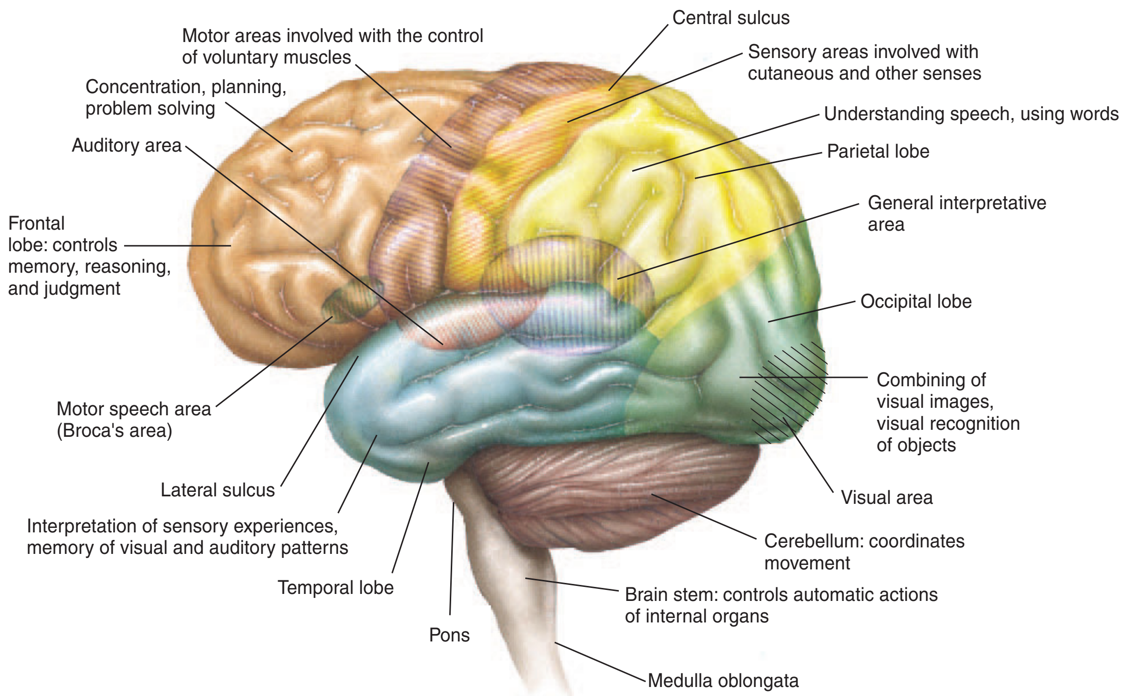


Figure 20.7

Specialized Areas of the Cerebrum
Each portion of the cerebrum has particular functions. This drawing identifies the general regions and their associated functions.

The function of the brain is not determined by structure alone. Many parts of the brain have specialized neurons that produce specific neurotransmitter molecules used only to stimulate specific sensitive cells that have the proper receptor sites. As we learn more about the functioning of the brain, we are finding more kinds of specialized neurotransmitter molecules. Their discovery allows for the treatment of many types of mental and emotional diseases. Manipulating these neurotransmitter molecules can help correct inappropriate functioning of the brain. However, one should not assume that we understand the brain. We are still at an early stage in our search to comprehend this organ that sets us apart from other animals (How Science Works 20.1).

Endocrine System Function

As mentioned previously, the endocrine system is basically a broadcasting system in which glands secrete messenger molecules, called hormones, that are distributed throughout the body by the circulatory system (figure 20.8). However, each kind of hormone affects only certain cells. The specific cells that a particular hormone affects are often called **target cells.** The hormones target certain cells because the cells have specific receptor molecules on their surfaces to which specific hormones attach. The cells that receive the messages typically respond in one of three ways: (1) Some cells release products that have been previously manufactured, (2) other cells are stimulated to synthesize molecules or to begin metabolic activities, and (3) some are stimulated to divide and grow.

These different kinds of responses mean that some endocrine responses are relatively rapid, whereas others are very slow. For example, the release of the hormones **epinephrine** and **norepinephrine*** from the adrenal medulla, located near the kidney, causes a rapid change in the behavior of an organism. The heart rate increases, blood pressure rises, blood is shunted to muscles, and the breathing rate increases. You have certainly experienced this reaction many times in your lifetime, such as when you nearly had an automobile accident or slipped and nearly fell.

Another hormone, called **antidiuretic hormone (ADH),** acts more slowly. It is released from the posterior pituitary gland at the base of the brain and regulates the rate at which the body loses water through the kidneys. It does this by

*Epinephrine and norepinephrine were formerly called adrenalin and noradrenalin.

HOW SCIENCE WORKS 20.1

How Do We Know What the Brain Does?

Today we know a great deal about the function of the brain, although there is still much more to learn. Certain functions have been identified as residing in specific portions of the brain as a result of many different kinds of studies over the last century. For example, persons who have had specific portions of their brains altered by damage from accidents or strokes have been studied. Their changes in behavior or the way they perceive things can be directly correlated to the portion of the brain that was damaged. During surgeries that require that the brain be exposed, a local anesthetic can be given and the patient can be conscious while the surgery is taking place. (The brain perceives pain from pain receptors throughout the body, however, because the brain does not have many pain receptors within it, touching or manipulating the brain does not cause pain to be perceived.) Specific portions of the brain can be stimulated and the patient can be asked to describe the sensations they have or their motor functions can be observed.

Many kinds of experiments have also been done with animals in which specific portions of the brain are destroyed and the changes in the behavior of an animal are noted. Electrodes have also been inserted into the brains of animals to stimulate certain portions of the brain.

More recently, techniques have been developed to make observations of changes in electrical activity of specific portions of the brain, without requiring electrodes or other invasive procedures. This allows researchers to present stimuli to human subjects and determine which parts of the brain alter their activity. In addition to localizing the part of the brain that responds, it is also possible to determine what parts of a complex stimulus are most important in changing brain activity. Among the new information gained by these techniques are that languages learned by adults are processed in different places in the brain than the languages they learned as children and that the brain has a built-in mechanism for recognizing unexpected words or musical notes.

Although we have learned much about the brain, there is still much to learn. Current experiments are seeking ways to regenerate nerve cells that have been damaged. A better understanding of the chemical events that take place in the brain would enable us to cure many kinds of debilitating mental illnesses.

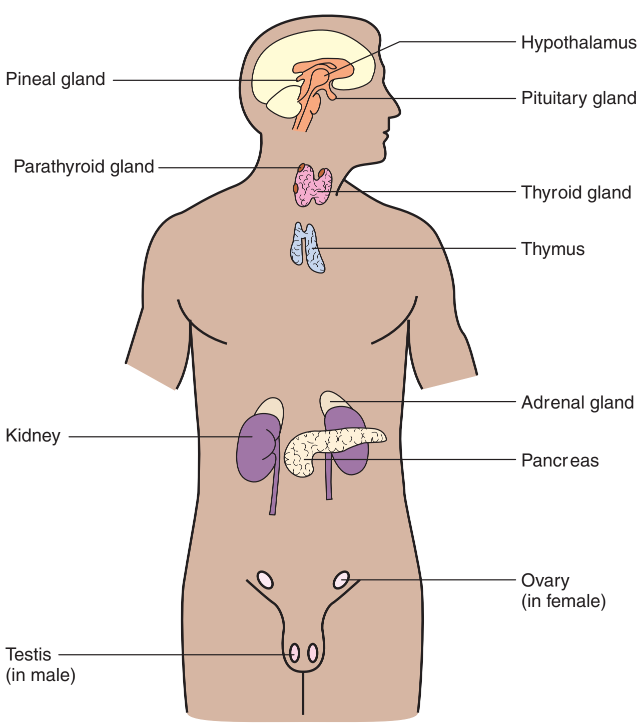


Figure 20.8

Endocrine Glands
The endocrine glands are located at various locations within the body and cause their effects by secreting hormones.

encouraging the reabsorption of water from their collecting ducts (see chapter 18). The effects of this hormone can be noticed in a matter of minutes to hours. Insulin is another hormone whose effects are quite rapid. Insulin is produced by the pancreas, located near the stomach, and stimulates cells—particularly muscle, liver, and fat cells—to take up glucose from the blood. After a high carbohydrate meal, the level of glucose in the blood begins to rise, stimulating the pancreas to release insulin. The increased insulin causes glucose levels to fall as the sugar is taken up by cells. People with diabetes have insufficient or improperly acting insulin or lack the receptors to respond to the insulin, and therefore have difficulty regulating glucose levels in their blood.

The responses that result from the growth of cells may take weeks or years to occur. For example, **growth-stimulating hormone** (**GSH**) is produced by the anterior pituitary gland over a period of years and results in typical human growth. After sexual maturity, the amount of this hormone generally drops to very low levels, and body growth stops. Sexual development is also largely the result of the growth of specific tissues and organs. The male sex hormone **testosterone,** produced by the testes, causes the growth of male sex organs and a change to the adult body form. The female counterpart, **estrogen,** results in the development of female sex organs and body form. In all of these cases, it is the release of hormones over long periods, continually stimulating the growth of sensitive tissues, that results in a normal developmental pattern. The absence or inhibition of any of these hormones early in life changes the normal growth process.

Glands within the endocrine system typically interact with one another and control production of hormones. One common control mechanism is called *negative-feedback control*. In **negative-feedback control** the increased amount of one hormone interferes with the production of a different hormone in the chain of events. The production of **thyroxine** and **triiodothyronine** by the thyroid gland exemplifies this kind of control. The production of these two hormones is stimulated by increased production of a hormone from the anterior pituitary called **thyroid-stimulating hormone (TSH).** The control lies in the quantity of the hormone produced. When the anterior pituitary produces high levels of thyroid-stimulating hormone, the thyroid is stimulated to grow and secrete more thyroxine and triiodothyronine. But when increased amounts of thyroxine and triiodothyronine are produced, these hormones have a negative effect on the pituitary so that it decreases its production of thyroid-stimulating hormone, leading to reduced production of thyroxine and triiodothyronine. If the amount of the thyroid hormones falls too low, the pituitary is no longer inhibited and releases additional thyroid-stimulating hormone. As a result of the interaction of these hormones, their concentrations are maintained within certain limits (figure 20.9).

It is possible for the nervous and endocrine systems to interact (How Science Works 20.2). The pituitary gland is located at the base of the brain and is divided into two parts. The posterior pituitary is directly connected to the brain and develops from nerve tissue. The other part, the anterior pituitary, is produced from the lining of the roof of the mouth in early fetal development. Certain pituitary hormones are produced in the brain and transported down axons to the posterior pituitary where they are stored before being released. The anterior pituitary also receives a continuous input of messenger molecules from the brain, but these are delivered by way of a special set of blood vessels that pick up hormones produced by the hypothalamus of the brain and deliver them to the anterior pituitary.

The pituitary gland produces a variety of hormones that are responsible for causing other endocrine glands, such as the thyroid, ovaries and testes, and adrenals, to secrete their hormones. Pituitary hormones also influence milk production, skin pigmentation, body growth, mineral regulation, and blood glucose levels (figure 20.10).

Because the pituitary is constantly receiving information from the hypothalamus of the brain, many kinds of sensory stimuli to the body can affect the functioning of the endocrine system. One example is the way in which the nervous system and endocrine system interact to influence the menstrual cycle. At least three different hormones are involved in the cycle of changes that affect the ovary and the lining of the uterus (see chapter 21 for details). It is well documented that stress caused by tension or worry can interfere with the normal cycle of hormones and delay or stop menstrual cycles. In addition, young women living in groups, such as in college dormitories, often find that their menstrual cycles become synchronized. Although the exact mechanism involved in this phenomenon is unknown, it is suspected that input from the nervous system causes this synchronization. (Odors and sympathetic feelings have been suggested as causes.)

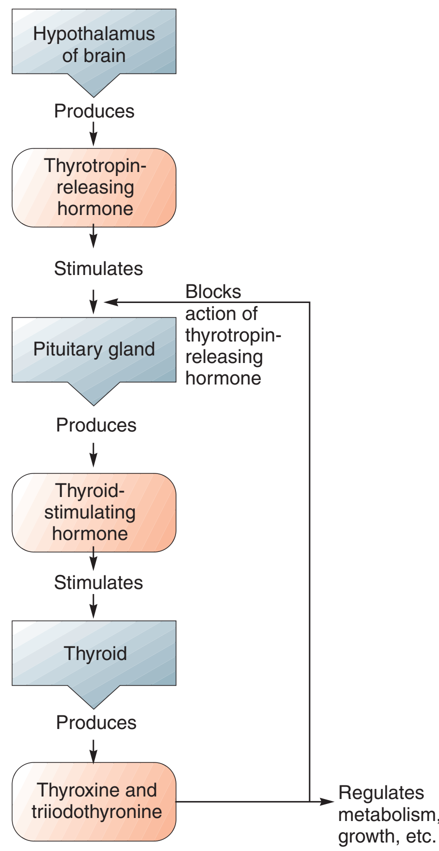


Figure 20.9

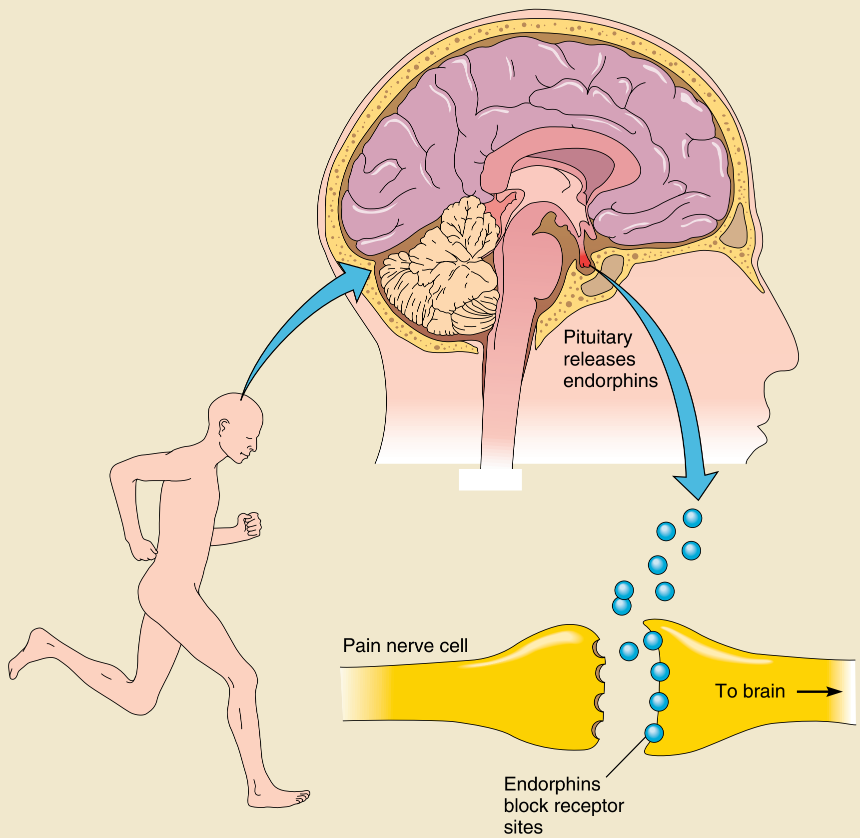
Negative-Feedback Control of Thyroid Hormone Levels
The levels of thyroxine and triiodothyronine increase and decrease in response to the amount of thyroid-stimulating hormone present. Increased levels of the thyroid hormones cause the pituitary to not respond to thyrotropin-releasing hormone, and the production of thyroid-stimulating hormone falls, so that eventually the thyroid hormone levels decrease. This is an example of negative-feedback control.

In many animals, the changing length of the day causes hormonal changes related to reproduction. In the spring, birds respond to lengthening days and begin to produce hormones that gear up their reproductive systems for the summer breeding season. The pineal body, a portion of the brain, serves as the receiver of light stimuli and changes the amounts of hormones secreted by the pituitary, resulting in changes in the levels of reproductive hormones. These hormonal changes modify the behavior of birds. Courtship, mating, and nest-building behaviors increase in intensity.

HOW SCIENCE WORKS 20.2

The Endorphins: Natural Pain Killers

The pituitary gland and brain produce a group of small molecules that act as pain suppressors. These are the *endorphins*. It is thought that these molecules are released when excessive pain or stress occurs in the body. They attach to the same receptor molecules of brain cells associated with the feeling of pain (see figure). The endorphins work on the brain in the same manner as morphine and opiate drugs. Once attached, the feeling of pain goes away, and a euphoric feeling takes over. Long-distance runners and other athletes talk about "feeling good" once they have "reached their stride," get their "second wind," or experience a "runner's high." These responses may be due to an increase in endorphin production. It is thought that endorphins are also released by mild electric stimulation or the use of acupuncture needles.



Therefore, it appears that a change in hormone level is affecting the behavior of the animal; the endocrine system is influencing the nervous system (figure 20.11).

It has been known for centuries that changes in the levels of sex hormones cause changes in the behavior of animals. Castration (removal of the testes) of male domesticated animals, such as cattle, horses, and pigs, is sometimes done in part to reduce their aggressive behavior and make them easier to control. In humans, the use of anabolic steroids to increase muscle mass is known to cause behavioral changes and "moodiness."

Although we still tend to think of the nervous and endocrine systems as being separate and different, it is becoming clear that they are interconnected. As we learn more about the molecules produced in the brain, it is becoming clear that the brain produces many molecules that act as hormones. Some of these molecules affect adjacent parts of the brain, others affect the pituitary, and still others may have effects on more distant organs. In any case, these two systems cooperate to bring about appropriate responses to environmental challenges. The nervous system is specialized for receiving and sending short-term messages, whereas

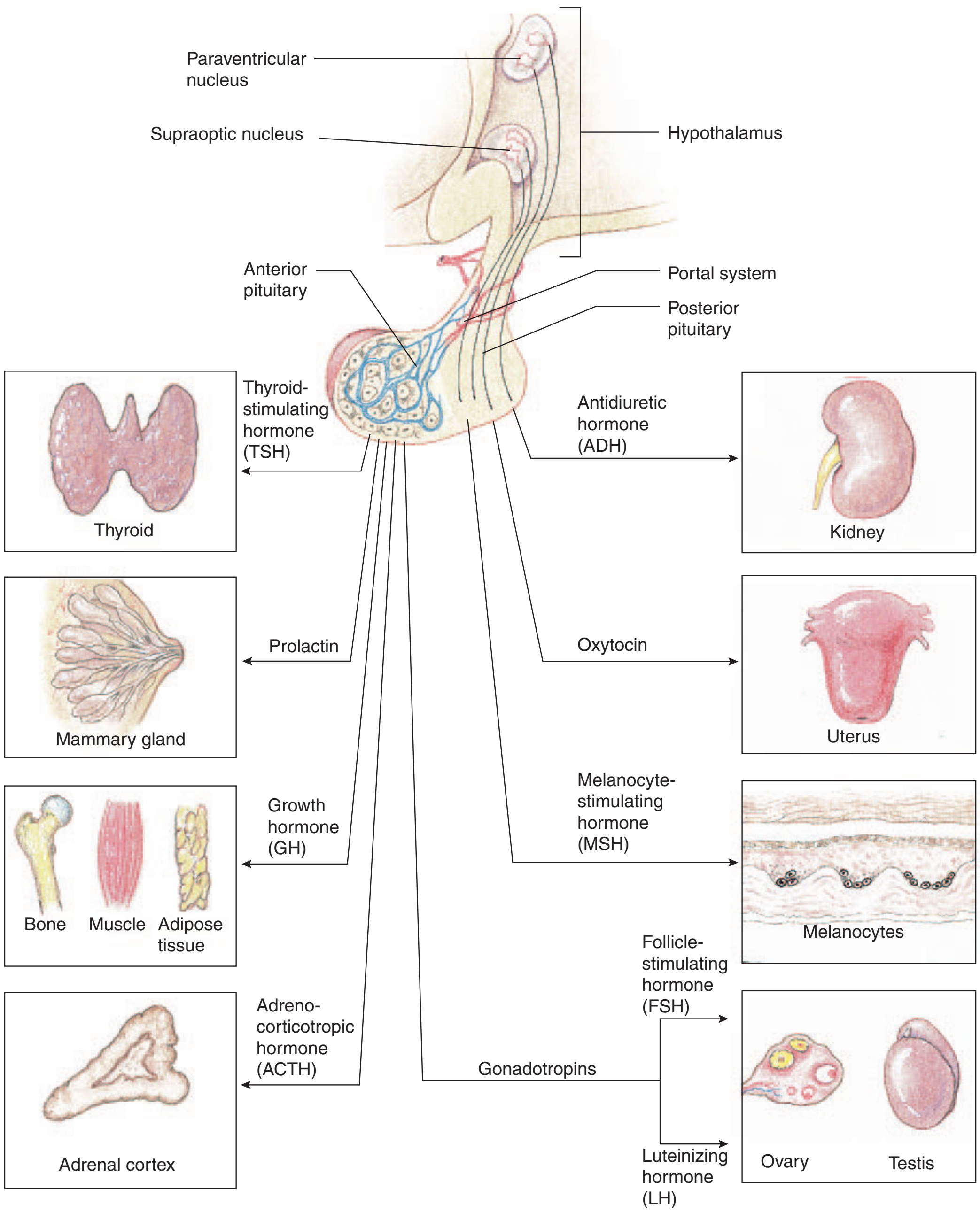


Figure 20.10

Hormones of the Pituitary

The anterior pituitary gland produces several hormones that regulate growth and the secretions of target tissues. The posterior pituitary produces hormones that change the behavior of the kidney and uterus but do not influence the growth of these organs.

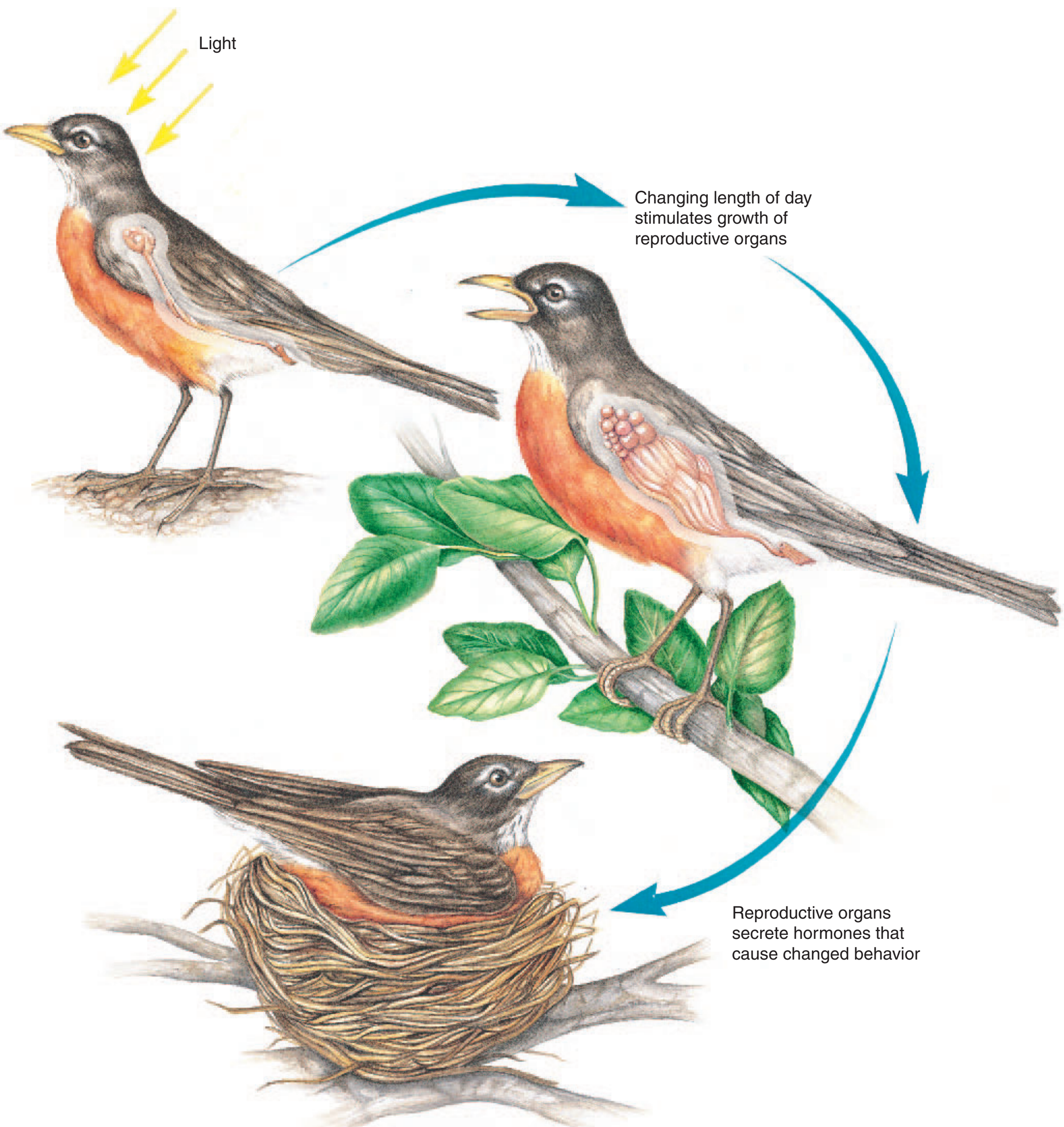


Figure 20.11

Interaction Between the Nervous and Endocrine Systems
In birds and many other animals, the brain receives information about the changing length of day, which causes the pituitary to produce hormones that stimulate sexual development. The testes or ovaries grow and secrete their hormones in increased amounts. Increased levels of testosterone or estrogen result in changed behavior, with increased mating, aggression, and nest-building activity.

activities that require long-term, growth-related actions are handled by the endocrine system.

20.2 Sensory Input

The activities of the nervous and endocrine systems are often responses to some kind of input received from the sense organs. Sense organs of various types are located throughout the body. Many of them are located on the surface, where environmental changes can be easily detected. Hearing, sight, and touch are good examples of such senses. Other sense organs are located within the body and indicate to the organism how its various parts are changing. For example, pain and pressure are often used to monitor internal conditions. The sense organs detect changes, but the brain is responsible for **perception**—the recognition that a stimulus has been received. Sensory abilities involve many different kinds of mechanisms, including chemical recognition, the detection of energy changes, and the monitoring of physical forces.

Chemical Detection

All cells have receptors on their surfaces that can bind selectively to molecules they encounter. This binding process can cause changes in the cells in several ways. In some cells it causes depolarization. When this happens, the binding of molecules to the cell can stimulate neurons and cause messages to be sent to the central nervous system, informing it of some change in the surroundings. In other cases, a molecule binding to the cell surface may cause certain genes to be expressed, and the cell responds by changing the molecules it produces. This is typical of the way the endocrine system receives and delivers messages.

Most cells have specific binding sites for particular molecules. Others, such as the taste buds on the tongue, appear to respond to classes of molecules. Traditionally we have distinguished four kinds of tastes: sweet, sour, salt, and bitter. However, recently, a fifth kind of taste, *umami* (meaty), has been identified that responds to the amino acid, glutamate, which is present in many kinds of foods and is added as a flavor enhancer (monosodium glutamate) to many kinds of foods.

The taste buds that give us the sour sensation respond to the presence of hydrogen ions (H^+). (Acid foods taste sour.) The hydrogen ions stimulate the cells in two ways: they enter the cell directly or they alter the normal movement of sodium and potassium ions across the cell membrane. In either case, the cell depolarizes and stimulates a nerve cell. Sodium chloride stimulates the taste buds that give us the sensation of a salty taste by directly entering the cell, which causes the cell to depolarize.

However, the sensations of sweetness, bitterness, and *umami* occur when molecules bind to specific surface receptors on the cell. Sweetness can be stimulated by many kinds of organic molecules, including sugars and artificial sweeteners, and also by inorganic lead compounds. When a molecule binds to a sweetness receptor, a molecule is split and its splitting stimulates an enzyme that leads to the depolarization of the cell. The sweet taste of lead salts in old paints partly explains why children sometimes eat paint chips. Because the lead interferes with normal brain development, this behavior can have disastrous results. Many other kinds of compounds of diverse structures give the bitter sensation. The cells that respond to bitter sensations have a variety of receptor molecules on their surface. When a substance binds to one of the receptors, the cell depolarizes. In the case of *umami,* it is the glutamate molecule that binds to receptors on the cells of the taste buds.

Each of these tastes has a significance from an evolutionary point of view. Carbohydrates are a major food source and many carbohydrates taste sweet, therefore, this sense would be useful in identifying foods that have high food value. Similarly, proteins and salts are necessary in the diet. Therefore, being able to identify these items in potential foods would be extremely valuable. This is particularly true for salt, which must often be obtained from mineral sources. On the other hand, bitter and sour materials are often harmful. Many plants produce toxic materials that are bitter tasting and acids are often the result of bacterial decomposition (spoiling) of foods. Being able to identify bitter and sour would allow organisms to avoid foods that would be harmful.

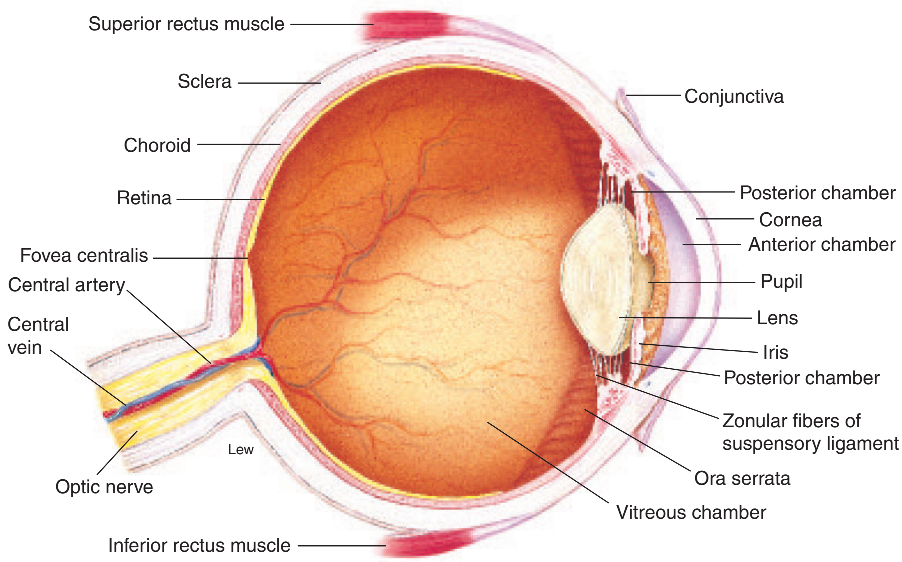
It is also important to understand that much of what we often refer to as *taste* involves such inputs as temperature, texture, and smell. Cold coffee has a different taste than hot coffee even though they are chemically the same. Lumpy, cooked cereal and smooth cereal have different tastes. If you are unable to smell food, it doesn't taste as it should, which is why you sometimes lose your appetite when you have a stuffy nose. We still have much to learn about how the tongue detects chemicals and the role other associated senses play in modifying taste.

The other major chemical sense, the sense of smell, is much more versatile; it can detect thousands of different molecules at very low concentrations. The cells that make up the **olfactory epithelium,** the cells that line the nasal cavity and respond to smells, apparently bind molecules to receptors on their surfaces. Exactly how this can account for the large number of recognizably different odors is unknown, but the receptor cells are extremely sensitive. In some cases a single molecule of a substance is sufficient to cause a receptor cell to send a message to the brain, where the sensation of odor is perceived. These sensory cells also fatigue rapidly. You have probably noticed that when you first walk into a room, specific odors are readily detected, but after a few minutes you are unable to detect them. Most perfumes and aftershaves are undetectable after 15 minutes of continuous stimulation.

Many internal sense organs also respond to specific molecules. For example, the brain and aorta contain cells that respond to concentrations of hydrogen ions, carbon dioxide, and oxygen in the blood. Remember, too, that the endocrine system relies on the detection of specific messenger molecules to trigger its activities.

Figure 20.12

The Structure of the Eye
The eye contains a cornea and lens that focus the light on the retina of the eye. The light causes pigments in the rods and cones of the retina to decompose. This leads to the depolarization of these cells and the stimulation of neurons that send messages to the brain.



Light Detection

The eyes primarily respond to changes in the flow of light energy. The structure of the eye is designed to focus light on a light-sensitive layer of the back of the eye known as the **retina** (figure 20.12). There are two kinds of receptors in the retina of the eye. The cells called **rods** respond to a broad range of wavelengths of light and are responsible for black-and-white vision. Because rods are very sensitive to light, they are particularly useful in dim light. Rods are located over most of the retinal surface except for the area of most acute vision known as the **fovea centralis.** The other receptor cells, called **cones,** are found throughout the retina but are particularly concentrated in the fovea centralis. Cones are not as sensitive to light, but they can detect different wavelengths of light. This combination of receptors gives us the ability to detect color when light levels are high, but we rely on black-and-white vision at night. There are three different varieties of cones: one type responds best to red light, another responds best to green light, and the third responds best to blue light. Stimulation of various combinations of these three kinds of cones allows us to detect different shades of color (figure 20.13).

Rods and the three different kinds of cones each contain a pigment that decomposes when struck by light of the proper wavelength and sufficient strength. The pigment found in rods is called **rhodopsin.** This change in the structure of rhodopsin causes the rod to depolarize. Cone cells have a similar mechanism of action, and each of the three kinds of cones has a different pigment. Because rods and cones synapse with neurons, they stimulate a neuron when depolarized and cause a message to be sent to the brain. Thus the pattern of color and light intensity recorded on the retina is detected by rods and cones and converted into a series of nerve impulses that are received and interpreted by the brain.

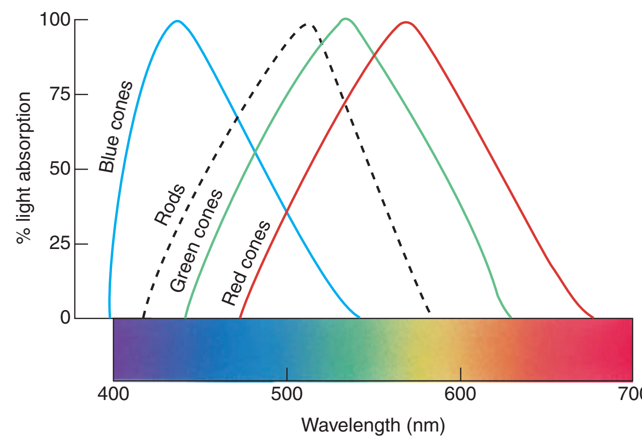


Figure 20.13

Light Reception by Cones
There are three different kinds of cones that respond differently to red, green, and blue wavelengths of light. Stimulation of combinations of these three kinds of cones gives us the ability to detect many different shades of color.

Sources: Data from W.B. Marks, W.H. Dobelle, and E.F. MacNichol, "Visual Pigments of Single Primate Cones," *Science* 143 (1964):45–52; and P.K. Brown and G. Wald, "Visual Pigments in Single Rods and Cones of the Human Retina," *Science* 144 (1964):45–52.

Sound Detection

The ears respond to changes in sound waves. Sound is produced by the vibration of molecules. Consequently, the ears are detecting changes in the quantity of energy and the quality of sound waves. Sound has several characteristics. Loudness, or volume, is a measure of the intensity of sound energy that arrives at the ear. Very loud sounds will literally vibrate

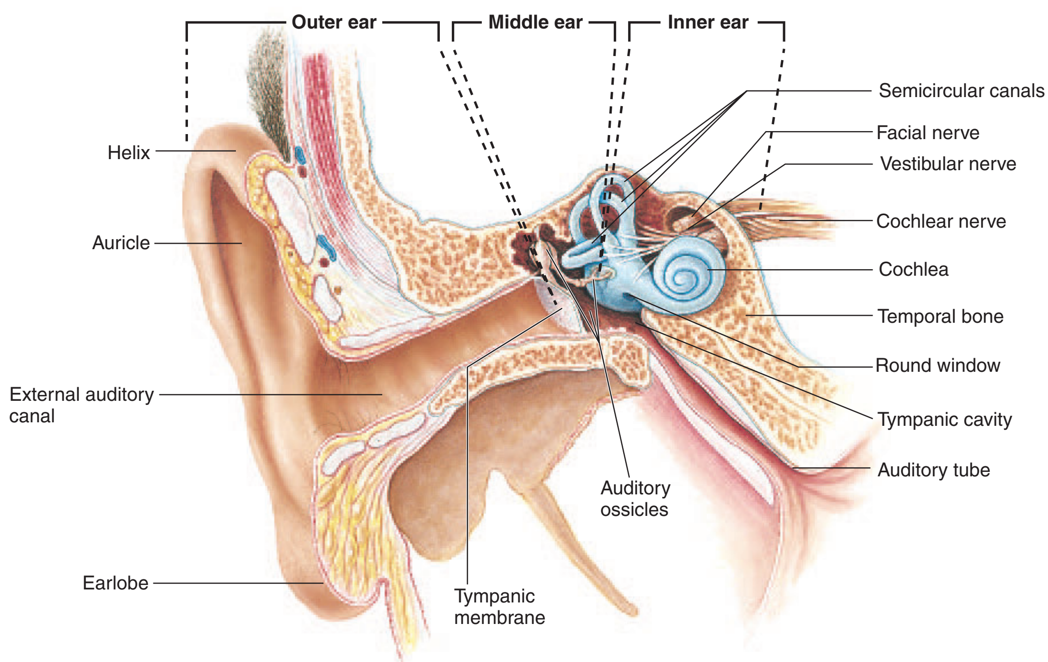


Figure 20.14

The Anatomy of the Ear
The ear consists of an external cone that directs sound waves to the tympanum. Vibrations of the tympanum move the ear bones and vibrate the oval window of the cochlea, where the sound is detected. The semicircular canals monitor changes in the position of the head, helping us maintain balance.

your body, and can cause hearing loss if they are too intense. Pitch is a quality of sound that is determined by the frequency of the sound vibrations. High-pitched sounds have short wavelengths; low-pitched sounds have long wavelengths.

Figure 20.14 shows the anatomy of the ear. The sound that arrives at the ear is first funneled by the external ear to the **tympanum,** also known as the *eardrum.* The cone-shaped nature of the external ear focuses sound on the tympanum and causes it to vibrate at the same frequency as the sound waves reaching it. Attached to the tympanum are three tiny bones known as the **malleus** (hammer), **incus** (anvil), and **stapes** (stirrup). The malleus is attached to the tympanum, the incus is attached to the malleus and stapes, and the stapes is attached to a small, membrane-covered opening called the **oval window** in a snail-shaped structure known as the **cochlea.** The vibration of the tympanum causes the tiny bones (malleus, incus, and stapes) to vibrate, and they in turn cause a corresponding vibration in the membrane of the oval window.

The cochlea of the ear is the structure that detects sound and consists of a snail-shaped set of fluid-filled tubes. When the oval window vibrates, the fluid in the cochlea begins to move, causing a membrane in the cochlea, called the **basilar membrane,** to vibrate. High-pitched, short-wavelength sounds cause the basilar membrane to vibrate at the base of the cochlea near the oval window. Low-pitched, long-wavelength sounds vibrate the basilar membrane far from the oval window. Loud sounds cause the basilar membrane to vibrate more vigorously than do faint sounds. Cells on this membrane depolarize when they are stimulated by its vibrations. Because they synapse with neurons, messages can be sent to the brain (figure 20.15).

Because sounds of different wavelengths stimulate different portions of the cochlea, the brain is able to determine the pitch of a sound. Most sounds consist of a mixture of pitches that are heard. Louder sounds stimulate the membrane more forcefully, causing the sensory cells in the cochlea to send more nerve impulses per second. Thus the brain is able to perceive the loudness of various sounds as well as the pitch.

Associated with the cochlea are two fluid-filled chambers and a set of fluid-filled tubes called the **semicircular canals.** These structures are not involved in hearing but are involved in maintaining balance and posture. In the walls of these canals and chambers are cells similar to those found on the basilar membrane. These cells are stimulated by movements of the head and by the position of the head with respect to the force

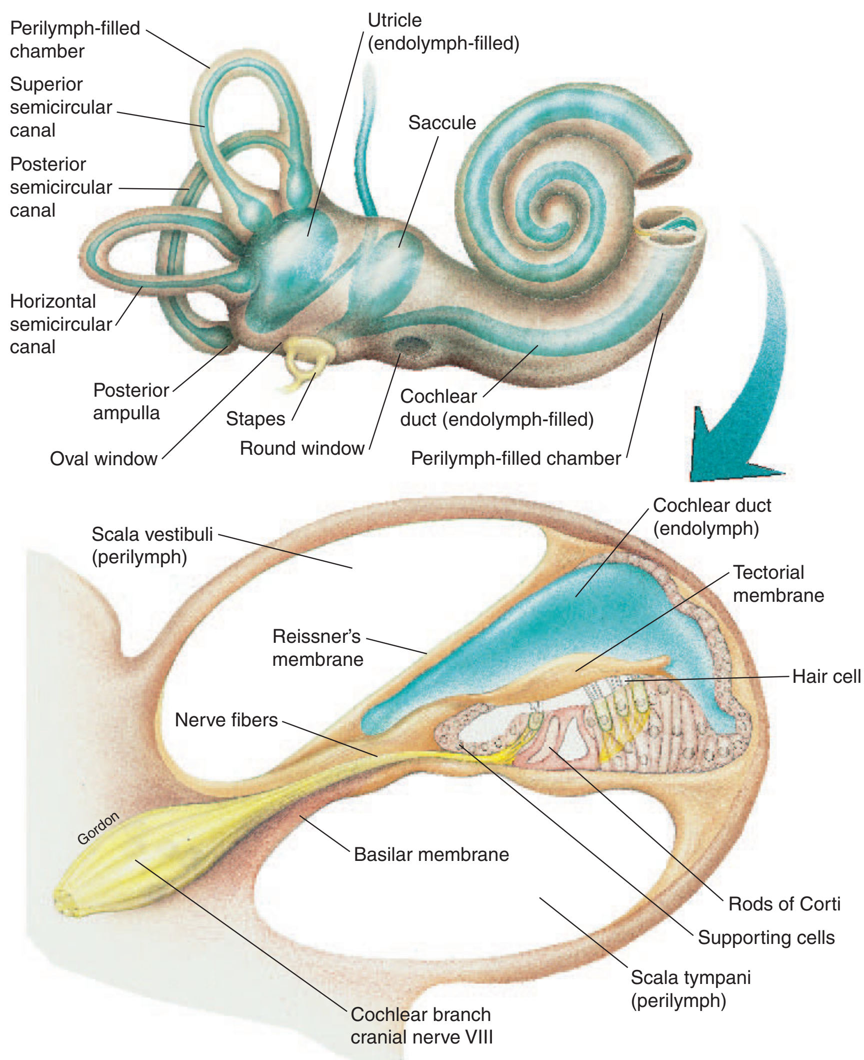


Figure 20.15

The Basilar Membrane
The cells that respond to vibrations and stimulate neurons are located in the cochlea. Vibrations of the oval window cause the fluid in the cochlea to vibrate, and the basilar membrane moves also. This movement causes the receptor cells to depolarize and send a message to the brain.

of gravity. The constantly changing position of the head results in sensory input that is important in maintaining balance.

Touch

What we normally call the sense of *touch* consists of a variety of different kinds of input. Some receptors respond to pressure, others to temperature, and others, which we call *pain receptors,* usually respond to cell damage. When these receptors are appropriately stimulated, they send a message to the brain. Because receptors are stimulated in particular parts of the body, the brain is able to localize the sensation. However, not all parts of the body are equally supplied with these receptors. The tips of the fingers, lips, and external genitals have the highest density of these nerve endings, whereas the back, legs, and arms have far fewer receptors.

Some internal receptors, such as pain and pressure receptors, are important in allowing us to monitor our internal activities. Many pains generated by the internal organs are often perceived as if they were somewhere else. For example, the pain associated with heart attack is often perceived to be in the left arm. Pressure receptors in joints and muscles are important in providing information about the degree of stress being placed on a portion of the body. This is also important information to send back to the brain so that adjustments can be made in movements to maintain posture. If you have ever had your foot "go to sleep" because the nerve stopped functioning, you have experienced what it is like to lose this constant input of nerve messages from the pressure sensors that assist in guiding the movements you make. Your movements become uncoordinated until the nerve function returns to normal.

20.3 Output Coordination

The nervous system and endocrine system cause changes in several ways. Both systems can stimulate muscles to contract and glands to secrete. The endocrine system is also able to change the metabolism of cells and regulate the growth of tissues. The nervous system acts upon two kinds of organs: muscles and glands. The actions of muscles and glands are simple and direct: muscles contract and glands secrete.

Muscles

The ability to move is one of the fundamental characteristics of animals. Through the coordinated contraction of many muscles, the intricate, precise movements of a dancer, basket-

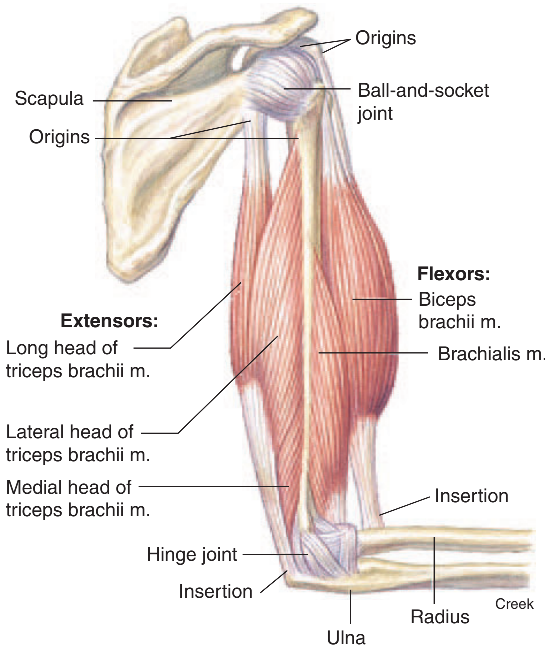


Figure 20.16

Antagonistic Muscles
Because muscles cannot actively lengthen, it is necessary to have sets of muscles that oppose one another. The contraction and shortening of one muscle cause the stretching of a relaxed muscle.

ball player, or writer are accomplished. It is important to recognize that muscles can pull only by contracting; they are unable to push by lengthening. The work of any muscle is done during its contraction. Relaxation is the passive state of the muscle. There must always be some force available that will stretch a muscle after it has stopped contracting and relaxes. Therefore, the muscles that control the movements of the skeleton are present in antagonistic sets—for every muscle's action there is another muscle that has the opposite action. For example, the biceps muscle causes the arm to flex (bend) as the muscle shortens. The contraction of its antagonist, the triceps muscle, causes the arm to extend (straighten) and at the same time stretches the relaxed biceps muscle (figure 20.16).

What we recognize as a muscle is composed of many muscle cells, which are in turn made up of *myofibrils* that are composed of two kinds of *myofilaments* (figure 20.17). The mechanism by which muscle contracts is well understood and involves the movement of protein filaments past one another as ATP is utilized. ATP (adenosine triphosphate) is the primary molecule used by cells for their immediate energy needs. The filaments in muscle cells are of two types, arranged in a particular pattern. Thin filaments composed of the proteins **actin, tropomyosin,** and **troponin** alternate with thick filaments composed primarily of a protein known as **myosin** (figure 20.18).

The myosin molecules have a shape similar to a golf club. The head of the club-shaped molecule sticks out from the thick filament and can combine with the actin of the thin filament. However, the troponin and tropomyosin proteins associated with the actin cover the actin in such a way that myosin cannot bind with it. When actin is uncovered, myosin can bind to it and contraction of a muscle will occur when ATP is utilized.

The process of muscle-cell contraction involves several steps. When a nerve impulse arrives at a muscle cell, its arrival causes the muscle cell to depolarize. When muscle cells depolarize, calcium ions (Ca^{2+}) contained within membranes are released among the actin and myosin filaments. The calcium ions (Ca^{2+}) combine with the troponin molecules, causing the troponin-tropomyosin complex to expose actin so that it can bind with myosin. While the actin and myosin molecules are attached, the head of the myosin molecule can flex as ATP is used and the actin molecule is pulled past the myosin molecule. Thus a tiny section of the muscle cell shortens (figure 20.19). When one of our muscles contracts, thousands of such interactions take place within a tiny portion of a muscle cell, and many cells within a muscle all contract at the same time.

There are three major types of muscle: skeletal, smooth, and cardiac. These differ from one another in several ways. *Skeletal muscle* is voluntary muscle; it is under the control of the nervous system. The brain or spinal cord sends a message to skeletal muscles, and they contract to move the legs, fingers, and other parts of the body. This does not mean that you must make a conscious decision every time you want to move a muscle. Many of the movements we make are learned initially but become automatic as a result of practice. For example, walking, swimming, or riding a bicycle required a great amount of practice originally, but now you probably perform these movements without thinking about them. They are, however, still considered voluntary actions.

Skeletal muscles are constantly bombarded with nerve impulses that result in repeated contractions of differing strength. Many neurons end in each muscle, and each one stimulates a specific set of muscle cells called a **motor unit** (figure 20.20). Because each muscle consists of many motor units, it is possible to have a wide variety of intensities of contraction within one muscle organ. This allows a single set of muscles to serve a wide variety of functions. For example, the same muscles of the arms and shoulders that are used to play a piano can be used in other combinations to tightly grip and throw a baseball. If the nerves going to a muscle are destroyed, the muscle becomes paralyzed and begins to shrink. Regular nervous stimulation of skeletal muscle is necessary for muscle to maintain size and strength. Any kind of prolonged inactivity leads to the degeneration of muscles known as atrophy. Muscle maintenance is one of the primary functions of physical therapy and a benefit of regular exercise.

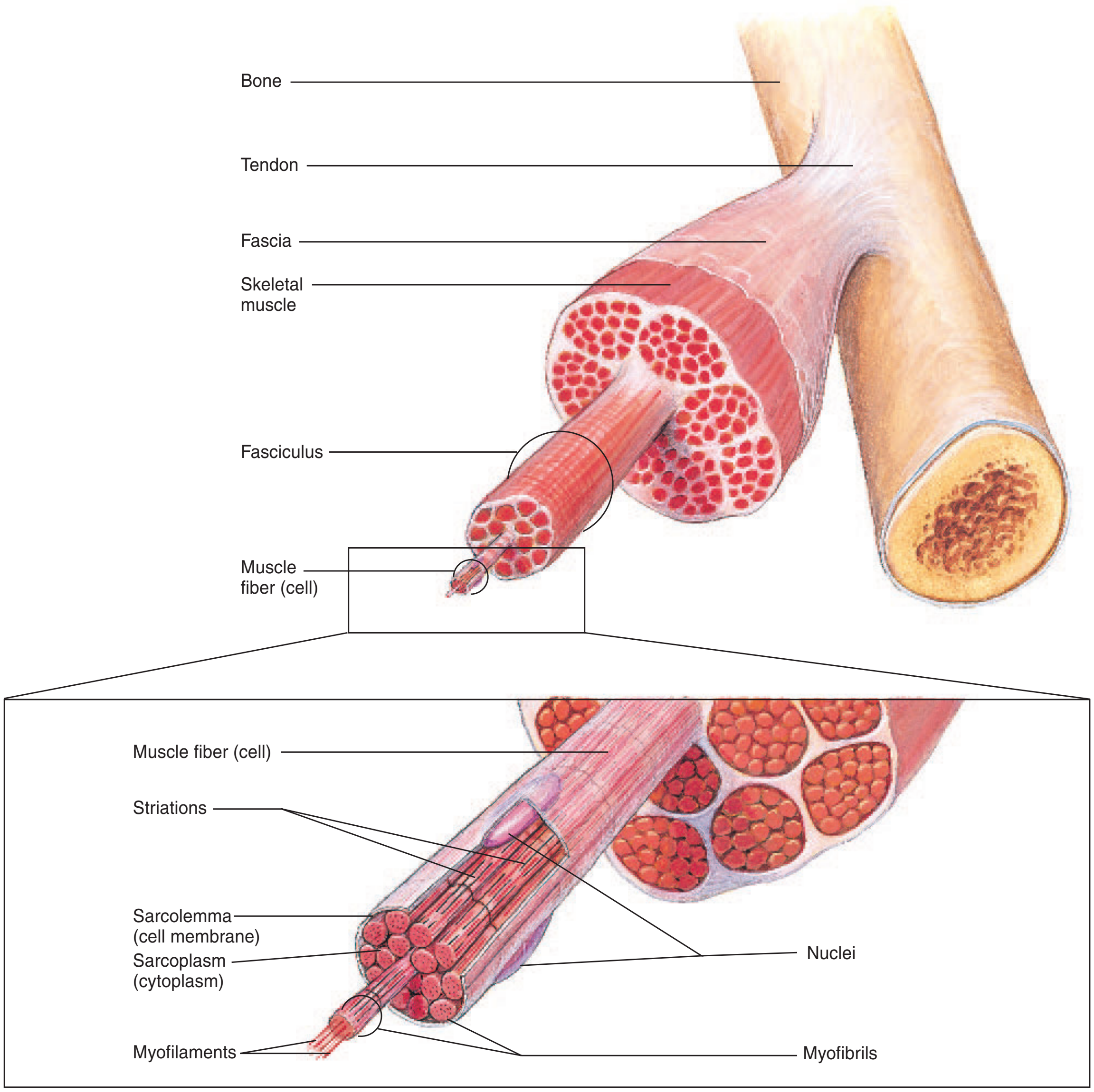


Figure 20.17

The Microanatomy of a Muscle
Muscles are made of cells that contain bundles known as myofibrils. The myofibrils are composed of myofilaments of two different kinds: thick myofilaments composed of myosin, and thin myofilaments containing actin, troponin, and tropomyosin.

Skeletal muscles are able to contract quickly, but they cannot remain contracted for long periods. Even when we contract a muscle for a minute or so, the muscle is constantly shifting the individual motor units within it that are in a state of contraction. A single skeletal muscle cell cannot stay in a contracted state.

Smooth muscles make up the walls of muscular internal organs, such as the gut, blood vessels, and reproductive organs. They have the property of contracting as a response to being stretched. Because much of the digestive system is being stretched constantly, the responsive contractions contribute to the normal rhythmic movements associated with the digestive system. These are involuntary muscles; they can contract on their own without receiving direct messages from the nervous system. This can be demonstrated by removing portions of the gut or uterus from experimental

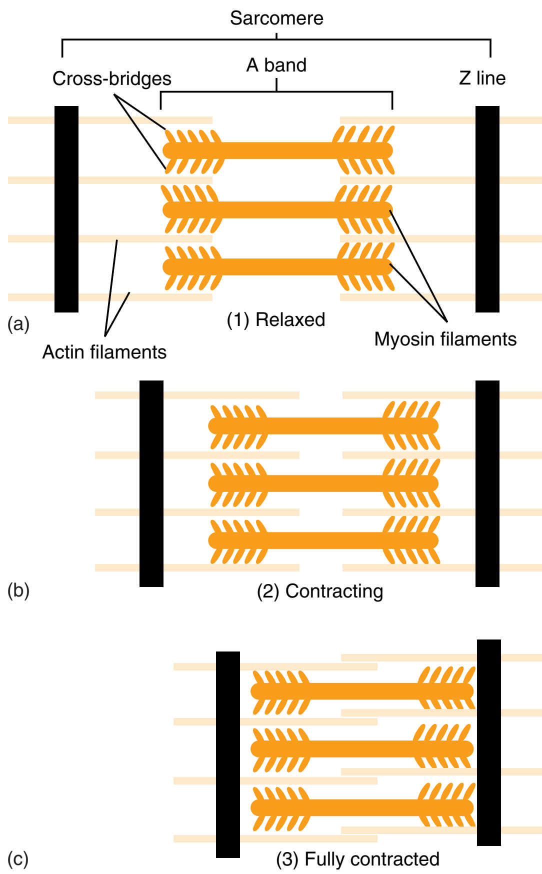


Figure 20.18

The Subcellular Structure of Muscle
The actin- and myosin-containing myofilaments are arranged in a regular fashion into units called sarcomeres (*a*). Each sarcomere consists of two sets of actin-containing myofilaments inserted into either end of bundles of myosin-containing myofilaments (*b*). The actin-containing myofilaments slide past the myosin-containing myofilaments, shortening the sarcomere (*c*).

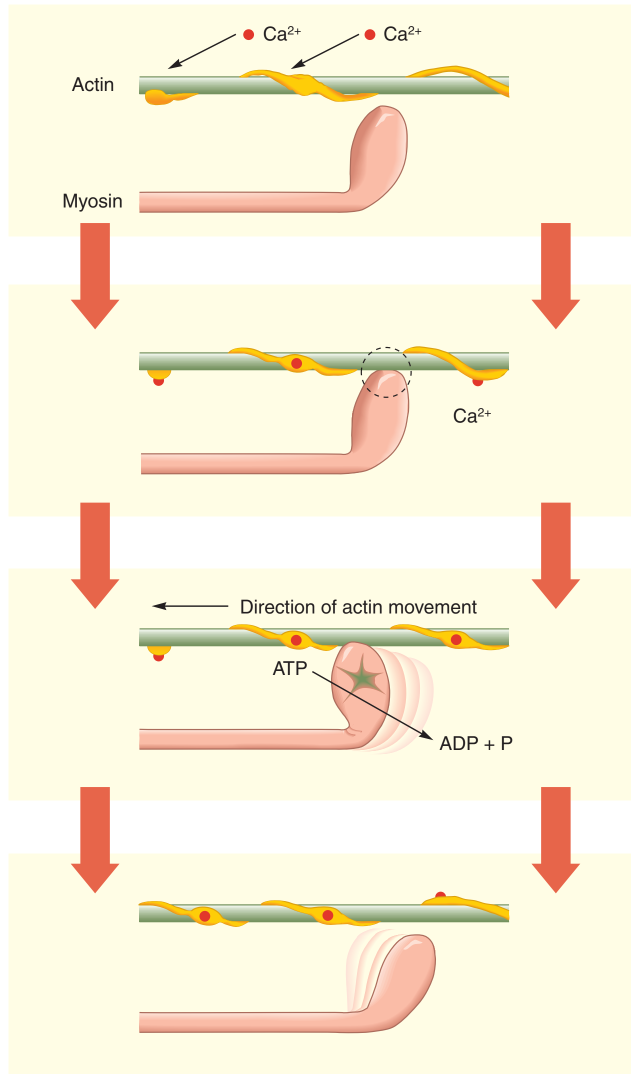


Figure 20.19

Interaction Between Actin and Myosin
When calcium ions (Ca^{2+}) enter the region of the muscle cell containing actin and myosin, they allow the actin and myosin to bind to each other. ATP is broken to ADP and P with the release of energy. This energy allows the club-shaped head of the myosin to flex and move the actin along, causing the two molecules to slide past each other.

animals. When these muscular organs are kept moist with special solutions, they go through cycles of contraction without any possible stimulation from neurons. However, they do receive nervous stimulation, which can modify the rate and strength of their contraction. This kind of muscle also has the ability to stay contracted for long periods without becoming fatigued. Many kinds of smooth muscle, such as the muscle of the uterus, also respond to the presence of hormones. Specifically, the hormone **oxytocin,** which is released from the posterior pituitary, causes strong contractions of the uterus during labor and birth. Similarly, several hormones produced by the duodenum influence certain muscles of the digestive system to either contract or relax.

Cardiac muscle is the muscle that makes up the heart. It has the ability to contract rapidly like skeletal muscle, but does not require nervous stimulation to do so. Nervous stimulation can, however, cause the heart to speed or slow its rate of contraction. Hormones, such as epinephrine and norepinephrine, also influence the heart by increasing its rate

Table 20.1

CHARACTERISTICS OF DIFFERENT KINDS OF MUSCLE

Kind of Muscle	Stimulus	Length of Contraction	Rapidity of Response
Skeletal	Nervous system	Short, tires quickly	Most rapid
Smooth	1. Self-stimulated 2. Also responds to nervous and endocrine systems	Long, doesn't tire quickly	Slow
Cardiac	1. Self-stimulated 2. Also responds to nervous and endocrine systems	Short, cannot stay contracted	Rapid

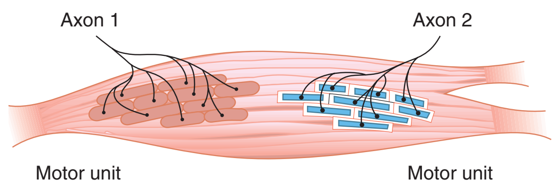


Figure 20.20

Motor Units
When a skeletal muscle contracts, individual groups of muscle cells are stimulated by specific nerve cells. They contract momentarily, then relax. The strength of contraction is determined by the number of motor units stimulated. The sequence of movements is determined by the order in which motor units are stimulated.

and strength of contraction. Cardiac muscle also has the characteristic of being unable to stay contracted. It will contract quickly but must have a short period of relaxation before it will be able to contract a second time. This makes sense in light of its continuous, rhythmic, pumping function. Table 20.1 summarizes the differences among skeletal, smooth, and cardiac muscles.

Glands

The glands of the body are of two different kinds. Those that secrete into the bloodstream are called endocrine glands. We have already talked about several of these: the pituitary, thyroid, ovary, and testis are examples. The exocrine glands are those that secrete to the surface of the body or into one of the tubular organs of the body, such as the gut or reproductive tract. Examples are the salivary glands, intestinal mucus glands, and sweat glands. Some of these glands, such as salivary glands and sweat glands, are under nervous control. When stimulated by the nervous system, they secrete their contents.

The Russian physiologist Ivan Petrovich Pavlov showed that salivary glands were under the control of the nervous system when he trained dogs to salivate in response to hearing a bell. You may recall from chapter 17 that, initially, the animals were presented with food at the same time the bell was rung. Eventually they would salivate when the bell was rung even if food was not present. This demonstrated that saliva release was under the control of the central nervous system.

Many other exocrine glands are under hormonal control. Many of the digestive enzymes of the stomach and intestine are secreted in response to local hormones produced in the gut. These are circulated through the blood to the digestive glands, which respond by secreting the appropriate digestive enzymes and other molecules.

Growth Responses

The hormones produced by the endocrine system can have a variety of effects. As mentioned earlier, hormones can stimulate smooth muscle to contract and can influence the contraction of cardiac muscle as well. Many kinds of glands, both endocrine and exocrine, are caused to secrete as a result of a hormonal stimulus. However, the endocrine system has one major effect that is not equaled by the nervous system: Hormones regulate growth. Several examples of the many kinds of long-term growth changes that are caused by the endocrine system were given earlier in the chapter. Growth-stimulating hormone (GSH) is produced over a period of years to bring about the increase in size of most of the structures of the body. A low level of this hormone results in a person with small body size. It is important to recognize that the amount of growth-stimulating hormone (GSH) present varies from time to time. It is present in fairly high amounts throughout childhood and results in steady growth. It also appears to be present at higher levels at certain times, resulting in growth spurts. Finally, as adulthood is reached, the level of this hormone falls, and growth stops.

Table 20.2

COMPARISON OF THE NERVOUS AND ENDOCRINE SYSTEMS

System	Kind of Action	Effects
Nervous	1. Nerve impulse travels along established routes. 2. Neurotransmitters allow impulse to cross synapses. 3. Rapid action.	1. Causes skeletal muscle contraction. 2 Modifies contraction of smooth and cardiac muscles. 3. Causes gland secretion.
Endocrine	1. Hormones released into bloodstream. 2. Receptors bind hormones to their target organs. 3. Often slow to act.	1. Stimulates smooth muscle contraction. 2. Stimulates gland secretion. 3. Regulates growth.

Similarly, testosterone produced during adolescence influences the growth of bone and muscle to provide men with larger, more muscular bodies than those of women. In addition, there is growth of the penis, growth of the larynx, and increased growth of hair on the face and body. The primary female hormone, estrogen, causes growth of reproductive organs and development of breast tissue. It is also involved, along with other hormones, in the cyclic growth and sloughing of the wall of the uterus.

SUMMARY

Throughout this chapter we have been comparing the functions of the nervous and endocrine systems, the kinds of effects they have, and their characteristics. Table 20.2 summarizes these differences.

A nerve impulse is caused by sodium ions entering the cell as a result of a change in the permeability of the cell membrane. Thus, a wave of depolarization passes down the length of a neuron to the synapse. The axon of a neuron secretes a neurotransmitter, such as acetylcholine, into the synapse, where these molecules bind to the dendrite of the next cell in the chain, resulting in an impulse in it as well. The acetylcholinesterase present in the synapse destroys acetylcholine so that it does not repeatedly stimulate the dendrite. The brain is composed of several functional units. The lower portions of the brain control automatic activities, the middle portion of the brain controls basic categorizing of sensory input, and the higher levels of the brain are involved in thinking and self-awareness.

Several kinds of sensory inputs are possible. Many kinds of chemicals can bind to cell surfaces and be recognized. This is how the sense of taste and the sense of smell function. Light energy can be detected because light causes certain molecules in the retina of the eye to decompose and stimulate neurons. Sound can be detected because fluid in the cochlea of the ear is caused to vibrate, and special cells detect this movement and stimulate neurons. The sense of touch consists of a variety of receptors that respond to pressure, cell damage, and temperature.

Muscles shorten because of the ability of actin and myosin to bind to one another. A portion of the myosin molecule is caused to bend when ATP is used, resulting in the sliding of actin and myosin molecules past each other. Skeletal muscle responds to nervous stimulation to cause movements of the skeleton. Smooth muscle and cardiac muscle have internally generated contractions that may be modified by nervous stimulation or hormones.

Glands are of two types: exocrine glands, which secrete through ducts into the cavity of an organ or to the surface of the skin, and endocrine glands, which release their secretions into the circulatory system. Digestive glands and sweat glands are examples of exocrine glands. Endocrine glands such as the ovaries, testes, and pituitary gland change the activities of cells and often cause responses that result in growth over a period of time. It is becoming clear that the endocrine system and the nervous system are interrelated. Actions of the endocrine system can change how the nervous system functions, and the reverse is also true. Much of this interrelation takes place in the brain-pituitary gland association.

THINKING CRITICALLY

Humans are considered to have a poor sense of smell. However, when parents are presented with baby clothing, they are able to identify the clothing with which their own infant had been in contact with a high degree of accuracy. Specially trained individuals, such as wine and perfume testers, are able to identify large numbers of different kinds of molecules that the average person cannot identify. Birds rely primarily on sound and sight for information about their environment; they have a poor sense of smell. Most mammals are known to have a very well-developed sense of smell. Is it possible that we have evolved into sound-and-sight-dependent organisms like birds and have lost the keen sense of smell of our ancestors? Or is it that we just don't use our sense of smell to its full potential? Can you devise an experiment that would help shed light on this question?

CONCEPT MAP TERMINOLOGY

Construct a concept map to show relationships among the following concepts.

central nervous system
motor neurons
nerve impulse
neurotransmitter
perception
peripheral nervous system
retina
sensory neurons
skeletal muscle
synapse

KEY TERMS

acetylcholine
acetylcholinesterase
actin
antidiuretic hormone (ADH)
axon
basilar membrane
central nervous system
cerebellum
cerebrum
cochlea
cones
dendrites
depolarized
endocrine glands
endocrine system
epinephrine
estrogen
exocrine glands
fovea centralis
gland
growth-stimulating hormone (GSH)
homeostasis
hormones
hypothalamus
incus
malleus
medulla oblongata
motor neurons
motor unit
myosin
negative-feedback control
nerve cell
nerve impulse
nerves
nervous system
neuron
neurotransmitter
norepinephrine
olfactory epithelium
oval window
oxytocin
perception
peripheral nervous system
pons
response
retina
rhodopsin
rods
semicircular canals
sensory neurons
soma
spinal cord
stapes
stimulus
synapse
target cells
testosterone
thalamus
thyroid-stimulating hormone (TSH)
thyroxine
triiodothyronine
tropomyosin
troponin
tympanum
voltage

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Topics	Questions	Media Resources
20.1 Integration of Input	1. Describe how the changing permeability of the cell membrane and the movement of sodium ions cause a nerve impulse. 2. What is the role of acetylcholine in a synapse? What is the role of acetylcholinesterase? 3. Describe three ways in which the nervous systems differs from the endocrine system. 4. Give an example of the interaction between the endocrine system and the nervous system. 5. Give an example of negative-feedback control in the endocrine system.	**Quick Overview** • Anatomy of a nerve **Key Points** • Integration of input **Animations and Review** • Nervous tissue • Synapse **Review** • Nervous system
20.2 Sensory Input	6. What is actually detected by the nasal epithelium, taste buds, cochlea of the ear, and retina of the eye?	**Quick Overview** • Interacting with your environment **Key Points** • Sensory input **Interactive Concept Maps** • Senses **Case Study** • Could your inner clocks make you the junk food junkie?
20.3 Output Coordination	7. How do skeletal, cardiac, and smooth muscles differ in (1) speed of contraction, (2) ability to stay contracted, and (3) cause of contraction? 8. What is the role of each of the following in muscle contraction: actin, myosin, ATP, troponin, and tropomyosin? 9. List three hormones and give their function. 10. List the differences between the following: a. Central and peripheral nervous system. b. Motor and sensory nervous system. c. Anterior and posterior pituitary.	**Quick Overview** • Muscles **Key Points** • Output coordination **Interactive Concept Maps** • Text concept map **Experience This!** • Muscle fatigue **Food for Thought** • Endocrine system