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UNIT III

Systems of Tissues and Organs

Foundational Concept: Complex systems of tissues and organs sense the internal and external environments of multicellular organisms and, through integrated functioning, maintain a stable internal environment within an ever-changing external environment.

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CHAPTER 8

Structure and Function of the Nervous and Endocrine Systems and Ways in Which These Systems Coordinate the Organ Systems

Read This Chapter to Learn About

- The Nervous System
- Biosignaling
- The Senses
- The Endocrine System

THE NERVOUS SYSTEM

The nervous system has the daunting task of coordinating all the body's activities. The **central nervous system** (CNS) is composed of the brain and spinal cord, and the **peripheral nervous system** (PNS) is composed of all nervous tissue located outside of the brain and spinal cord. Nerves are the primary structures within the PNS. In order to understand the functioning of the CNS and PNS, it is necessary to look at the detailed function of neurons, the basic units of function within the nervous system.

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The Neuron

Neurons perform the critical function of transmitting messages throughout the body. There are several types of neurons: sensory, motor, and interneurons. **Sensory (afferent) neurons** exist in the PNS, pick up sensory impulses, and direct their messages toward the CNS. **Motor (efferent) neurons** exist in the PNS and direct their messages away from the CNS to peripheral parts of the body. **Interneurons**, which transfer messages, are found only in the CNS.

While neurons perform the critical function of transmitting messages throughout the body, there are also a large number of glial cells present in the nervous system. **Glial cells** provide support to neurons and, unlike mature neurons, are capable of mitosis.

The basic structure of a neuron can be seen in Figure 8-1. The major structures within the neuron are as follows:

- **Dendrites.** They are projections that pick up incoming messages.
- **Cell body.** It processes messages and contains the nucleus and other typical cell organelles.
- **Axons.** They are projections that carry electrical messages down their length.
- **Synaptic knobs.** They are extensions at the ends of an axon that send electrical impulses converted to chemical messages in the form of neurotransmitters to other neurons.

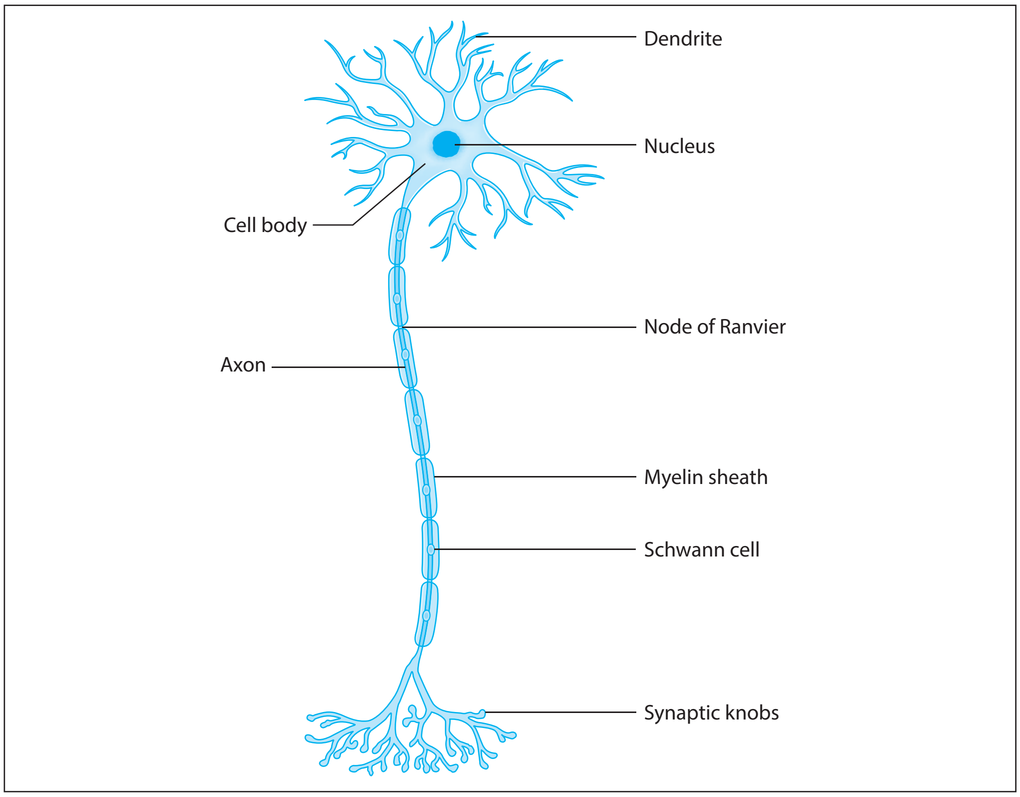

FIGURE 8-1 Neuron structure.

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- **Myelin sheath.** It is a covering, produced by Schwann cells (specialized glial cells), that surrounds the axon of some neurons; gaps between the myelin are called nodes of Ranvier.
- **Synapse.** It is the space between the synaptic knob of one neuron and the dendrite of another neuron.

Basic Function of a Neuron

Neurons send messages in the form of electrical impulses throughout the body. They do this through a complex series of processes involving changes from a resting potential to an action potential and communication via neurotransmitters.

RESTING POTENTIAL

In order to understand how neurons generate electrical impulses to send messages, it is necessary to understand the state of the neurons when they are not generating electrical impulses. This is termed the **resting potential** of the neurons. It requires the maintenance of an unequal balance of ions on either side of the membrane to keep the membrane polarized. To maintain the resting potential, a great deal of ATP is required.

During the resting potential, sodium-potassium (Na^+/K^+) pumps within the membrane of the axon are used to actively transport ions into and out of the axon. The Na^+/K^+pumps bring 2 K^+ ions into the axon while sending out 3 Na^+ ions. This results in a high concentration of Na^+ outside the membrane and a high concentration of K^+ inside the membrane. There are also many negatively-charged molecules such as proteins within the neuron so that ultimately the inside of the neuron is more negative than the outside of the neuron. The resting potential is about −70 mV. Figure 8-2 shows the resting potential in a neuron.

ACTION POTENTIAL

To transmit a message, the resting potential of the neuron must be disrupted and depolarized such that the inside of the cell becomes slightly less negative. For this **action potential** to occur, there is a threshold voltage that must be achieved to initiate the action potential, which is about −50 mV. Once the action potential has initiated, voltage gated channels in the membrane of the axon open. Specifically, Na^+ channels open, allowing Na^+ to flow passively across the membrane into the axon in a local area. This local flow of Na^+ causes the next Na^+ channel to open. This continues down the length of the axon toward the synaptic knobs like a wave as seen in Figure 8-3.

Although the speed of the action potential varies depending on the axon diameter and whether the axon is myelinated or not, its strength cannot. Action potentials are an all-or-nothing event. If the threshold voltage is not hit, the action potential does not happen. If the threshold value is achieved or exceeded, the action potential occurs with the same electrical charge of about +35 mV each time.

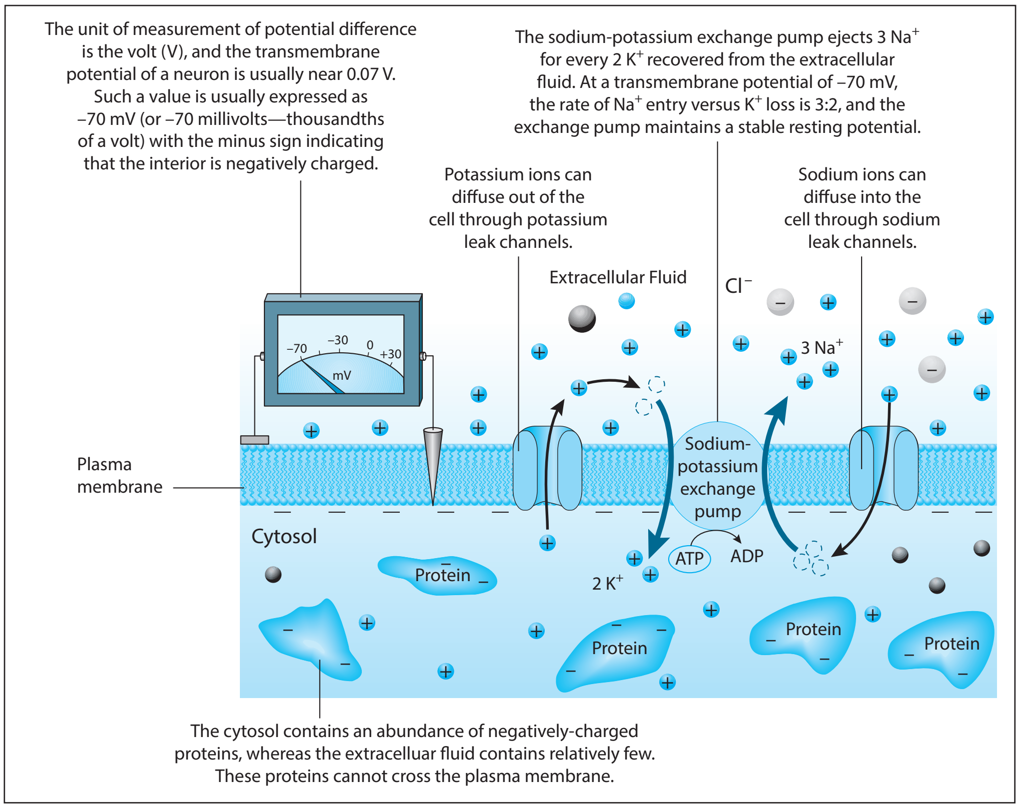

FIGURE 8-2 Resting potential. During the resting potential, the sodium-potassium pumps maintain an unequal balance of ions inside and outside the axon.

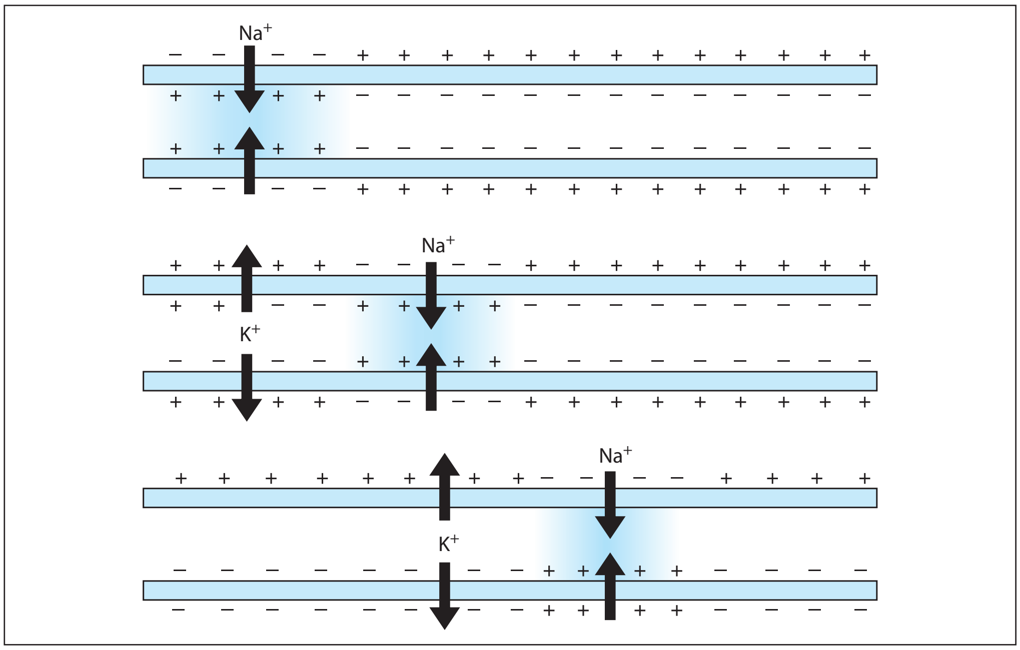

FIGURE 8-3 During the action potential, Na^+ enters the neuron causing depolarization.

In myelinated neurons, the voltage gated ion channels are only permeable to ions at the nodes of Ranvier. This allows for the action potential to jump from one node to the next in the process of **salutatory conduction**.

As soon as the Na^+ channels open and depolarize a small area of the axon, K^+ channels open, allowing K^+ to leak passively out of the axon. This restores the more negative charge within the axon, temporarily preventing the initiation of another action potential during a refractory period. The Na^+/K^+pump can then be used to completely restore the resting potential by repolarization. By the time an action potential reaches the end of an axon, the rest of the axon is already repolarized.

Communication Between Neurons

More than 50 types of **neurotransmitters** have been identified in humans, each with very diverse functions. Each neuron specializes in specific types of neurotransmitters and contains vesicles full of them within their synaptic knobs. When an action potential reaches the synaptic knobs, the vesicles containing neurotransmitters fuse with the membrane by exocytosis and release their contents to the synapse. This neurotransmitter release requires calcium to occur. The neuron that releases the neurotransmitter is termed the **presynaptic neuron** and the neuron that responds to the neurotransmitter is termed the **postsynaptic neuron**. The neurotransmitter will bind to the receptors on the postsynaptic neurons.

The nature of the receptor determines the response in the postsynaptic neuron. In some cases, the binding of the neurotransmitter to a receptor initiates an **excitatory response** in which some sodium channels open in an attempt to hit the threshold value to generate an action potential in the postsynaptic neuron. This is a graded response in that the more neurotransmitter binding to receptors in the synapse, the more sodium that leaks into the postsynaptic neuron, which increases the odds of an action potential occurring. In other cases, the binding of the neurotransmitter to a receptor will initiate an **inhibitory response** that discourages the generation of an action potential in the postsynaptic neuron. This usually occurs by the addition of chloride ions (Cl^-) to the interior of the axon, making it more negative and less likely that the threshold value needed for an action potential will be generated.

A single neuron may receive messages in the form of neurotransmitters from multiple other neurons. In some cases, a neuron can receive excitatory and inhibitory signals at the same time. The response of this neuron is all or nothing, either an action potential occurs or it does not. If the excitatory signals outweigh the inhibitory signals, an action potential occurs. If the inhibitory signals outweigh the excitatory signals, an action potential does not occur.

Once a neurotransmitter has been released into the synapse and has interacted with a receptor, it must be cleared from the synapse to avoid sending repeated messages. Depending on the type of neurotransmitter, removal may be via reuptake, where the neurotransmitters are taken back into the presynaptic neuron, or by enzymatic degradation of the neurotransmitter in the synapse.

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The Central Nervous System

The **central nervous system** (CNS) is composed of the brain and spinal cord. The brain and spinal cord both consist of many neurons and supporting glial cells. **White matter** within the brain and spinal cord consists of myelinated axons. **Gray matter** consists of clusters of cell bodies of neurons.

Cranial bones and vertebrae protect the CNS, as do protective membranes called the **meninges**. There are three meninges (dura mater, arachnoid, and pia mater). Between two of the meninges and within cavities of the brain, there is **cerebrospinal fluid**. This fluid has several critical functions such as providing nutrients and removing wastes as well as providing cushioning and support for the brain. Cerebrospinal fluid is made by the brain and is eventually reabsorbed by the blood.

The **blood–brain barrier** is another mechanism of protection for the brain. While the name implies that the blood–brain barrier is a structure, it is not. It is a mechanism that selects for components in the blood that are allowed to circulate into the brain via brain capillaries. This selection is based on a unique membrane permeability that allows for the easy passage of most lipid soluble molecules, while preventing other molecules from entering the brain tissue. The benefits of the blood–brain barrier are that it protects the brain from substances in the blood that might cause damage

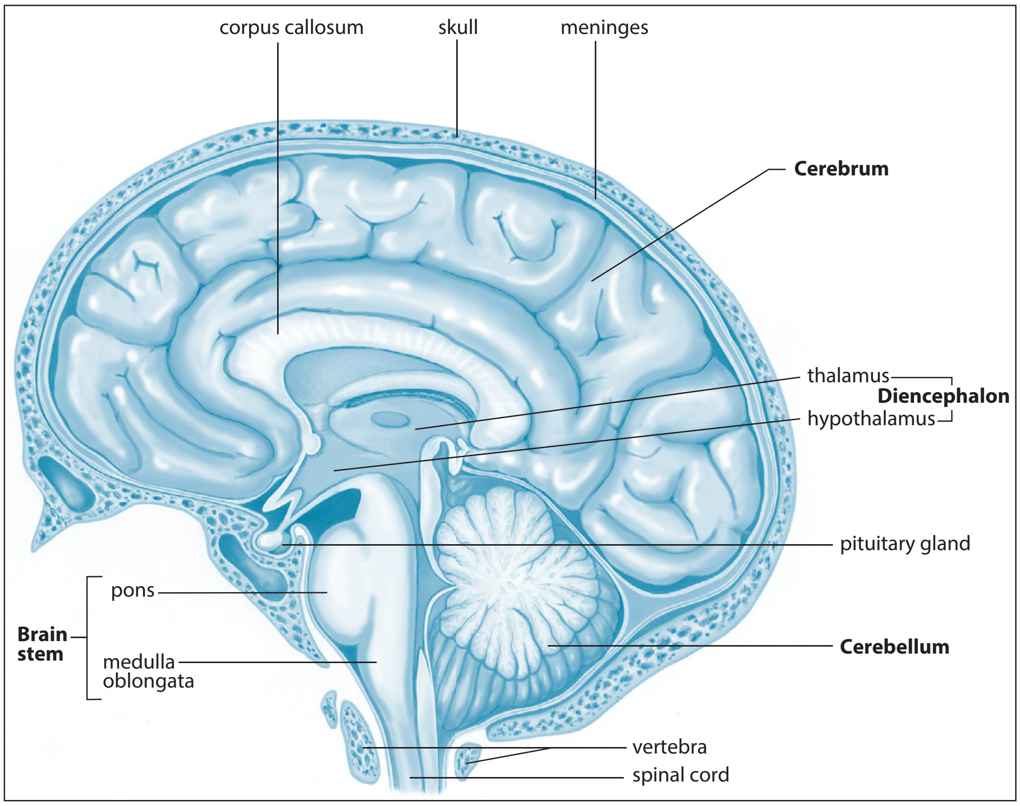

FIGURE 8-4 Brain structure. The cerebrum of the brain is divided into right and left hemispheres connected by the corpus callosum. *Source:* From Sylvia S. Mader, *Biology*, 8th ed., McGraw-Hill, 2004; reproduced with permission of The McGraw-Hill Companies.

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and it maintains a consistent environment for the brain, which is not very tolerant of fluctuations.

STRUCTURE AND FUNCTION OF THE BRAIN

The **brain** is the central command center of the nervous system. It processes conscious thought and sensory information, it coordinates motor activities of skeletal muscle and other organ systems within the body, and it maintains vital functions such as heart rate and ventilation.

The brain is divided into the **cerebrum**, **cerebellum**, **brain stem**, and **diencephalon** as seen in Figure 8-4. The cerebrum in particular has extremely diverse functions. The right and left hemispheres process information in different ways. The right side of the brain tends to specialize in spatial and pattern perception, while the left side of the brain tends to specialize in analytical processing and language. The connection of the two hemispheres via the corpus callosum is essential to integrating the functions of both sides of the brain.

Integration of functions of the brain is also accomplished via the **limbic system**. Complex activities such as mood and emotions, as well as memory, cannot be achieved in a single area of the brain. Instead, several areas of the brain must interact. The limbic system, a tract of neurons that connects several areas of the brain, including the cerebrum, hypothalamus, and medulla, and areas associated with the sense of smell, provides for this interaction. Within the limbic system, the hippocampus helps convert short-term memories to long-term memories.

The functions of each of the parts of the brain can be seen in the following table:

TABLE 8-1 Major Structures of the Brain and their Functions

Structure	Function
Cerebrum	The cerebrum is the largest portion of the brain and is divided into right and left hemispheres as well as into four lobes (frontal, parietal, occipital, and temporal). Within the cerebrum there are specific areas for each of the senses, motor coordination, and association areas. All thought processes, memory, learning, and intelligence are regulated via the cerebrum. The cerebral cortex is the outer tissue of the cerebrum.
Cerebellum	The cerebellum is located at the base of the brain. It is responsible for sensory-motor coordination for complex muscle movement patterns and balance.
Brain stem	The brain stem is composed of several structures and ultimately connects the brain to the spinal cord. The **pons** connects the spinal cord and cerebellum to the cerebrum and diencephalon. The **medulla oblongata** (or medulla) has reflex centers for vital functions such as the regulation of breathing, heart rate, and blood pressure. Damage to the medulla is usually fatal. Messages entering the brain from the spinal cord must pass through the medulla.

(*Continued*)

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TABLE 8-1 Major Structures of the Brain and their Functions (cont.)

Structure	Function
Brain stem	The **reticular activating system (RAS)** is a tract of neurons that runs through the medulla into the cerebrum. It acts as a filter to prevent the processing of repetitive stimuli. The RAS is also an activating center for the cerebrum. When the RAS is not activated, sleep occurs.
Diencephelon	The diencephalon is composed of two different structures. The **hypothalamus** is used to regulate the activity of the pituitary gland in the endocrine system. In addition, the hypothalamus regulates conditions such as thirst, hunger, sex drive, and temperature. The **thalamus** is located adjacent to the hypothalamus and serves as a relay center for sensory information entering the cerebrum. It routes incoming information to the appropriate parts of the cerebrum.

The Spinal Cord and Reflex Actions

The **spinal cord** serves as a shuttle for messages going toward and away from the brain. It also acts as a reflex center, having the ability to process certain incoming messages and provide an autonomic response without processing by the brain. Spinal reflexes are important because they are faster than sending a message to the brain for processing.

The **reflex arc** seen in Figure 8-5 is a set of neurons that consists of a receptor, a sensory neuron, an interneuron, a motor neuron, and an effector. The reflex arc involves both the CNS and the PNS. The **receptor** transmits a message to a sensory neuron, which routes the message to an interneuron located in the spinal cord. The **interneuron** processes the message in the cord and sends a response out through the motor neuron. The **motor neuron** passes the message to an **effector**, which can carry out the appropriate response.

The Peripheral Nervous System

The **peripheral nervous system** (PNS) is composed of pairs of nerves that are bundles of axons. There are 12 pairs of **cranial nerves** branching off the brain stem and 31 pairs of **spinal nerves** branching off the spinal cord. Some nerves are composed of only sensory neurons, others of only motor neurons, and others of a combination of sensory and motor neurons. The nerves that exist in the PNS are categorized into one of two divisions: the somatic nervous system or the autonomic nervous system.

The **somatic nervous system** controls conscious functions within the body such as sensory perception and voluntary movement due to innervation of skeletal muscle. The **autonomic nervous system** controls the activity of involuntary functions within the body to maintain homeostasis. The autonomic nervous system is further subdivided into the sympathetic and parasympathetic branches. Both branches innervate most internal organs. The **sympathetic branch** is regulated by the neurotransmitters

epinephrine (adrenaline) and **norepinephrine** (noradrenaline). When activated, the sympathetic branch produces the **fight-or-flight response** in which heart rate increases, ventilation increases, blood pressure increases, and digestion decreases. These responses prepare the body for immediate action.

The **parasympathetic branch** is antagonistic to the sympathetic branch and is the default system used for relaxation. Generally, it decreases heart rate, decreases ventilation rate, decreases blood pressure, and increases digestion. The neurotransmitter **acetylcholine** is the primary regulator of this system.

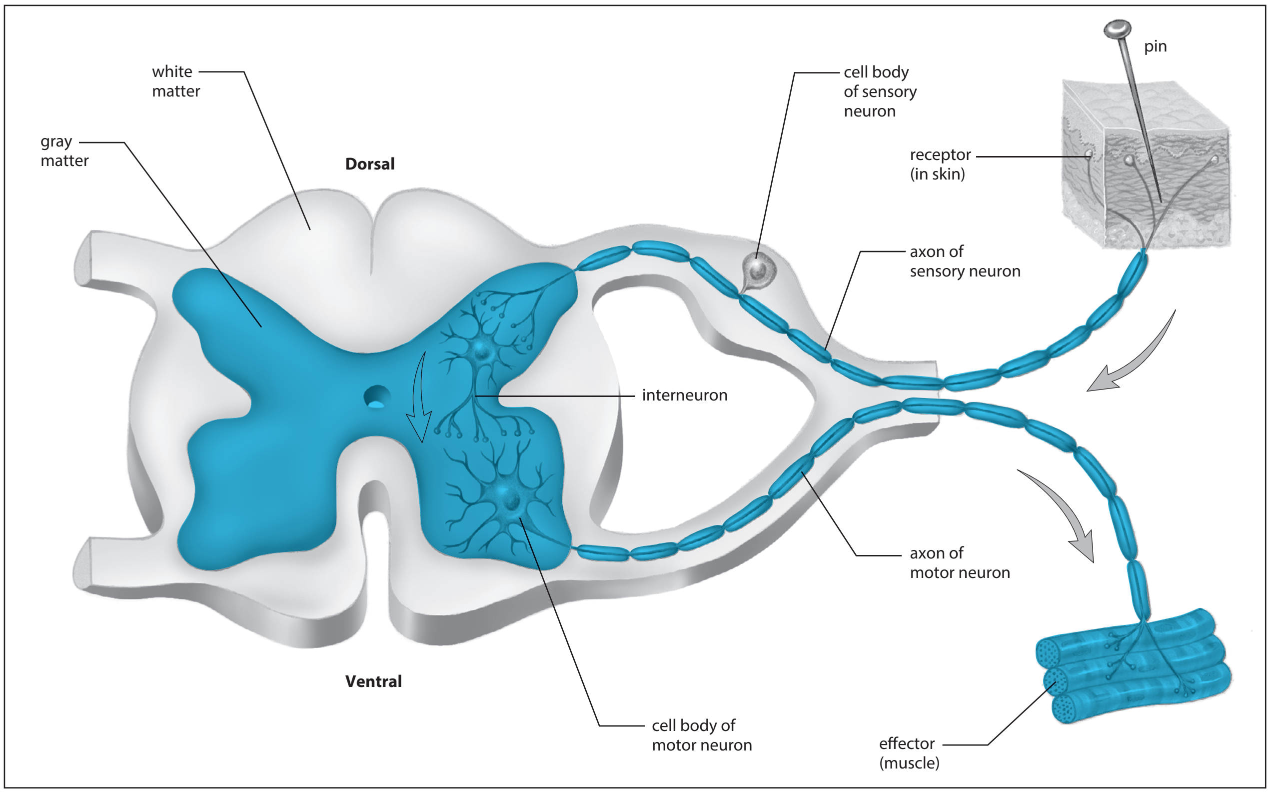

FIGURE 8-5 A reflex arc. A stimulus is carried by a sensory neuron to interneurons located in the spinal cord, which relays messages to motor neurons. *Source:* From Sylvia S. Mader, *Biology*, 8th ed., McGraw-Hill, 2004; reproduced with permission of The McGraw-Hill Companies.

BIOSIGNALING

There are many mechanisms by which **biosignaling** is achieved. Gated ion channels have already been exemplified in action and resting potentials. Another means for biosignaling is the use of **G protein–coupled receptors**. These transmembrane receptors are able to sense various molecules—such as hormones, growth factors, and neurotransmitters—to activate signal transduction pathways within cells. They essentially allow cells to gather information from their environment and to act on that information by changing cell functioning.

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Each type of G protein–coupled receptors displays high levels of specificity to unique signals. Humans are thought to have as many as 1000 different types of G protein–coupled receptors, each specific to a unique signal. The G protein–coupled receptors are single polypeptides embedded within the plasma membrane of a cell with portions looping inside and outside of the cell. Signaling molecules bind at the extracellular loops. The structure of G protein–coupled receptors has been highly conserved over evolutionary time.

When G protein–coupled receptors interact with a signaling molecule, it initiates a conformational change in the receptor. This triggers an interaction between the receptor and G proteins in the plasma membrane. G proteins are named as such because they have the ability to bind to **guanosine triphosphate** (GTP) and **guanosine diphosphate** (GDP). When G proteins are active, they can interact with other membrane proteins via signal transduction, ultimately relaying messages in the cell, typically by the use of second messenger systems. A simplified diagram of this process can be seen in Figure 8-6.

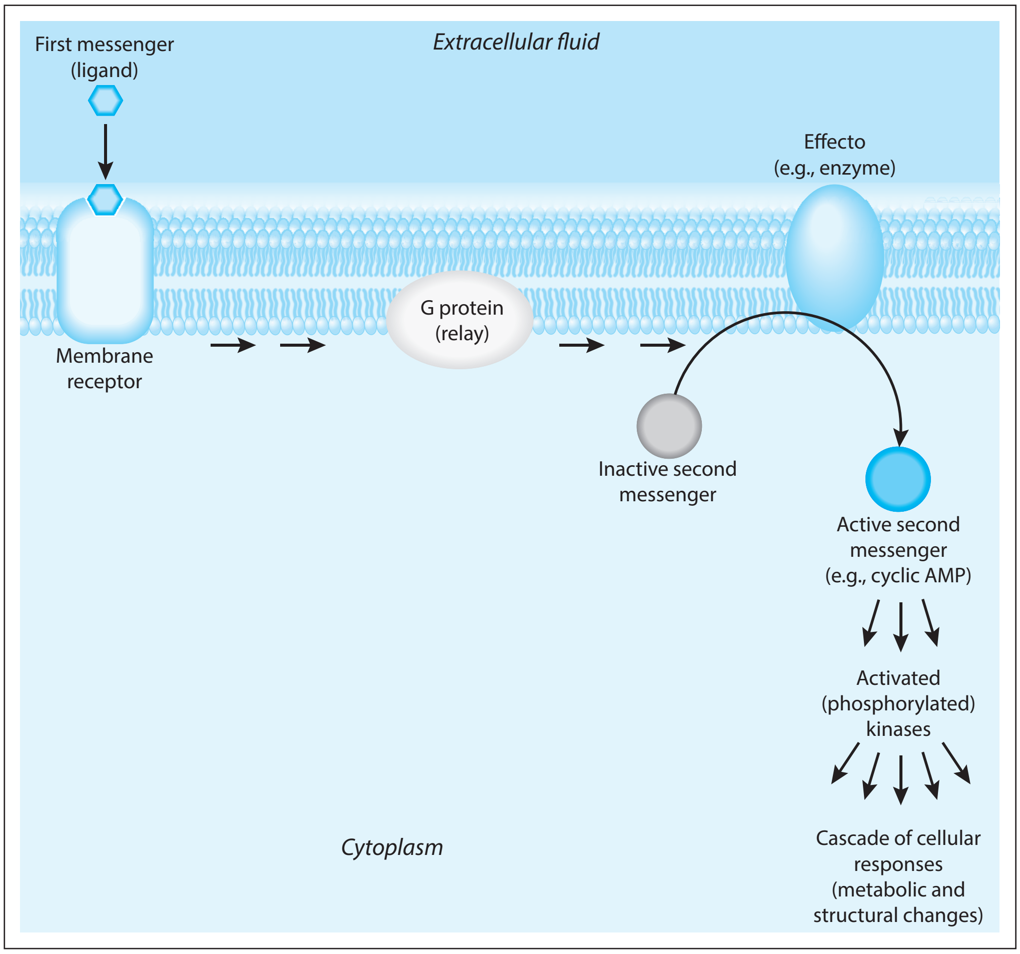

FIGURE 8-6 G protein–coupled receptors.

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A common target of activated G proteins is adenylyl cyclase that catalyzes the synthesis of **cyclic adenosine monophosphate** (cAMP) from ATP. In humans, cAMP is involved in signaling in many systems of the body, including the nervous and endocrine systems. The enzyme **phospholipase C** also serves as a target for activated G proteins. This enzyme is involved in the synthesis of the second messengers diacylglycerol (DAG) and inositol triphosphate (IP3) from phosphatidylinositol in plasma membranes. These second messengers are important in various responses through the body, including the blood-clotting pathways.

THE SENSES

Sensory receptors located throughout the body are able to communicate with the nervous system, ultimately allowing for the perception of sensory information via the senses. There are various types of sensory receptors that differ based on the stimulus to which they are sensitive. Typical sensory receptors in the body, as well as the stimulus they are sensitive to, are seen in the following table.

TABLE 8-2 Sensory Receptors and their Stimuli

Receptor	Stimulus Detected	Functions or Senses
Chemoreceptors	Chemicals	Gustation (taste) and olfaction (smell)
Thermoreceptors	Temperature	Monitoring body temperature
Photoreceptors	Light	Vision
Mechanoreceptors	Pressure	Tactile perception in the skin, proprioception (sense of body awareness), hearing, and equilibrium
Pain receptors	Pressure and chemicals	Conveys messages to the CNS concerning tissue damage

Receptor Potential

Each sensory receptor is sensitive to a particular stimulus. The intensity of the stimulus is conveyed by a graded **receptor potential**. The greater the stimulus, the larger the receptor potential will be. When the receptor potential hits the threshold level, an **action potential** is generated. Over time, most sensory receptors stop responding to repeated stimuli in the process of sensory adaptation so that action potentials are no longer generated and you are no longer aware of the stimulus.

The Special Senses

The special senses of the body include taste, smell, hearing, balance (equilibrium), and vision. The receptors for each of the special senses are located within the head in specialized structures.

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TASTE

The sense of taste relies upon **chemoreceptors** located **within taste buds on the tongue** and, to a lesser degree, in other parts of the mouth. Five primary sensations can be perceived by the receptors of the tongue. These include sweet, sour, salty, bitter, and umami. These can be stimulated independently or in combinations to produce the perception of a variety of tastes. Different regions of the tongue have different sensitivities to particular tastes. In addition to information provided by chemoreceptors located within the taste buds, a large portion of the perception of taste is actually dependent on the sense of smell.

SMELL

The **chemoreceptors** for olfaction (smell) are located in small patches in the top of each nasal cavity and are covered in mucus. When chemicals from the air dissolve in mucus, they stimulate the receptors. The message from the receptor eventually makes its way to the cerebrum as well as to the limbic system. Unlike the chemoreceptors in the mouth, those in the nose are sensitive to about 1,000 different chemicals. Combinations of signals from several receptors allow people to perceive more than 10,000 different scents.

HEARING AND EQUILIBRIUM

The structures of the ear seen in Figure 8-7 are responsible for the sense of hearing as well as the sense of balance or equilibrium. **Mechanoreceptors** in the ear are sensitive to pressure and sound waves that enter the outer ear. The structures of the **outer ear** consist of the **pinna**, which funnels sound waves toward the **auditory canal**. Once in the auditory canal, sound waves need to travel to the middle ear.

The **middle ear** contains the **tympanic membrane** (eardrum), which produces vibrations in response to sound waves. **Ossicles**, three bones in the middle ear (the malleus, incus, and stapes) amplify the signal as it moves toward the inner ear.

The **inner ear** consists of a variety of structures. The amplified signals from the ossicles will reach the **cochlea**. Inside the cochlea exists the **organ of Corti**, which contains specialized mechanoreceptors called **hair cells** that contain fluid with small "hairs" on the surface. When the fluid in the hair cells vibrates, the hairs send a message that is transduced into action potentials. These action potentials travel via the auditory nerve to the cerebrum for processing.

The **vestibular apparatus** within the inner ear is used to maintain a sense of equilibrium. Within the vestibular apparatus, **semicircular canals** of the inner ear contain hair cells filled with fluid. This fluid moves during motion of the head, changing the positioning of the hairs within the cell. The hair cells then send a message to the cerebrum for processing regarding the positioning of the head. The vestibular apparatus also contains the **vestibule**, which helps in the perception of balance when the head and body are not moving.

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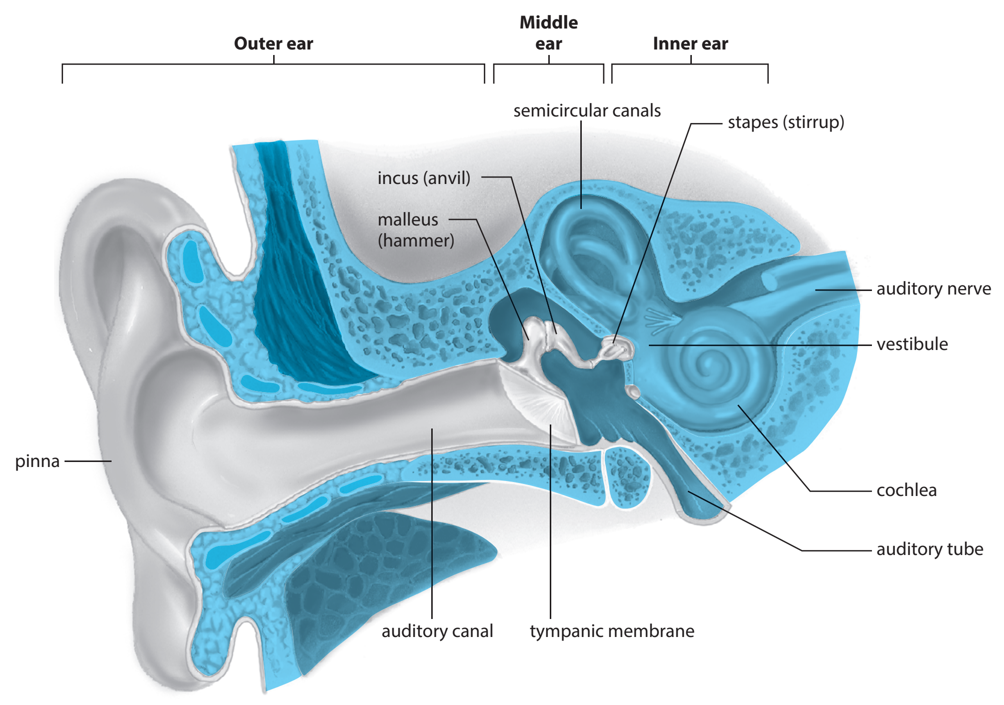

FIGURE 8-7 Ear structure. The outer ear collects sound waves, which then pass to the middle ear, where the sound waves are amplified. The inner ear is responsible for both hearing and equilibrium. *Source:* From Sylvia S. Mader, *Biology*, 8th ed., McGraw-Hill, 2004; reproduced with permission of The McGraw-Hill Companies.

VISION

The eyes are responsible for vision and contain two types of **photoreceptors** that are sensitive to different forms of light. The **rods** are used for night vision and black-and-white vision, while the **cones** are used for color vision. Cones come in three varieties and are sensitive to red, blue, or green light.

The eye has three layers. The outer layer is the **sclera** or the white of the eye. The middle layer of the eye is the **choroid**, which is used to supply oxygen and nutrients to other tissues of the eye. The inner layer of the eye is the **retina**, which contains photoreceptors and is connected to the optic nerve.

Light waves enter the eye through the transparent **cornea**, which protects the underlying lens of the eye seen in Figure 8-8. As light enters the cornea, it moves through the **pupil**. The diameter of the pupil can be adjusted by the **iris** that surrounds it. The **lens** focuses the light into an image on the retina located at the back of the eye. The rods and cones convert the image into patterns, which are sent to the cerebrum for processing via the **optic nerves**. The area where the optic nerve leaves the retina is lacking in photoreceptors and is commonly referred to as the **blind spot**.

The shape of pigments located in the rods and cones is modified when a stimulus is received. These modified pigments change the membrane permeability, resulting in a receptor potential that will ultimately produce an action potential that can be

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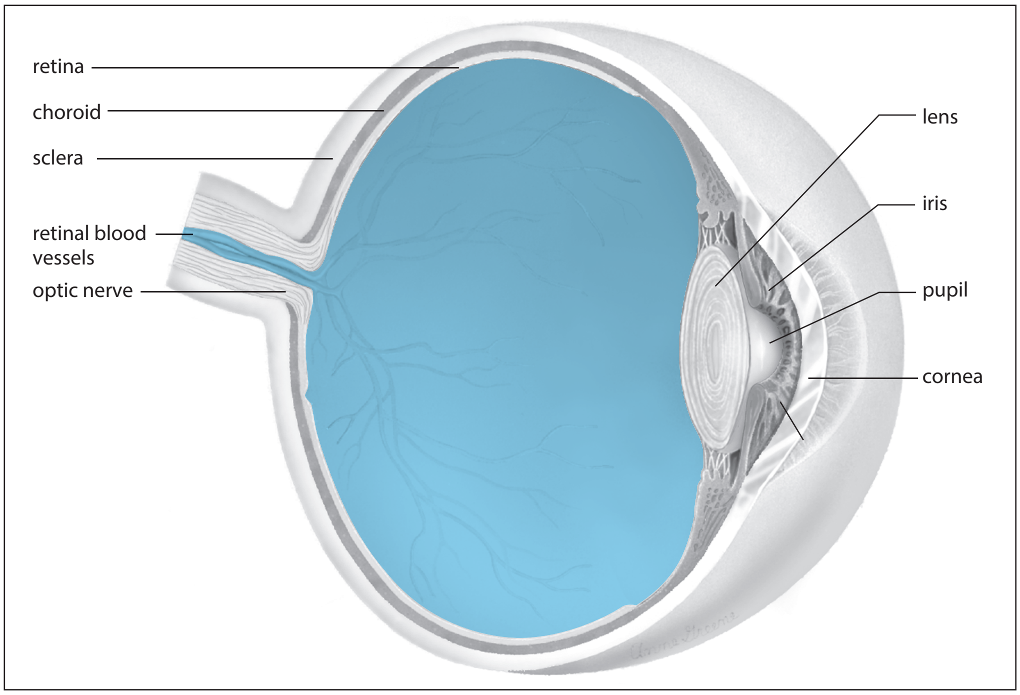

FIGURE 8-8 Eye structure. The photoreceptors for vision are located in the retina on the inner layer of the eye. *Source:* From Sylvia S. Mader, *Biology*, 8th ed., McGraw-Hill, 2004; reproduced with permission of The McGraw-Hill Companies.

transported by the optic nerves. **Retinol** is a pigment found in rods and cones, which binds to the **protein opsin**. Rods and each kind of cone all have a different form of opsin that can be distinguished from each other. The specific opsin found in rods is rhodopsin. Modification of any type of opsin results in stimulation of the receptor and a message being sent to the cerebrum for processing.

THE ENDOCRINE SYSTEM

To maintain homeostasis in the body, it is necessary to regulate the functioning of specific targets within the body. The endocrine system functions in this regulation. It is made up of endocrine glands located throughout the body. These glands secrete hormones that function to achieve this regulation.

Endocrine Glands

As stated previously, **endocrine glands** secrete hormones into the bloodstream. Some endocrine structures also have the ability to serve exocrine functions as well. An **exocrine gland** secretes its products onto a surface, into a body cavity, or within organs. The **pancreas** is an example of a gland with endocrine and exocrine functions.

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Its ability to secrete the hormones insulin and glucagon into the blood qualifies it as an endocrine gland, while its ability to secrete digestive enzymes into the small intestine also qualifies it as an exocrine gland.

The endocrine system is composed of endocrine glands located throughout the body. There are some glands that specialize at endocrine function, while others have multiple functions, at least one of which is the secretion of hormones. The major endocrine glands can be seen in Figure 8-9.

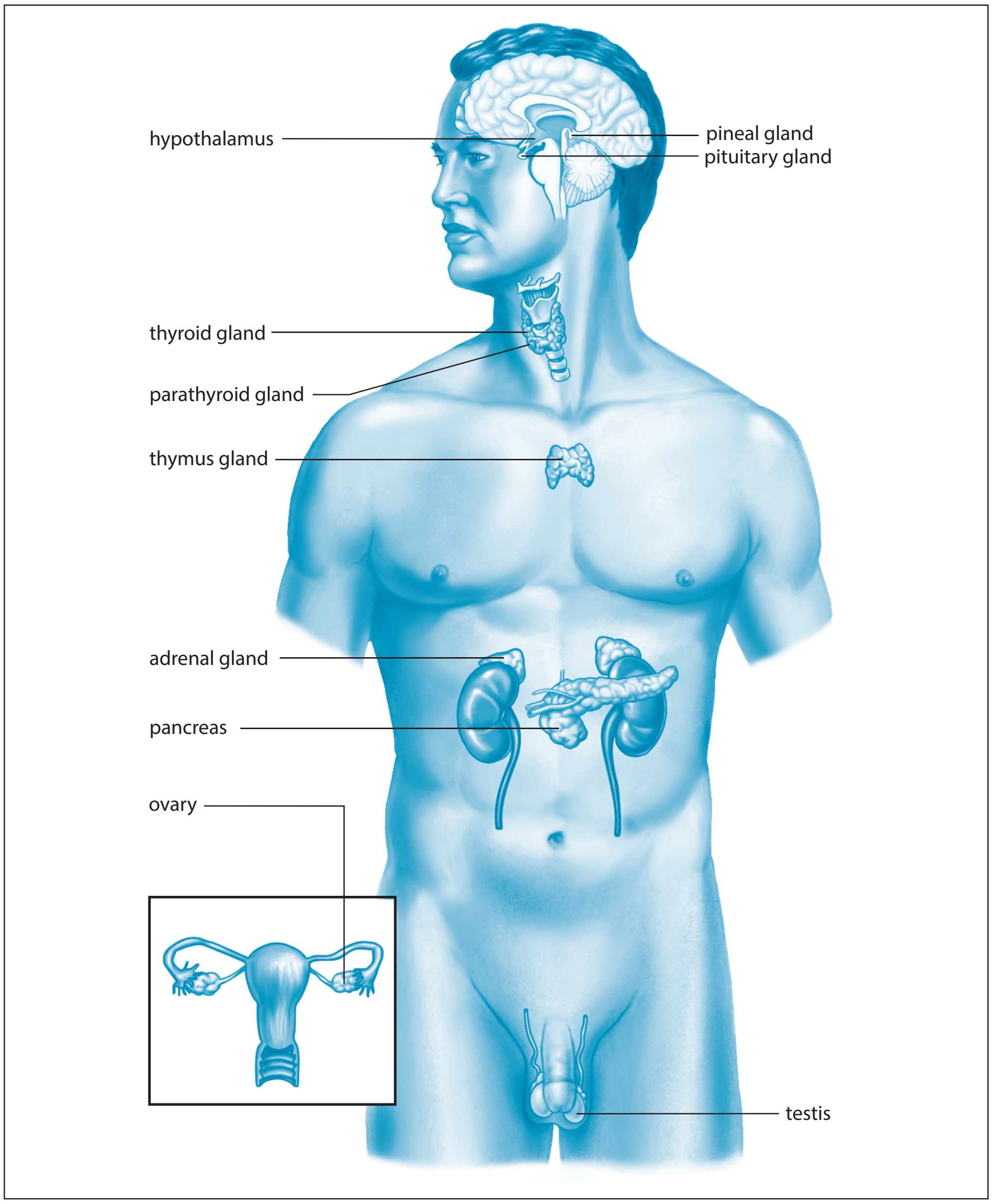

FIGURE 8-9 The endocrine system. Anatomic location of major endocrine structures of the body. *Source:* From Sylvia S. Mader, *Biology*, 8th ed., McGraw-Hill, 2004; reproduced with permission of The McGraw-Hill Companies.

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Hormones

A **hormone** is a chemical messenger secreted into the bloodstream that travels to a specific target in the body and changes the functioning of that target. The target can be individual cells, tissues, or entire organs.

There are two major categories of hormones: steroids (lipid-soluble) and nonsteroids (water-soluble, peptide). **Steroid hormones** are derivatives of the lipid cholesterol and are produced from terpenoid precursors, whereas **nonsteroid hormones**: (peptide hormones) are made of either modified amino acids or small proteins. The target cell receptors for steroid hormones exist in the cytoplasm of the cell, while the receptors for nonsteroid hormones exist on the cell membrane of the cell.

Hormone secretion is regulated by several mechanisms, and the different types of hormones function in different ways in the cell.

REGULATION OF HORMONE SECRETION

The secretion of hormones is usually regulated via **negative feedback mechanisms**. During negative feedback, the response of the endocrine system or a target is the opposite of a stimulus. For example, if the level of a specific hormone gets particularly high (the stimulus), then the secretion of that hormone will be reduced (opposite of the stimulus). Additionally, some conditions such as low blood calcium (the stimulus) may trigger the release of hormones to cause an opposite response (the breakdown of bone tissue to increase blood calcium levels). It is not uncommon to see **antagonistic hormones**—two hormones with opposing functions, such as a hormone to raise blood sugar and another to lower blood sugar. Being able to adjust a particular situation in the body from high and low ends is necessary to maintain **homeostasis**. Failure of the endocrine system to maintain homeostasis can lead to conditions such as diabetes, hyper- or hypothyroidism, growth abnormalities, and many others.

Although not nearly as common as negative feedback mechanisms, **positive feedback mechanisms** do exist. In this case, the stimulus causes actions in the body (regulated by hormones) that further amplify that stimulus, moving the body away from homeostasis. While this may sound like a bad thing, it is necessary in some cases, such as childbirth, where one hormone amplifies another. Positive feedback mechanisms are short lived, and eventually homeostasis is returned via lack of stimulus.

The nervous system can override endocrine feedback mechanisms in some cases. When the body is extremely stressed or experiencing trauma, the nervous system can exert control over the endocrine system to make adjustments to help the body cope with the situation. The **hypothalamus** in the brain is the main link between the endocrine and nervous systems. The hypothalamus monitors body conditions and makes changes when it deems appropriate. It produces regulatory hormones that influence glands such as the pituitary, which, in turn, regulates other glands in the endocrine system.

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Hormone Specificity

Because hormones travel through the bloodstream, they encounter countless potential targets as they circulate. The specificity of hormones is based on their interaction with a receptor on the target cells. Only cells that have a receptor for a specific hormone will be affected by that hormone. Once a hormone binds to the receptor, the cells functioning will be changed in some way. These changes can involve gene expression, chemical reactions, membrane changes, metabolism, and so forth. Because the hormones must travel through the blood, it is a relatively slow process.

Mechanisms of Action of Hormones

As stated earlier, the two types of hormones differ in their chemical composition, receptor sites, and mechanisms of action. The target cell receptors for steroid hormones exist in the cytoplasm of the cell, while the receptors for nonsteroid hormones exist on the cell membrane of the cell. These differences affect the mechanism of action of the two types of hormones.

STEROID HORMONE MECHANISM OF ACTION

Steroids are derivatives of cholesterol, which are lipid soluble and can easily cross the plasma membrane. Once inside a cell, the steroid locates and binds to a cytoplasmic receptor. The steroid-receptor complex moves into the nucleus and interacts with DNA to cause activation of certain genes. This serves as the signal to initiate transcription and translation so that a new protein is expressed by the cell. This new protein will in some way change how the cell is functioning. A summary of steroid hormone action can be seen in Figure 8-10.

PEPTIDE HORMONE MECHANISM OF ACTION

Peptide hormones are composed of amino acid derivatives or small proteins and do not cross the plasma membrane. They recognize a receptor on the plasma membrane surface. The hormone itself is termed a **first messenger**, since it will never enter the cell and only triggers a series of events within the cell, many of which are moderated by G proteins found in the plasma membrane. The binding of the hormone to the receptor initiates a series of reactions in the cell, which ultimately lead to the production of a second messenger molecule within the cell. A common second messenger of nonsteroid hormones is **cyclic adenosine monophosphate** (cAMP). Cyclic AMP is a derivative of ATP. The second messenger changes the function of the target cell by altering enzymatic activities and cellular reactions. A summary of nonsteroid hormone action can be seen in Figure 8-11.

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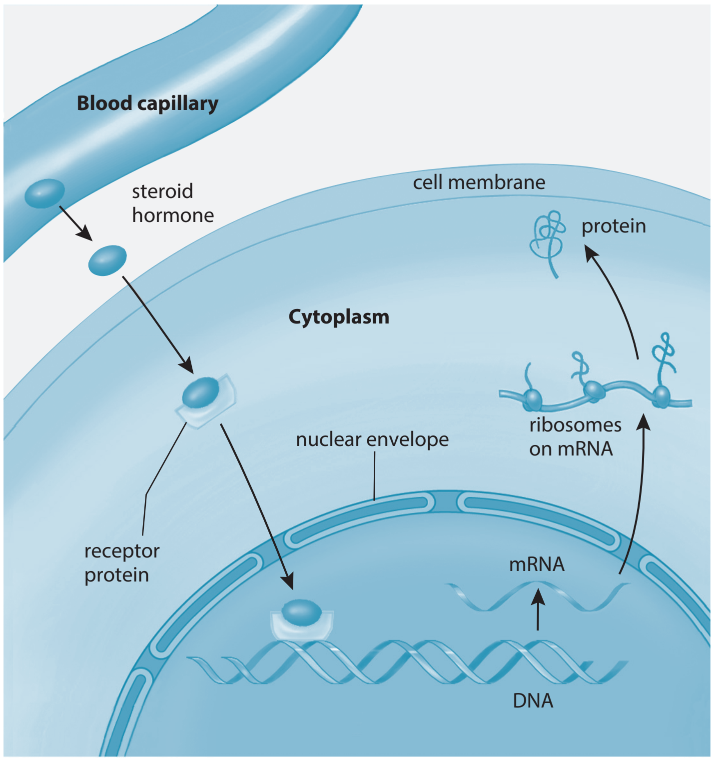

FIGURE 8-10 Steroid hormone mechanism of action. Steroid hormones act only on the cells in which they find their receptors in the cytoplasm of the cell. *Source:* From Sylvia S. Mader, *Biology*, 8th ed., McGraw-Hill, 2004; reproduced with permission of The McGraw-Hill Companies.

Other Chemical Messengers

In addition to steroid and nonsteroid hormones, there is another category of chemical messengers—the **prostaglandins**. These are lipid-based molecules released from cell membranes, not from endocrine glands. Prostaglandins function as a sort of local hormone involved in functions as diverse as regulation of body temperature, blood clotting, the inflammatory response, and menstrual cramping caused by uterine contractions.

Major Endocrine Glands and Their Products

The major endocrine glands of the body include the hypothalamus, pituitary gland (separated into the anterior lobe and posterior lobe), pineal gland, thyroid gland, parathyroid glands, and adrenal glands. Some organs within the body also have endocrine functions and these include the thymus gland, ovaries, testes, pancreas, heart, placenta, kidneys, stomach, and small intestine.

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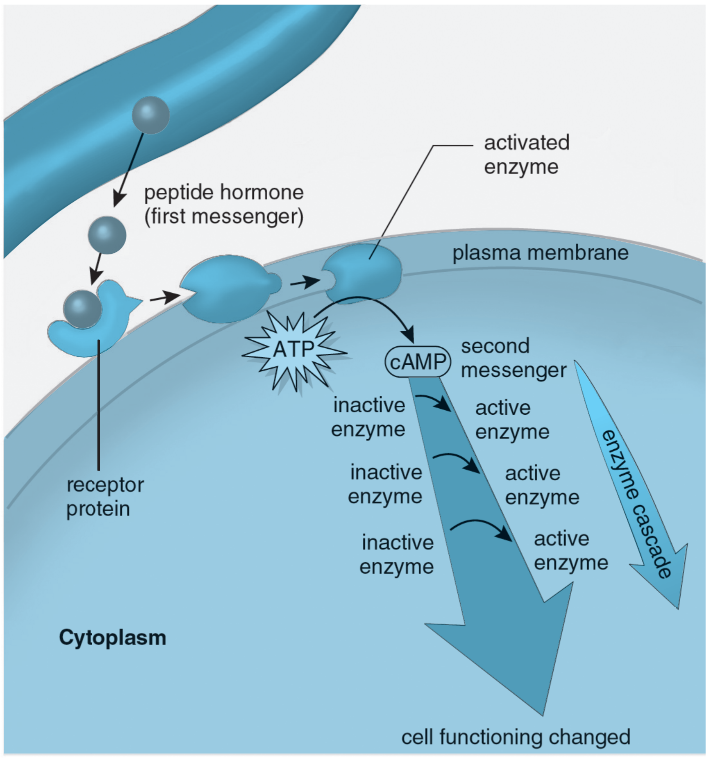

FIGURE 8-11 Nonsteroid hormone mechanism of action. Nonsteroid (peptide) hormones serve as first messengers and find their receptors on the cell membrane of the cell. *Source:* From Sylvia S. Mader, *Biology*, 8th ed., McGraw-Hill, 2004; reproduced with permission of The McGraw-Hill Companies.

The **hypothalamus** and **pituitary gland** have a unique relationship based on their proximity to each other in the brain, as seen in Figure 8-12. The pituitary gland secretes many hormones; some of these hormones influence the secretion of hormones from other endocrine glands. The regulatory hormones made by the hypothalamus control the secretion of hormones from the anterior pituitary. The hypothalamus produces releasing hormones that stimulate the release of anterior pituitary hormones as well as inhibiting hormones, which inhibit the release of hormones from the anterior pituitary. The hypothalamus also makes antidiuretic hormone and oxytocin, but both are stored and released from the posterior pituitary.

The following table lists the major hormones and the glands that produce them. Unless marked with an asterisk, each of these hormones is a nonsteroid.

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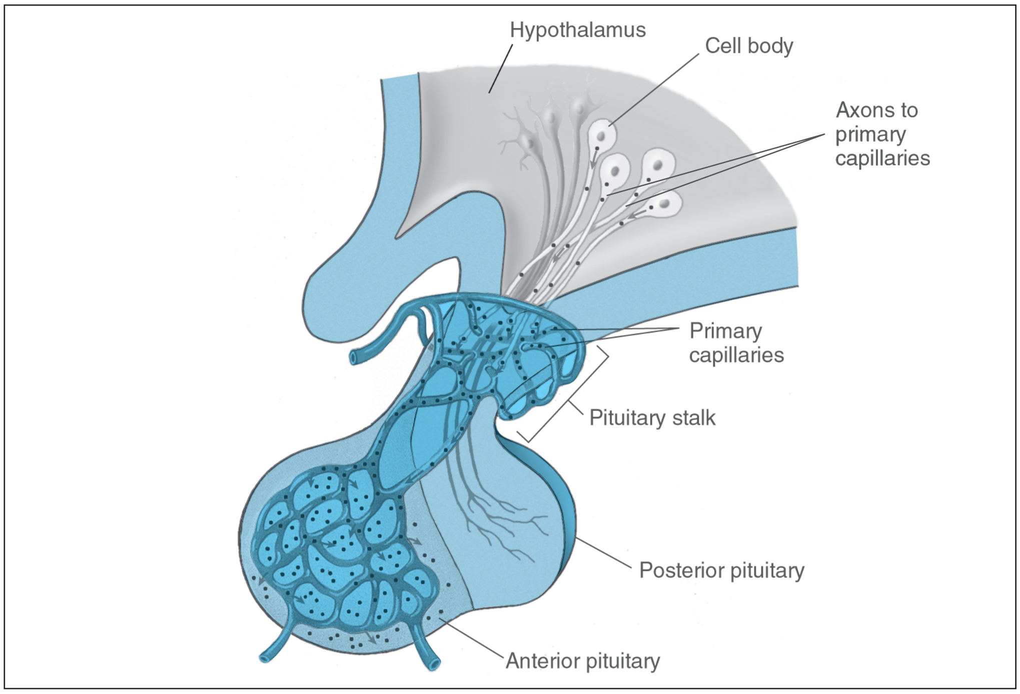

FIGURE 8-12 The hypothalamus and the pituitary gland. The hypothalamus produces regulatory hormones that travel to the pituitary gland. *Source:* From George B. Johnson, *The Living World*, 3rd ed., McGraw-Hill, 2003; reproduced with permission of The McGraw-Hill Companies.

TABLE 8-3 Endocrine Structures and the Hormones That They Make (*Steroid Hormones)

Endocrine Structure	Hormones Made and Function
Anterior pituitary	• **Follicle-stimulating hormone (FSH):** in women, FSH stimulates the secretion of estrogen in the ovaries and assists in egg production via meiosis; in men, FSH has a role in sperm production. • **Luteinizing hormone (LH):** in women, LH stimulates the production of estrogen and progesterone by the ovaries and causes ovulation; in men, LH is involved in testosterone secretion from the testes. • **Thyroid-stimulating hormone (TSH):** stimulates the thyroid gland • **Growth hormone (GH):** stimulates growth of muscle, bone, and cartilage • **Prolactin (PRL):** stimulates the production of milk • **Adrenocorticotropic hormone (ACTH):** stimulates the cortex of the adrenal glands • **Endorphins:** act on the nervous system to reduce the perception of pain
Posterior pituitary (these hormones are made by the hypothalamus but are released by the posterior pituitary)	• **Antidiuretic hormone (ADH):** allows for water retention by the kidneys and decreases urine volume; also known as vasopressin • **Oxytocin (OT):** causes uterine contractions during childbirth; also stimulates milk ejection

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TABLE 8-3 Endocrine Structures and the Hormones That They Make (*Steroid Hormones) (cont.)

Endocrine Structure	Hormones Made and Function
Pineal gland	• **Melatonin:** influences patterned behaviors such as sleep, fertility, and aging
Thyroid gland	• **Thyroid hormone (TH):** regulates metabolism throughout the body; also acts on the reproductive, nervous, muscular, and skeletal systems to promote normal functioning; T3 and T4 require iodine to function properly • **Calcitonin (CT):** influences osteoblasts, which build bone in response to high blood calcium levels; ultimately lowers blood calcium levels
Parathyroid glands	• **Parathyroid hormone (PTH):** influences osteoclasts, which break down bone in response to low blood calcium levels; this ultimately increases blood calcium levels; PTH is antagonist to CT
Adrenal medulla (inner portion of the adrenals)	• **Epinephrine:** released in response to stress; causes fight-or-flight response; also known as adrenaline • **Norepinephrine:** released in response to stress; causes fight-or-flight response; also known as noradrenaline
Adrenal cortex (outer portion of the adrenals)	• **Glucocorticoids*:** help cells convert fats and proteins into molecules that can be used in cellular respiration to make ATP; high levels inhibit the inflammatory response of the immune system; examples are cortisol and cortisone • **Mineralocorticoids*:** increase sodium retention by the kidneys and potassium excretion; an example is aldosterone • **Gonadocorticoids*:** secreted in small amounts; examples are androgens and estrogens
Thymus	• **Thymopoietin:** stimulates the maturation of certain white blood cells involved with the immune system (T cells); decreases with age as the thymus gland atrophies • **Thymosin:** stimulates the maturation of certain white blood cells involved with the immune system; decreases with age as the thymus gland shrivels
Ovaries	• **Estrogen*:** involved in the development of female secondary sex characteristics as well as follicle development and pregnancy • **Progesterone*:** involved in uterine preparation and pregnancy
Testes	• **Testosterone*:** a type of androgen needed for the production of sperm as well as for the development and maintenance of male secondary sex characteristics
Pancreas	• **Insulin:** decreases blood sugar after meals by allowing glucose to enter cells to be used for cellular respiration; a lack of insulin or lack of response by cell receptors to insulin is the cause of diabetes mellitus; made by the beta islet cells • **Glucagon:** increases blood sugar levels between meals by allowing for the breakdown of glycogen; antagonistic to insulin; made by the alpha islet cells
Heart	• **Atrial natriuretic peptide (ANP):** made by the heart to lower blood pressure

(*Continued*)

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TABLE 8-3 Endocrine Structures and the Hormones That They Make (*Steroid Hormones) (cont.)

Endocrine Structure	Hormones Made and Function
Kidneys	• **Renin/angiotensin:** used to regulate blood pressure by altering the amount of water retained by the kidneys • **Erythropoietin (EPO):** stimulates the production of red blood cells from stem cells in the red bone marrow
Stomach	• **Gastrin:** released when food enters the stomach; causes the secretion of gastric juice needed to begin the digestion of proteins
Small intestine	• **Cholecystokinin (CCK):** stimulates the release of pancreatic digestive enzymes to the small intestine; also stimulates the release of bile from the gallbladder to the small intestine • **Secretin:** stimulates the release of fluids from the pancreas and bile that are high in bicarbonate to neutralize the acids from the stomach
Placenta (temporary organ during pregnancy)	• **Human chorionic gonadotropin (HCG):** signals the retention of the lining of the uterus (endometrium) during pregnancy • **Relaxin:** used to release ligaments attaching the pubic bones to allow for more space during childbirth • **Estrogen:** needed to maintain pregnancy • **Progesterone:** needed to maintain pregnancy