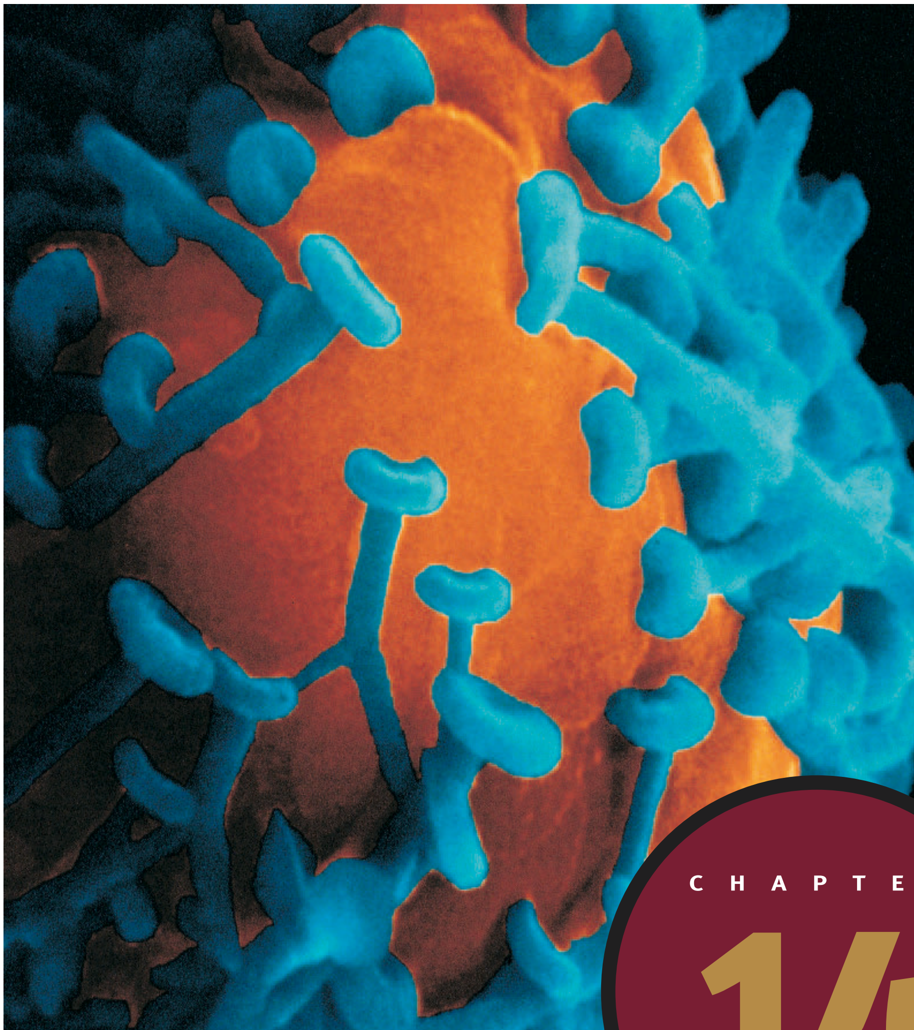


Colorized SEM of presynaptic terminals associated with a postsynaptic neuron.

Integration of Nervous System Functions

CHAPTER

14

The nervous system is involved in almost all bodily functions. Although humans have larger, more complex brains than other animals, many human nervous system functions are similar to those of other animals. The sensory input we receive and most of the ways we respond to that input are not uniquely human functions. Yet, the human brain is also capable of unique and complex functions, such as recording history, reasoning, and planning, to a degree unparalleled in the animal kingdom. Many of these functions can only be studied in humans. That's why much of human brain function remains elusive and why an understanding of the human brain remains one of the most challenging frontiers of anatomy and physiology.

This chapter presents the concept of *sensation* (466) and then discusses the *control of skeletal muscles* (478), the *brainstem functions* (485), *other brain functions* (487), and the *effects of aging on the nervous system* (493).

Sensation

Objectives

- *Name the senses and describe how sensations occur.*
- *Describe the different types of sensory receptors and the stimuli they detect.*
- *Describe the sensory nerve tracts and how awareness of stimuli occur.*
- *Describe the major functional areas of the cerebral cortex and explain their interactions.*

The **senses** are the means by which the brain receives information about the environment and the body. Historically, five senses were recognized: smell, taste, sight, hearing, and touch. Today, the senses are divided into two basic groups: general and special senses. The **general senses** are those with receptors distributed over a large part of the body. They are divided into two groups: the somatic and visceral senses (table 14.1). The **somatic senses,** which provide sensory information about the body and the environment, include touch, pressure, temperature, proprioception, and pain. The **visceral senses,** which provide information about various internal organs, consist primarily of pain and pressure.

Special senses are more specialized in structure and are localized to specific parts of the body (see table 14.1). The special senses are smell, taste, sight, hearing, and balance. Chapter 15 considers the special senses in detail.

Sensation, or **perception,** is the conscious awareness of stimuli received by sensory receptors. The brain constantly receives a wide variety of stimuli from both inside and outside the body. Stimulation of sensory receptors does not immediately result in sensation. Sensory receptors respond to stimuli by generating action potentials that are propagated to the spinal cord and brain. Sensations result when action potentials reach the cerebral cortex. Some other parts of the brain are involved in sensation. For example, the thalamus is involved in the sensation of pain.

Awareness

Not all of the sensory information detected by sensory receptors results in sensation. Some action potentials reach areas of the brain where they are not consciously perceived. For example, although we are consciously aware of body position and movements, much of this sensory information is propagated to the cerebellum, where it is processed on an unconscious level. Sensory information from receptors that monitor blood pressure, blood oxygen, and pH levels are processed unconsciously by the medulla oblongata. For example, blood pressure must be regulated to maintain homeostasis. If we had to consciously regulate blood pressure we might not be able to think of much else.

The cerebral cortex screens much of what it receives, ignoring many of the action potentials that reach it. In addition, humans exhibit selective awareness. That is, we are more aware of sensations on which we have our attention focused than on other sensations. The CNS cannot be consciously aware of all stimuli. If we were simultaneously aware of all the stimuli that the brain constantly receives, it's unlikely we would be able to function. Being aware of so many stimuli would require us to constantly make conscious decisions about the stimuli to which we should respond. Instead, homeostasis is controlled largely without our conscious involvement. For example, as you read this paragraph, it's unlikely that you are aware of the weight of the book in your hands if you are holding it, or the weight of your arms on the desk or on your lap if you are reading at a desk. It's unlikely that you are aware of the small noises around you or the clothes touching your body until your attention is drawn to them. You certainly aren't aware of changes in your blood pressure, body fluid pH, and blood glucose levels.

Sensation requires the following steps:

1. Stimuli originating either inside or outside of the body must be detected by sensory receptors and converted into action potentials, which are propagated to the CNS by nerves.

Table 14.1 Classification of the Senses

Types of Sense	Receptor Type	Initiation of Response
Somatic		
Touch	Mechanoreceptors	Compression of receptors
Pressure	Mechanoreceptors	Compression of receptors
Temperature	Thermoreceptors	Temperature around nerve endings
Proprioception	Mechanoreceptors	Compression of receptors
Pain	Nociceptors	Irritation of nerve endings (e.g., mechanical, chemical, or themal)
Visceral		
Pain	Nociceptors	Irritation of nerve endings
Pressure	Mechanoreceptors	Compression of receptors
Special		
Smell	Chemoreceptors	Binding of molecules to membrane receptors
Taste	Chemoreceptors	Binding of molecules to membrane receptors
Sight	Photoreceptors	Chemical change in receptors initiated by light
Hearing	Mechanoreceptors	Bending of microvilli on receptor cells
Balance	Mechanoreceptors	Bending of microvilli on receptor cells

2. Within the CNS, nerve tracts convey action potentials to the cerebral cortex and to other areas of the CNS.
3. Action potentials reaching the cerebral cortex must be translated so the person can be aware of the stimulus.

Sensory Receptors

Types of Sensory Receptors

The different senses depend upon sensory receptors specialized to respond to specific types of stimuli (see table 14.1). **Mechanoreceptors** respond to mechanical stimuli, such as compression, bending, or stretching of cells. The senses of touch, pressure, proprioception, hearing, and balance all depend on a variety of mechanoreceptors. **Chemoreceptors** respond to chemicals that become attached to receptors on their membranes. Smell and taste depend on chemoreceptors. **Thermoreceptors** respond to changes in temperature at the site of the receptor and are necessary for the sense of temperature. **Photoreceptors** respond to light striking the receptor cells and are necessary for vision. **Nociceptors** (nō-si-sep′ters; Latin, *noceo* means hurt), or **pain receptors,** respond to painful mechanical, chemical, or thermal stimuli. Most sensory receptors typically respond to one type of stimulus, but some nociceptors respond to more than one type of stimulus.

At least eight major types of sensory nerve endings, which differ in their structure and the types of stimuli to which they are most sensitive, are involved in general sensation (table 14.2 and figure 14.1). Many of these nerve endings are associated with the skin; others are associated with deeper structures, such as tendons, ligaments, and muscles; and some can be found in both the skin and deeper structures. In general, sensory nerve endings are classified into three groups based on their location: **exteroreceptors** (cutaneous receptors) are associated with the skin, **visceroreceptors** are associated with the viscera or organs, and **proprioceptors** are associated with joints, tendons, and other connective tissue. Exteroreceptors provide information about the external environment, visceroreceptors provide information about the internal environment, and proprioceptors provide information about body position, movement, and the extent of stretch or the force of muscular contractions.

Structurally, the simplest and most common sensory nerve endings are the **free nerve endings** (see figure 14.1), which are relatively unspecialized neuronal branches similar to dendrites. Free nerve endings are distributed throughout almost all parts of the body. Most visceroreceptors consist of free nerve endings, which are responsible for a number of sensations, including pain, temperature, itch, and movement. The free nerve endings responsible for temperature detection respond to three types of sensations. One type, the **cold receptors,** increases its rate of action potential production as the skin is cooled. The second type, **warm receptors,** increases its rate of action potential production as skin temperature increases. Both cold and warm receptors respond most strongly to changes in temperature. Cold receptors are 10–15 times more numerous in any given area of skin than warm receptors. The third type is a pain receptor, which is stimulated by extreme cold or heat. At very cold temperatures (0°–12°C), only pain receptors are stimulated. The pain sensation ends as the temperature increases above 15°C. Between 12° and 35°C, cold fibers are stimulated. Nerve fibers from warm receptors are stimulated between 25° and

Table 14.2 Sensory Nerve Endings

Type of Nerve Ending	Structure	Function
Free nerve ending	Branching, no capsule	Pain, itch, tickle, temperature, joint movement, and proprioception
Merkel's disk	Flattened expansions at the end of axons; each expansion associated with a Merkel's cell	Light touch and superficial pressure
Hair follicle receptor	Wrapped around hair follicles or extending along the hair axis, each axon supplies several hairs, and each hair receives branches from several neurons, resulting in considerable overlap	Light touch; responds to very slight bending of the hair
Pacinian corpuscle	Onion-shaped capsule of several cell layers with a single central nerve process	Deep cutaneous pressure, vibration, and proprioception
Meissner's corpuscle	Several branches of a single axon associated with wedge-shaped epitheloid cells and surrounded by a connective tissue capsule	Two-point discrimination
Ruffini's end organ	Branching axon with numerous small, terminal knobs surrounded by a connective tissue capsule	Continuous touch or pressure; responds to depression or stretch of the skin
Muscle spindle	Three to 10 striated muscle fibers enclosed by a loose connective tissue capsule, striated only at the ends, with sensory nerve endings in the center	Proprioception associated with detection of muscle stretch; important for control of muscle tone
Golgi tendon organ	Surrounds a bundle of tendon fascicles and is enclosed by a delicate connective tissue capsule; nerve terminations are branched with small swellings applied to individual tendon fascicles	Proprioception associated with the stretch of a tendon; important in the control of muscle contraction

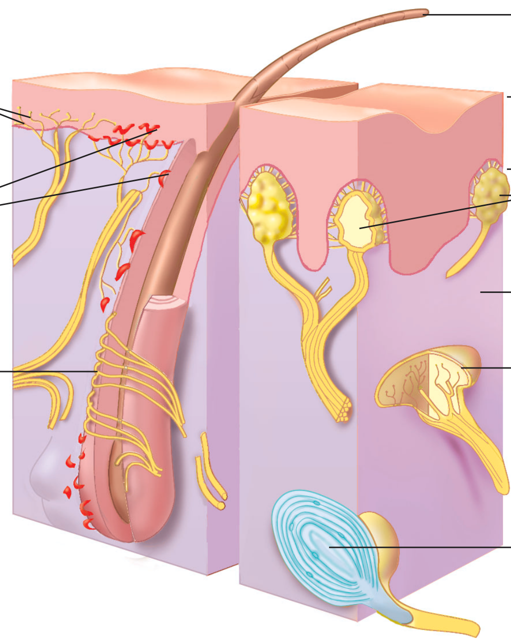


Figure 14.1 Sensory Nerve Endings in the Skin

47°C. "Comfortable" temperatures, between 25° and 35°C, therefore stimulate both warm and cold receptors. Temperatures above 47°C stimulate cold and pain receptors but don't stimulate warm receptors.

P R E D I C T 1

How might a very cold object placed in the hand be misperceived as being hot?

Merkel's (mer′kĕlz), or **tactile, disks,** are more complex than free nerve endings (see figure 14.1) and consist of axonal branches that end as flattened expansions, each associated with a specialized epithelial cell. They are distributed throughout the basal layers of the epidermis just superficial to the basement membrane and are associated with dome-shaped mounds of thickened epidermis in hairy skin. Merkel's disks are involved with the sensations of light touch and superficial pressure. These receptors can detect a skin displacement of less than 1 mm (1/25 of an inch).

Hair follicle receptors, or **hair end organs,** respond to very slight bending of the hair and are involved in light touch (see figure 14.1). These nerve endings are extremely sensitive and require very little stimulation to elicit a response. The sensation, however, is not very well localized. The dendritic tree at the distal end of a sensory axon has several hair follicle receptors. The field of hairs innervated by these receptors overlaps with the fields of hair follicle receptors of adjacent axons. The considerable overlap that exists in the endings of sensory neurons helps explain why light touch is not highly localized, yet because of converging signals within the CNS, it is very sensitive (see chapter 12).

Pacinian (pa-sin′ē-an, pa-chin′ē-an), or **lamellated, corpuscles** are complex nerve endings that resemble an onion (see figure 14.1). A single dendrite extends to the center of each lamellated corpuscle. The corpuscles are located within the deep dermis or hypodermis, where they are responsible for deep cutaneous pressure and vibration. Pacinian corpuscles associated with the joints help relay **proprioceptive** (prō-prē-ō-sep′tiv; perception of position) information about joint positions.

Meissner's (mīs′nerz), or **tactile, corpuscles** are distributed throughout the dermal papillae (see figure 14.1; see chapter 5) and are involved in two-point discrimination touch. **Two-point discrimination** (fine touch) is the ability to detect simultaneous stimulation at two points on the skin. The distance between two points that a person can detect as separate points of stimulation differs for various regions of the body. This sensation is important in evaluating the texture of objects. Meissner's corpuscles are numerous and close together in the tongue and fingertips but are less numerous and more widely separated in other areas such as the back (figure 14.2).

Ruffini's (rū-fē′nēz) **end organs** are located in the dermis of the skin (see figure 14.1), primarily in the fingers. They respond to pressure on the skin directly superficial to the receptor and to stretch of adjacent skin. These nerve endings are important in responding to continuous touch or pressure.

Muscle spindles (figure 14.3) consist of 3–10 specialized skeletal muscle fibers. They are located in skeletal muscles and provide information about the length of the muscle (see "Stretch Reflex" on p. 407). Muscle spindles are important to the control and tone of postural muscles. Brain centers act through descending tracts to either increase or decrease action potentials in gamma motor neurons. Stimulation of the gamma motor system, caused by stretch of the muscle, activates the stretch reflex, which in turn increases the tone of the muscles involved.

Golgi tendon organs are proprioceptive nerve endings associated with the fibers of a tendon near the junction between the

Figure 14.2 Two-Point Discrimination

Two-point discrimination can be demonstrated by touching a person's skin with the two points of a compass. When the two points are close together, the individual perceives only one point. When the two points of the compass are opened wider, the person becomes aware of two points.

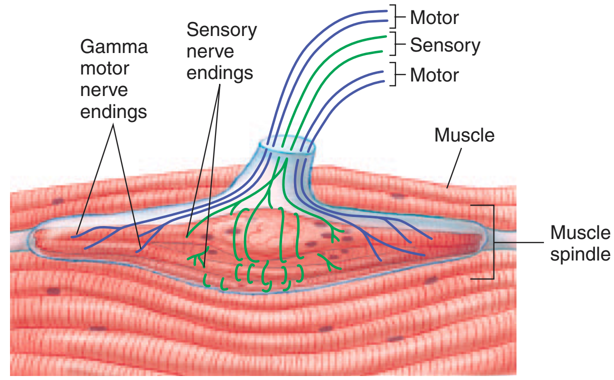


Figure 14.3 Muscle Spindle

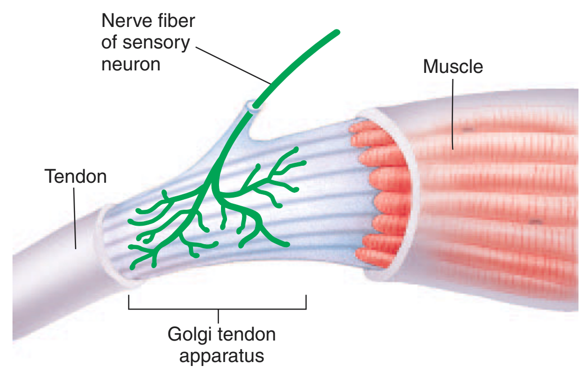


Figure 14.4 Golgi Tendon Organ

muscle and tendon (figure 14.4). They are activated by an increase in tendon tension, whether it's caused by contraction of the muscle or by passive stretch of the tendon.

1. ***In general, into what three groups can sensory nerve endings be classified?***
2. ***List the eight major types of sensory nerve endings, indicate where they are located, and state the functions they perform.***

Responses of Sensory Receptors

Interaction of a stimulus with a sensory receptor produces a local potential called a **receptor,** or **generator, potential.** Some sensory receptor cells, called **primary receptors,** have axons that conduct action potentials in response to the receptor potential. When the ends of these neurons are stimulated, a receptor potential is produced. If it reaches threshold, an action potential is produced and is propagated toward the CNS. Most sensory neurons, including all those in table 14.2, belong to this category. Other receptor cells, called **secondary receptors,** have no axons and the receptor potentials produced in those cells do not result in action potentials. Instead, the receptor potentials cause the release of neurotransmitter molecules from the receptor cell that bind to receptors on the membrane of a neuron. This causes a receptor potential in the neuron, which produces an action potential if threshold is reached. The receptor cells of the special senses of smell, taste, hearing, and balance belong to this category.

Some sensations have the quality of **accommodation,** or **adaptation,** a decreased sensitivity to a continued stimulus. After exposure to a stimulus for a time, the response of the receptors or the sensory pathways to a certain stimulus strength lessens from that which occurs when the stimulus was first applied. The local depolarization that produces a receptor potential accommodates, or returns to, its resting level even though the stimulus is still applied. For example, when a person first gets dressed, tactile receptors and pathways relay information to the brain that create an awareness that the clothes are touching the skin. After a time, the action potentials from the skin decrease, and the clothes are ignored.

Another way that sensations change through time occurs in proprioception. Proprioception provides information about the precise position and the rate of movement of various body parts, the weight of an object being held in the hand, and the range of movement of a joint. This information is involved in activities like walking, climbing stairs, shooting a basketball, driving a car, eating, or writing. Receptors for this system are located around joints and in muscles. Two types of proprioceptors are involved in providing positional information: tonic receptors and phasic receptors. **Tonic receptors** generate action potentials as long as a stimulus is applied and accommodate very slowly. Information from tonic proprioceptors allows a person to know, for example, where the little finger is at all times without having to look for it. **Phasic receptors,** by contrast, accommodate rapidly and are most sensitive to changes in stimuli. For example, information from phasic proprioceptors allows us to know where our hand is as it moves, thus we can control its movement through space and predict where it will be in the next moment.

We are usually not conscious of tonic or phasic input, but through selective awareness we can call up the information when we wish. For example, where is the thumb of your right hand at this moment? Were you aware of its position a few seconds ago?

3. What are primary and secondary receptors? What effect does a receptor potential have on them?
4. Define adaptation. Describe tonic and phasic receptors.

Sensory Nerve Tracts

The spinal cord and brainstem contain a number of sensory pathways that transmit action potentials from the periphery to various parts of the brain. Each pathway is involved with specific modalities (the type of information transmitted). The neurons that make up each pathway are associated with specific types of sensory receptors. For example, thermoreceptors located in the skin generate action potentials that are propagated along the sensory pathway for pain and temperature, whereas Golgi tendon organs located in tendons generate action potentials that are propagated along the sensory pathway involved with proprioception.

The names of most ascending pathways, or tracts, in the CNS indicate their origin and termination (figure 14.5 and table 14.3). Each pathway usually is given a composite name in which the first half of the word indicates its origin and the second half indicates its termination. Ascending pathways therefore usually begin with the prefix *spino-,* indicating that they originate in the spinal cord. For example, a spinothalamic (spī′nō-tha-lam′ik) tract is one that originates in the spinal cord and terminates in the thalamus. An exception to this rule of nomenclature is the dorsal-column/medial-lemniscal system, whose name is a combination of the pathway names in the spinal cord and brainstem. The specific function of each ascending tract, however, is not suggested by its name.

Table 14.3 Ascending Spinal Pathways

Pathway	Modality (Information Transmitted)	Origin	Termination
Spinothalamic		Cutaneous receptors	Cerebral cortex
Lateral	Pain and temperature		
Anterior	Light touch, pressure, tickle, and itch sensation		
Dorsal-column/medial-lemniscal system	Proprioception, two-point discrimination, pressure, and vibration	Cutaneous receptors, joints	Cerebral cortex and cerebellum
Spinocerebellar	Proprioception to cerebellum	Joints, tendons	Cerebellum
Posterior			
Anterior			
Spinoolivary	Proprioception relating to balance	Joints, tendons	Accessory olivary nucleus, then to cerebellum
Spinotectal	Tactile stimulation causing visual reflexes	Cutaneous receptors	Superior colliculus
Spinoreticular	Tactile stimulation arousing consciousness	Cutaneous receptors	Reticular formation

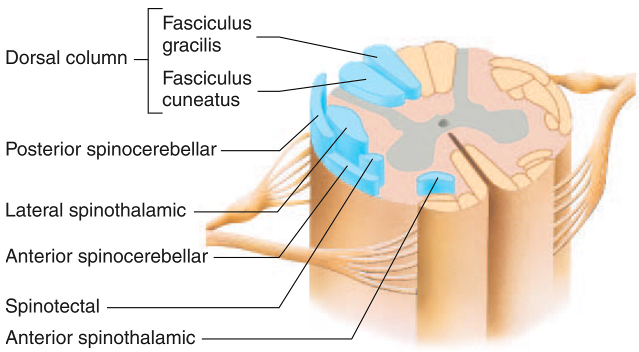


Figure 14.5 Cross Section of the Spinal Cord at the Cervical Level Depicting the Ascending Pathways

Ascending pathways are labeled on the left side of the figure only (*blue*) although they exist on both sides.

The major ascending pathways or tracts involved in the conscious perception of external stimuli are the spinothalamic system and the dorsal-column/medial-lemniscal system (see table 14.3). Those carrying sensations that we are not consciously aware of are the spinocerebellar, spinoolivary, spinotectal, and spinoreticular tracts.

Spinothalamic System

The **spinothalamic system** is one of the two major systems that convey cutaneous sensory information to the brain. Of those two systems it is the least able to localize the source of the stimulus. The spinothalamic system is divided into lateral and anterior spinothalamic tracts. The **lateral spinothalamic tract** (figure 14.6*a*) carries pain and temperature information. The **anterior spinothalamic tract** (figure 14.6*b*) carries light touch, pressure, tickle, and itch sensations. Light touch is also called crude touch (poorly localized); although the receptors of these nerves respond to very light touch, the stimulus is not well localized.

Three neurons in sequence—the primary, secondary, and tertiary—are involved in the pathway from the peripheral receptor to the cerebral cortex. The **primary neuron** cell bodies of the spinothalamic system are in the dorsal root ganglia. The primary neurons relay sensory input from the periphery to the posterior horn of the spinal cord, where they synapse with interneurons. The interneurons, which are not specifically named in the three-neuron sequence, synapse with secondary neurons. Axons from the **secondary neurons** cross to the opposite side of the spinal cord through the anterior portion of the gray and white commissures and enter the spinothalamic tract, where they ascend to the thalamus. The secondary neurons synapse with cell bodies of tertiary neurons in the thalamus. **Tertiary neurons** from the thalamus project to the somatic sensory cortex.

Primary neurons contributing to the lateral spinothalamic tract (pain and temperature) ascend or descend only one or two segments before synapsing with secondary neurons, whereas those entering the anterior spinothalamic tract (light touch and pressure) may ascend or descend for 8–10 segments before synapsing. Throughout this distance the primary neurons of the anterior spinothalamic system send out collateral branches that synapse with secondary neurons at several intermediate levels. Thus collateral branches from a number of sensory neurons, each conducting information from a different patch of skin, may converge on a single secondary neuron in the spinal cord. The total number of ascending neuron fibers is much less than the number of sensory neurons.

Primary Cell Body	Secondary Cell Body	Tertiary Cell Body	Crossover
Dorsal root ganglion	Posterior horn of spinal cord	Thalamus	
			Level at which primary neuron enters cord
			Eight to 10 segments from where primary neuron entered cord; many collaterals
Dorsal root ganglion	Medulla oblongata	Thalamus	Medulla oblongata
Dorsal root ganglion	Posterior horn of spinal cord	Cerebellum	
			Uncrossed
			Some uncrossed; some cross at point of origin and recross in cerebellum
Dorsal root ganglion	Posterior horn of spinal cord	Accessory olivary nucleus	At point of origin; recross to reach cerebellum
Dorsal root ganglion	Posterior horn of spinal cord	Superior colliculus	At point of origin
Dorsal root ganglion	Posterior horn of spinal cord	Reticular formation	Some uncrossed; some cross spinal cord at point of entry

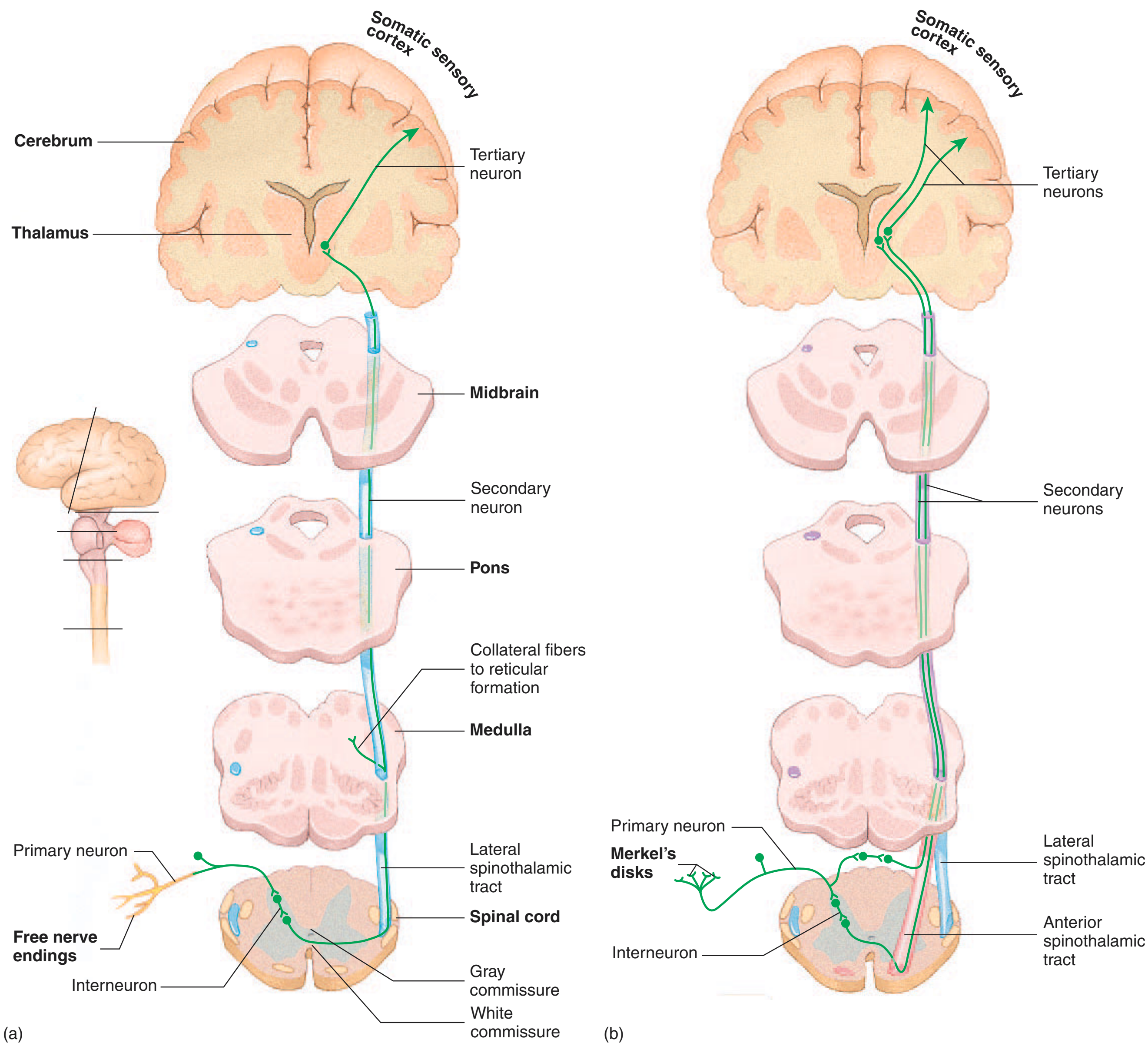


Figure 14.6 Spinothalamic System

(*a*) The lateral spinothalamic tract, which transmits action potentials for pain and temperature. Lines on the inset indicate levels of section. (*b*) The anterior spinothalamic tract, which transmits action potentials for light touch.

P R E D I C T 2

Explain why light touch is very sensitive but is not able to localize the exact point of stimulation.

Lesions on one side of the spinal cord that interrupt the lateral spinothalamic tract eliminate pain and temperature sensation below that level on the opposite side of the body. Lesions on one side of the spinal cord that interrupt the anterior spinothalamic tract, however, do not eliminate all of the light touch and pressure sensations below the level of the lesion because of the large number of collateral branches crossing the cord at various levels.

Dorsal-Column/Medial-Lemniscal System

The **dorsal-column/medial-lemniscal** (lem-nis′kăl) **system** carries the sensations of two-point discrimination, proprioception, pressure, and vibration (figure 14.7). This system is named for the dorsal column of the spinal cord and the medial lemniscus, which

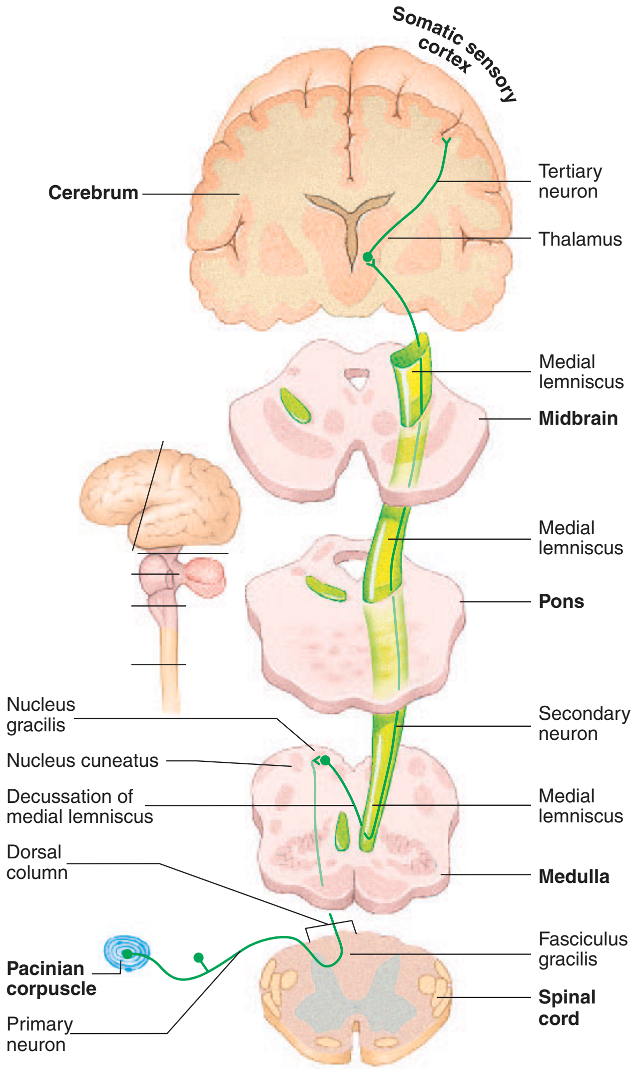


Figure 14.7 **Dorsal-Column/Medial-Lemniscal System**

The fasciculus gracilis and fasciculus cuneatus convey proprioception and two-point discrimination. Only the fasciculus gracilis pathway is shown. Lines on the inset indicate levels of section.

is the continuation of the dorsal column in the brainstem. The term *lemniscus* means ribbon and refers to the thin, ribbonlike appearance of the pathway as it passes through the brainstem.

Primary neurons of the dorsal-column/medial-lemniscal system are located in the dorsal root ganglia. They are the largest cell bodies in the dorsal root ganglia, especially those for two-point discrimination. Axons of the primary neurons of the dorsal-column/medial-lemniscal system enter the spinal cord and ascend the entire length of the spinal cord, without crossing to its opposite side, and synapse with secondary neurons located in the medulla oblongata.

In the spinal cord, the dorsal-column/medial-lemniscal system is divided into two separate tracts (see figure 14.5) based on the source of the stimulus. The **fasciculus gracilis** (gras′i-lis; thin) conveys sensations from nerve endings below the midthoracic level, and the **fasciculus cuneatus** (kū′nē-ā′tŭs; wedge-shaped) conveys impulses from nerve endings above the midthorax. The fasciculus gracilis terminates by synapsing with secondary neurons in the **nucleus gracilis** and with neurons of the posterior spinocerebellar tracts. The fasciculus cuneatus terminates by synapsing with secondary neurons in the **nucleus cuneatus.** Both the nucleus gracilis and the nucleus cuneatus are in the medulla oblongata. The secondary neurons then exit the nucleus gracilis and the nucleus cuneatus, cross to the opposite side of the medulla through the decussations of the medial lemniscus, and ascend through the medial lemniscus to terminate in the thalamus. Tertiary neurons from the thalamus project to the somatic sensory cortex (see page 474).

P R E D I C T 3

Two people, Bill and Mary, were each involved in an accident and each experienced a loss of proprioception, fine touch, and vibration on the left side of the body below the waist. It was determined that Bill had damage to his spinal cord as a result of the accident and that Mary had damage to her brainstem. Explain which side of the spinal cord was damaged in Bill and which side of the brainstem was damaged in Mary.

Trigeminothalamic Tract

As the fibers of the spinothalamic tracts pass through the brainstem, they are joined by fibers of the **trigeminothalamic tract** (trigeminal nerve, or cranial nerve V). This tract carries the same sensory information as the spinothalamic tracts and dorsal-column/medial-lemniscal system but from the face, nasal cavity, and oral cavity, including the teeth. The trigeminothalamic tract is similar to the spinothalamic tracts and dorsal-column/medial-lemniscal system in that primary neurons from one side of the face synapse with secondary neurons, which cross to the opposite side of the brainstem. The secondary neurons synapse with tertiary neurons in the thalamus. Tertiary neurons from the thalamus project to the somatic sensory cortex.

Spinocerebellar System and Other Tracts

The spinocerebellar tracts (see figure 14.5) carry proprioceptive information to the cerebellum so that information concerning actual movements can be monitored and compared to cerebral information representing intended movements.

Two spinocerebellar tracts extend through the spinal cord: (1) the **posterior spinocerebellar tract** (figure 14.8), which originates in the thoracic and upper lumbar regions and contains uncrossed nerve fibers that enter the cerebellum through the inferior cerebellar peduncles; and (2) the **anterior spinocerebellar tract,** which carries information from the lower trunk and lower limbs and contains both crossed and uncrossed nerve fibers that enter the cerebellum through the superior cerebellar peduncle. The crossed fibers recross in the cerebellum. Both spinocerebellar tracts transmit proprioceptive information to the cerebellum from the same side of the body as the cerebellar hemisphere to which they project. Why the anterior spinocerebellar tract crosses twice to accomplish this feat is unknown. Much of the proprioceptive information carried from the legs by the fasciculus gracilis of the dorsal-column/medial-lemniscal system is transferred by synapses in the inferior thorax to the spinocerebellar system and enters the

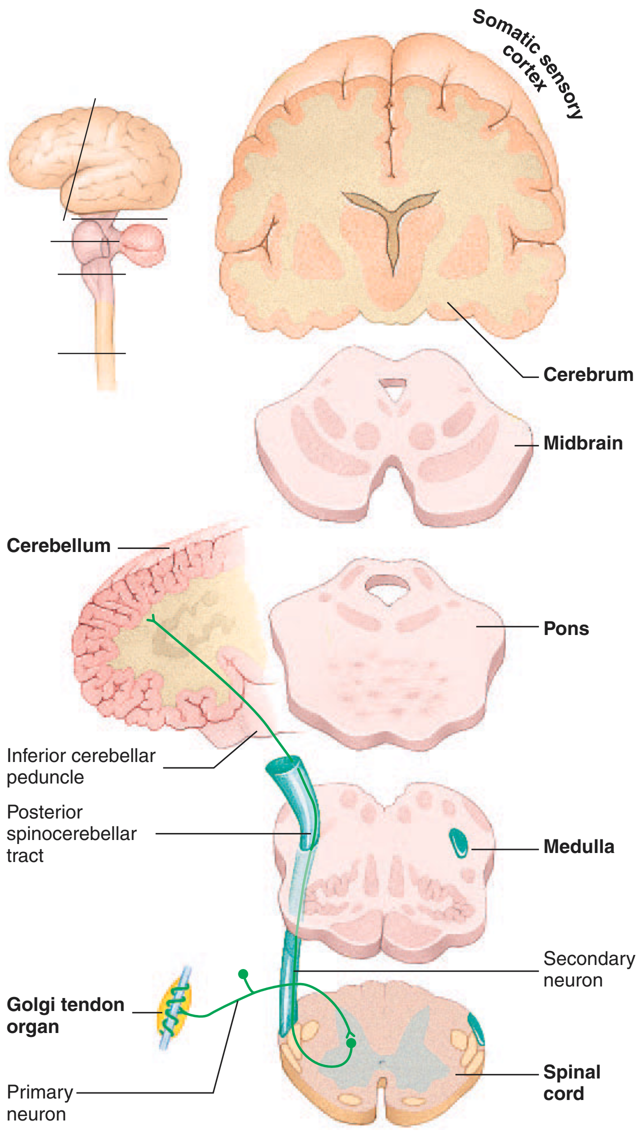


Figure 14.8 **Posterior Spinocerebellar Tract**

This tract transmits proprioceptive information from the thorax, upper limbs, and upper lumbar region to the cerebellum. Lines on the inset indicate levels of section.

cerebellum as unconscious proprioceptive information. In addition, the spinocerebellar tracts convey no information from the arms to the cerebellum. This input enters the cerebellum through the inferior peduncle from the cuneate nucleus of the dorsal-column/medial-lemniscal system. The dorsal-column/medial-lemniscal system, therefore, is involved not only in conscious awareness of proprioception but also unconscious neuromuscular functions.

P R E D I C T 4

Most of the neurons from the fasciculus gracilis synapse in the inferior thorax and enter the spinocerebellar system, whereas most of the neurons from the fasciculus cuneatus synapse in the nucleus cuneatus and then continue to the thalamus and cerebrum. It can therefore be deduced that most of the proprioception from the lower limbs is unconscious and most of the proprioception from the upper limbs is conscious. Explain why this difference in the two sets of limbs is of value.

The **spinoolivary tracts** project to the accessory olivary nucleus and to the cerebellum, where action potentials carried by these tracts contribute to coordination of movement associated primarily with balance. The **spinotectal** (spī-nō-tek′tăl) **tracts** end in the superior colliculi of the midbrain and transmit action potentials involved in reflexes that turn the head and eyes toward a point of cutaneous stimulation. The **spinoreticular tracts** transmit action potentials involved in arousing consciousness in the reticular activating system through cutaneous stimulation.

Descending Pathways Modifying Sensation

The corticospinal (see p. 481) and other descending pathways send collateral branches to the thalamus, reticular formation, trigeminal nuclei, and spinal cord. Neuromodulators (see chapter 11), such as endorphins, released from axons originating in these CNS regions decrease the frequency of action potentials in sensory tracts. Through this route, the cerebral cortex or other brain regions may reduce the conscious perception of sensations.

5. ***What are the functions of the lateral and anterior spinothalamic tracts and the dorsal-column/medial-lemniscal system? Describe where the neurons of these tracts cross over and synapse.***
6. ***What kind of information is carried in the spinocerebellar tracts? Where do the anterior and posterior spinocerebellar tracts originate? Do these tracts terminate on the same or opposite side of the body from where they originate?***
7. ***What are the functions of the spinoolivary, spinotectal, and spinoreticular tracts?***
8. ***How do descending pathways modulate sensation?***

Sensory Areas of the Cerebral Cortex

Figure 14.9 depicts a lateral view of the left cerebral cortex with some of its functional areas labeled. Sensory pathways project to specific regions of the cerebral cortex, called **primary sensory areas,** where these sensations are perceived.

Most of the postcentral gyrus is called the **primary somatic sensory cortex,** or **general sensory area.** The terms *area* and *cortex* are often used interchangeably for the same functional region of the cerebral cortex. Fibers carrying general sensory input, such as pain, pressure, and temperature, synapse in the thalamus, and thalamic neurons relay the information to the primary somatic sensory cortex.

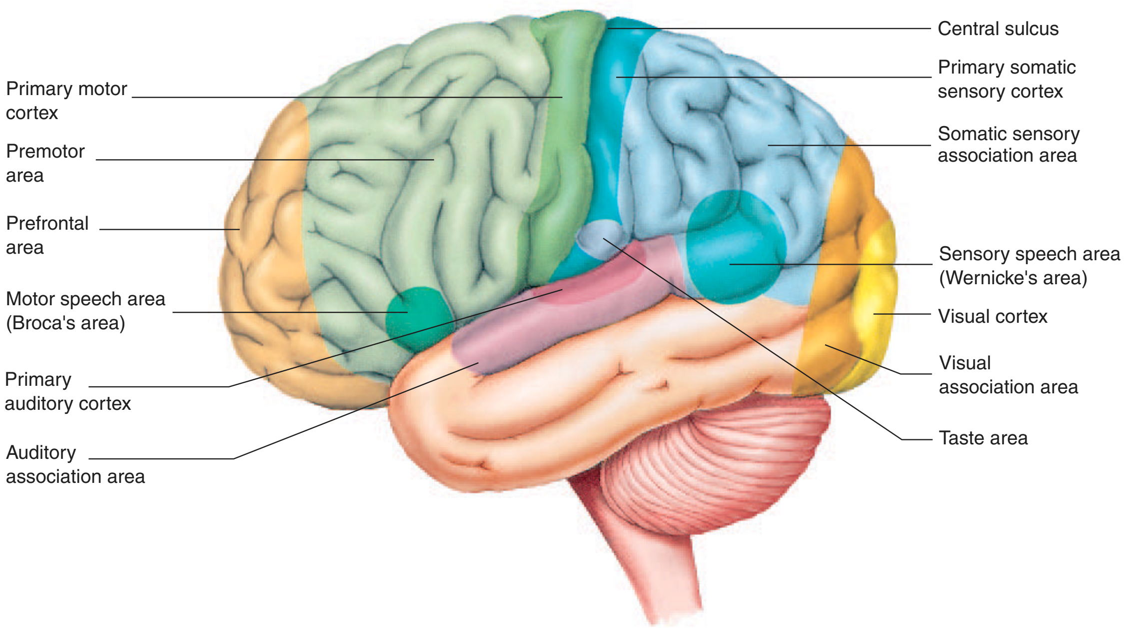


Figure 14.9 **Functional Regions of the Lateral Side of the Left Cerebral Cortex**

The somatic sensory cortex is organized topographically relative to the general plan of the body (figure 14.10). Sensory impulses conducting input from the feet project to the most superior portion of the somatic sensory cortex, and sensory impulses from the face project to the most inferior portion. The pattern of the somatic sensory cortex in each hemisphere is arranged in the form of an upside-down half homunculus (hō-mŭngk′ū-lŭs; a little human) representing the opposite side of the body, with the feet located superiorly and the head located inferiorly. The size of various regions of the somatic sensory cortex is related to the number of sensory receptors in that area of the body. The density of sensory receptors is much greater in the face than in the legs; therefore, a greater area of the somatic sensory cortex contains sensory neurons associated with the face, and the homunculus has a disproportionately large face.

There are other primary sensory areas of the cerebral cortex (see figure 14.9). The **taste area,** where taste sensations are consciously perceived in the cortex, is located at the inferior end of the postcentral gyrus. The **olfactory cortex** (not shown in figure 14.9) is on the inferior surface of the frontal lobe and is the area in which both conscious and unconscious responses to odor are initiated (see chapter 15). The **primary auditory cortex,** where auditory stimuli are processed by the brain, is located in the superior part of the temporal lobe. The **visual cortex,** where portions of visual images are processed, is located in the occipital lobe. In the visual cortex, color, shape, and movement are processed separately rather than as a complete "color motion picture." These sensory areas are discussed more fully in chapter 15.

The primary sensory areas of the cerebral cortex must be intact for conscious perception, localization, and identification of a stimulus. Cutaneous sensations, although integrated within the cerebrum, are perceived as though they were on the surface of the body. This is called **projection** and indicates that the brain refers a cutaneous sensation to the superficial site at which the stimulus interacts with the sensory receptors.

Cortical areas immediately adjacent to the primary sensory centers, called **association areas,** are involved in the process of recognition. The **somatic sensory association area** is posterior to the primary somatic sensory cortex, and the **visual association area** is anterior to the visual cortex (see figure 14.9). Sensory action potentials originating in the retina of the eye reach the visual cortex, where the image is "perceived." Action potentials then pass from the visual cortex to the visual association area, where the present visual information is compared to past visual experience ("Have I seen this before?"). On the basis of this comparison, the visual association area "decides" whether or not the visual input is recognized and passes judgment concerning the significance of the input. For example, we generally pay less attention to people in a crowd we have never seen before than to someone we know.

The visual association area, like other association areas of the cortex, has reciprocal connections with other parts of the cortex that influence decisions. For example, the visual association area has input from the frontal lobe, where emotional value is placed on the visual

Clinical Focus Pain

Pain is a sensation characterized by a group of unpleasant perceptual and emotional experiences that trigger autonomic, psychologic, and somatic motor responses. Pain sensation has two components: (1) rapidly conducted action potentials carried by large-diameter, myelinated axons, resulting in sharp, well-localized, pricking, or cutting pain, followed by (2) more slowly propagated action potentials, carried by smaller, less heavily myelinated axons, resulting in diffuse burning or aching pain. Research indicates that pain receptors have very uniform sensitivity that doesn't change dramatically from one instant to another. Variations in pain sensation result from the differences in integration of action potentials from the pain receptors and the mechanisms by which pain receptors are stimulated.

Although the dorsal-column/medial-lemniscal system contains no pain fibers, tactile and mechanoreceptors are often activated by the same stimuli that affect pain receptors. Action potentials from the tactile receptors help localize the source of pain and monitor changes in the stimuli. Superficial pain is highly localized because of the simultaneous stimulation of pain receptors and mechanoreceptors in the skin. Deep or visceral pain is not highly localized because of fewer mechanoreceptors in the deeper structures, and it is normally perceived as a diffuse pain.

Dorsal-column/medial-lemniscal system neurons are involved in what is called the **gate-control theory** of pain control. Primary neurons of the dorsal-column/medial-lemniscal system send out collateral branches that synapse with interneurons in the posterior horn of the spinal cord. These interneurons have an inhibitory effect on the secondary neurons of the lateral spinothalamic tract. Thus pain action potentials traveling through the lateral spinothalamic tract can be suppressed by action potentials that originate in neurons of the dorsal-column/medial-lemniscal system. The arrangement may act as a "gate" for pain action potentials transmitted in the lateral spinothalamic tract. Increased activity in the dorsal-column/medial-lemniscal system tends to close the gate, thereby reducing pain action potentials transmitted in the lateral spinothalamic tract. Descending pathways from the cerebral cortex or other brain regions can also regulate this "gate."

The gate-control theory may explain the physiologic basis for the following methods that have been used to reduce the intensity of chronic pain: electric stimulation of the dorsal-column/medial-lemniscal neurons, transcutaneous electric stimulation (applying a weak electric stimulus to the skin), acupuncture, massage, and exercise. The frequency of action potentials that are transmitted in the dorsal-column/medial-lemniscal system is increased when the skin is rubbed vigorously and when the limbs are moved and may explain why vigorously rubbing a large area around a source of pricking pain tends to reduce the intensity of the painful sensation. Exercise normally decreases the sensation of pain, and exercise programs are important components in the management of chronic pain not associated with illness. Action potentials initiated by acupuncture procedures may act through a gating mechanism in which inhibition of action potentials in neurons that transmit pain action potentials upward in the spinal cord are influenced by activity sensory cells that send collateral branches to the posterior horn.

Referred Pain

Referred pain is a painful sensation in a region of the body that is not the source of the pain stimulus. Most commonly, referred pain is sensed in the skin or other superficial structures when internal organs are damaged or inflamed. This sensation usually occurs because both the area to which the pain is referred and the area where the actual damage occurs are innervated by neurons from the same spinal segment.

Many cutaneous sensory neurons and visceral sensory neurons that transmit action potentials from pain receptors converge on the same ascending neurons; however, the brain cannot distinguish between the two sources of painful stimuli, and the painful sensation is referred to the most superficial structures innervated by the converging neurons. This referral may occur because the number of receptors is much greater in superficial structures than in deep structures and the brain is more "accustomed" to dealing with superficial stimuli.

Referred pain is clinically useful in diagnosing the actual cause of the painful stimulus. Heart attack victims often feel cutaneous pain radiating from the left shoulder down the arm. Other examples of referred pain are shown in figure A.

Phantom Pain

Phantom pain occurs in people who have had appendages amputated or a structure such as a tooth removed. Frequently these people perceive pain, which can be intense, or other sensations, in the amputated structure as if it were still in place. If a neuron pathway that transmits action potentials is stimulated at any point along that pathway, action potentials are initiated and propagated toward the CNS. Integration results in the perception of pain that is projected to the site of the sensory receptors, even if those sensory receptors are no longer present. A similar phenomenon can be easily demonstrated by bumping the ulnar nerve as it crosses the elbow (the funny bone). A sensation of pain is often felt in the fourth and fifth digits, even though the neurons were stimulated at the elbow.

A factor that may be important in phantom pain results from the lack of touch, pressure, and proprioceptive impulses from the amputated limb. Those action potentials suppress the transmission of pain action potentials in the pain pathways, as explained by the gate control theory of pain. When a limb is amputated, the inhibitory effect of sensory information is removed. As a consequence, the intensity of phantom pain may be increased. Another factor in phantom pain may be that the brain retains an image of the amputated body part and creates an impression that the part is still there.

Chronic Pain

Pain is important in warning us of potentially injurious conditions because pain receptors are stimulated when tissues are

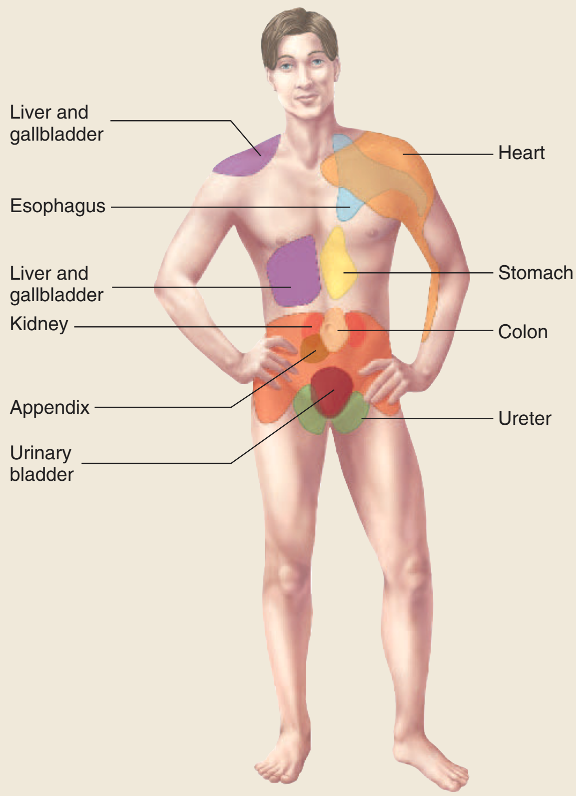


Figure A Areas of Referred Pain on the Body Surface
Pain from the indicated internal organs is referred to the surface areas shown.

injured. Pain itself, however, can become a problem. **Chronic pain,** such as migraine headaches, localized facial pain, or back pain, can be very debilitating and pain loses its value of providing information about the condition of the body. Chronic pain is usually not a response to immediate, direct tissue injury. People suffering from chronic pain often feel helpless and hopeless, and they may become dependent on drugs. The pain can interfere with vocational pursuits, and the victims are often unemployed or even housebound and socially isolated. They are easily frustrated or angered, and they suffer symptoms of major depression. These qualities are associated with what is called **chronic pain syndrome.** Over 2 million people in the United States at any given time suffer chronic pain sufficient to impair activity.

Chronic pain may originate with acute pain associated with an injury or may develop for no apparent reason. How sensory signals are processed in the thalamus and cerebrum may determine if the input is evaluated as only a discomfort, a minor pain, or a severe pain and how much distress is associated with the sensation. The brain actively regulates the amount of pain information that gets through to the level of perception, thereby suppressing much of the input. If this dampening system becomes less functional, pain perception may increase. Other nervous system factors, such as a loss of some sensory modalities from an area, or habituation of pain transmission, which may remain even after the stimulus is removed, may actually intensify otherwise normal pain sensations. The depression, anxiety, and stress associated with chronic pain syndrome can also perpetuate the pain sensations. Treatment often requires a multidisciplinary approach, including such interventions as surgery or psychotherapy. Some sufferers respond well to drug therapy, but some drugs, such as opiates, have a diminishing effect and may become addictive.

Sensitization in Chronic Pain

Tissue damage within an area of injury, such as the skin, can cause an increase in the sensitivity of nerve endings in the area of damage, a condition called **peripheral sensitization.** Research has also revealed a novel class of pain receptors that are not activated by traditional noxious stimuli but are recruited only when tissues become inflamed. These receptors, once activated, add to the total barrage of sensory signals to the brain and intensify the sensation of pain.

The CNS may also respond to tissue damage by decreasing its threshold and increasing its sensitivity to pain. This condition is called **central sensitization.** Under this condition, neurons in the CNS release the excitatory amino acids, glutamate and aspartate. Central sensitization apparently results from a specific subset of aspartate receptors that have little function in normal sensation. These receptors are only recruited during repetitive neuron firing, such as when intense pain sensations are experienced. These receptors open Ca^{+} channels, which results in the production of nitric oxide and the maintenance of a hyperexcitable state in the CNS cells. This chronic hyperexcitable state results in persistent, chronic pain states.

This information concerning peripheral and central sensitization, and the knowledge that sensitization involves neuronal and chemical receptors not normally involved in sensation, may lead to the discovery of new drugs for treating chronic pain. Rather than searching for new analgesics, which may decrease a broad range of sensations, an opportunity is now available to develop a new class of drugs, the “antihyperalgesics,” that may block sensitization without diminishing other sensations, including that to normal pain.

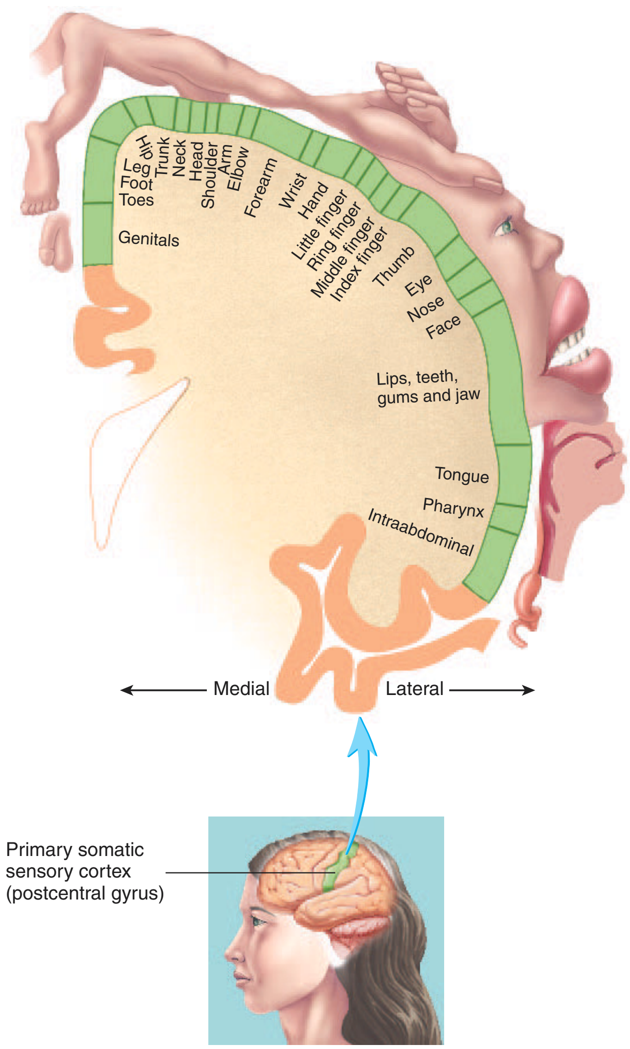


Figure 14.10 **Topography of the Somatic Sensory Cortex**

Cerebral cortex seen in coronal section on the left side of the brain. The figure of the body (homunculus) depicts the nerve distributions; the size of each body region shown indicates relative innervation. The cortex occurs on both sides of the brain but appears on only one side in this illustration. The inset shows the somatic sensory region of the left hemisphere (*green*).

input. Because of these numerous connections, visual information is judged several times as it passes beyond the visual association area. This may be one of the reasons why two people who witness the same event can present somewhat different versions of what happened.

P R E D I C T 5

Using the visual association areas as an example, explain the general functions of the association areas around the other primary cortical areas (see figure 14.9).

9. *Describe in the cerebral cortex the locations of the special sensory areas and their association areas.*
10. *Describe the topographical arrangement of the sensory and motor areas in the cerebral cortex.*
11. *What are the related functions of the primary motor area, the premotor area, and the prefrontal area of the cerebral cortex?*

P R E D I C T 6

A man has constipation, which causes distention and painful cramping in his colon. What kind of pain would he experience (local or diffuse) and where would it be perceived? Explain.

Control of Skeletal Muscles

Objective

- *Describe the motor functions of the cerebral cortex.*
- *Describe the motor pathways of the spinal cord.*
- *Describe modulation of the motor systems by the basil nuclei and cerebellum.*

The motor system of the brain and spinal cord is responsible for maintaining the body's posture and balance; as well as moving the trunk, head, limbs, and eyes; and communicating through facial expressions and speech. Reflexes mediated through the spinal cord (see chapter 12) and brainstem (see chapter 13) are responsible for some body movements. They occur without conscious thought. **Voluntary movements,** on the other hand, are movements consciously activated to achieve a specific goal, such as walking or typing. Although consciously activated, the details of most voluntary movements occur automatically. After walking begins, it is not necessary to think about the moment-to-moment control of every muscle because neural circuits exist that automatically control the limbs. After learning how to do complex tasks, such as typing, they can be performed relatively automatically.

Voluntary movements depend upon upper and lower motor neurons. **Upper motor neurons** directly or through interneurons connect to lower motor neurons. The cell bodies of upper motor neurons are in the cerebral cortex and in brainstem nuclei. **Lower motor neurons** have axons that leave the central nervous system and extend through peripheral nerves to supply skeletal muscles. The cell bodies of lower motor neurons are located in the anterior horns of the spinal cord gray matter and in cranial nerve nuclei of the brainstem.

Voluntary movements depend upon the following:

1. The initiation of most voluntary movement begins in the premotor areas of the cerebral cortex and results in the stimulation of upper motor neurons.
2. The axons of the upper motor neurons form the descending nerve tracts. They stimulate lower motor neurons which stimulate skeletal muscles to contract.
3. The cerebral cortex interacts with the basal nuclei and cerebellum in the planing, coordination, and execution of movements.

Motor Areas of the Cerebral Cortex

The **precentral gyrus** is also called the **primary motor cortex,** or **primary motor area** (see figure 14.9). Action potentials initiated in this region control many voluntary movements, especially the fine motor movements of the hands. Upper motor neurons are not confined to the precentral gyrus—only about 30% of them are located there. Another 30% are in the premotor area, and the rest are in the somatic sensory cortex.

The cortical functions of the precentral gyrus are arranged topographically according to the general plan of the body—similar to the topographic arrangement of the postcentral gyrus (figure 14.11). The neuron cell bodies controlling motor functions of the feet are in the most superior and medial portions of the precentral gyrus, whereas those for the face are in the inferior region. Muscle groups with many motor units are represented by relatively large areas of the precentral gyrus. For example, muscles performing precise movements, such as those controlling the hands and face, have many motor units, each of which has a small number of muscle fibers. Multiple-motor unit summation (see chapter 10) can precisely control the force of contraction of these muscles because only a few muscle fibers at a time are recruited. Muscle groups with few motor units are represented by relatively small areas of the precentral gyrus, even if the muscles innervated are quite large. Muscles, such as those controlling movements of the thigh and leg, have proportionately fewer motor units than hand muscles, but many more and much larger muscle fibers per motor unit. They are less precisely controlled because the activation of a motor unit stimulates the contraction of many large muscle fibers.

The **premotor area,** located anterior to the primary motor cortex (see figure 14.9), is the staging area in which motor functions are organized before they are initiated in the motor cortex. For example, if a person decides to take a step, the neurons of the premotor area are stimulated first. The determination is made in the premotor area as to which muscles must contract, in what order, and to what degree. Action potentials are then passed to the upper motor neurons in the motor cortex, which actually initiate the planned movements.

Apraxia

The premotor area must be intact for a person to carry out complex, skilled, or learned movements, especially ones related to manual dexterity, for example, a surgeon's use of a scalpel or a student's use of a pencil. Impairment in the performance of learned movements, called apraxia (ă-prak′sē-ă), can result from a lesion in the premotor area. Apraxia is characterized by hesitancy and reduced dexterity in performing these movements.

The motivation and foresight to plan and initiate movements occur in the next most anterior portion of the brain, the **prefrontal area,** an association area that is well developed only in primates and especially in humans. It is involved in motivation and regulation of emotional behavior and mood. The large size of this area of the brain in humans may account for their relatively well-developed forethought and motivation and for the emotional complexity of humans.

Prefrontal Lobotomy

In relation to its involvement in motivation, the prefrontal area is also thought to be the functional center for aggression. Beginning in 1935, one method used to eliminate uncontrollable aggression or anxiety in psychiatric hospital patients was to surgically remove or destroy the prefrontal regions of the brain, a procedure called a **prefrontal,** or **frontal, lobotomy.** The operation was sometimes successful in eliminating aggression, but this effect was often only temporary. In addition, some patients developed epilepsy or personality changes, such as lack of inhibition or a lack of initiative and drive. Later studies failed to confirm the usefulness of lobotomies, and the practice was largely discontinued in the late 1950s.

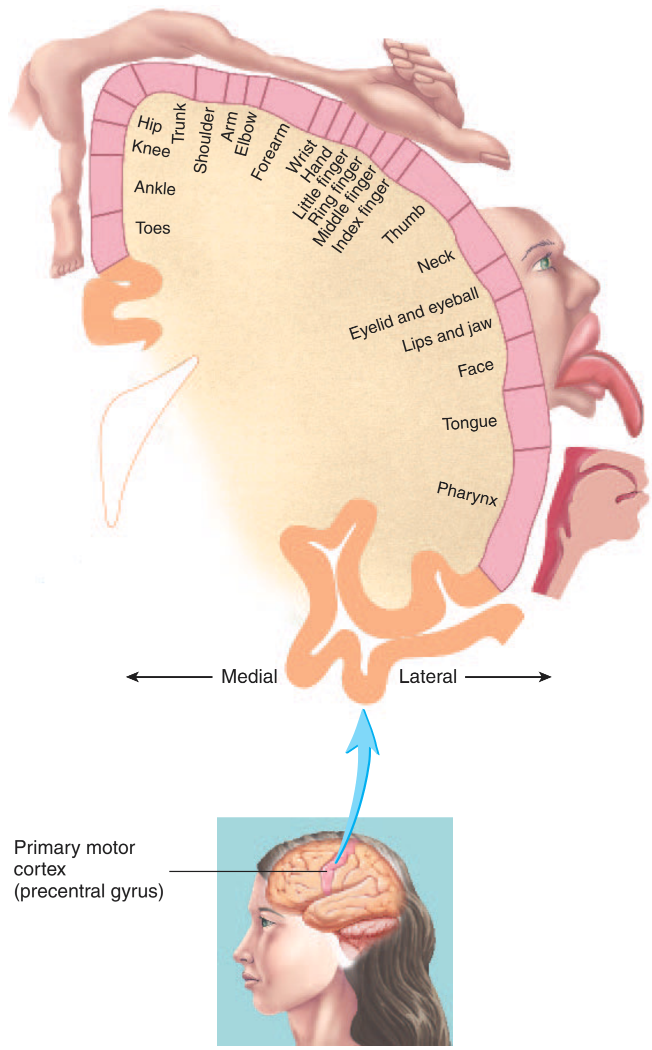


Figure 14.11 **Topography of the Primary Motor Cortex**

Cerebral cortex seen in coronal section on the left side of the brain. The figure of the body (homunculus) depicts the nerve distributions; the size of each body region shown indicates relative innervation. The cortex occurs on both sides of the brain but appears on only one side in this illustration. The inset shows the motor region of the left hemisphere (*pink*).

Motor Nerve Tracts

Motor nerve tracts are descending pathways containing axons that carry action potentials from regions of the brain to the brainstem or spinal cord. The names of descending nerve tracts are based on their origin and termination (figure 14.12 and table 14.4). Much like the names of ascending tracts, the prefix indicates its origin and the suffix indicates its destination. For example, the corticospinal tract is a motor tract that originates in the cerebral cortex and terminates in the spinal cord.

Amyotrophic Lateral Sclerosis

Amyotrophic (ă-mī-ō-trō′fik) **lateral sclerosis (ALS),** also called Lou Gehrig's disease, usually affects people between the ages of 40 and 70. About 10% of the cases of ALS are inherited. It begins with weakness and clumsiness and progresses within 2–5 years to loss of muscle control. The disease selectively destroys both upper and lower motor neurons. The inherited form of ALS apparently results from a mutation in DNA coding for the enzyme **superoxide dismutase (SOD)** and is located on chromosome 21. SOD is involved in eliminating free radicals from the body. Free radicals are molecules with an odd number of electrons in their outer shells, which makes them highly reactive. They can strip electrons from proteins, lipids, or nucleic acids, thereby destroying their functions and resulting in cell dysfunction or death. Free-radical damage has been implicated in ALS, arteriosclerosis, arthritis, cancer, and aging. Superoxide is one of the most important and toxic free radicals. It forms as the result of oxygen reacting with other free radicals. Although oxygen is critical for aerobic metabolism, it's also dangerous to tissues. SOD catalyzes the conversion of superoxide to hydrogen peroxide, which is then converted by catalase to oxygen and water. Apparently, if SOD is defective, superoxide is not degraded and can destroy cells. Motor neurons appear to be particularly sensitive to superoxide attack.

Table 14.4 Descending Spinal Pathways

Pathway	Functions Controlled	Origin	Termination	Crossover
Direct	Muscle tone and conscious skilled movements, especially of the hands			
Corticospinal	Movements, especially of the hands	Cerebral cortex (upper motor neuron)	Anterior horn of spinal cord (lower motor neuron)	
Lateral				Inferior end of medulla oblongata
Anterior				At level of lower motor neuron
Corticobulbar	Facial and head movements	Cerebral cortex (upper motor neuron)	Cranial nerve nuclei in brainstem (lower motor neuron)	Varies for the various cranial nerves
Indirect	Unconscious movements			
Rubrospinal	Movement coordination	Red nucleus	Anterior horn of spinal cord	Midbrain
Vestibulospinal	Posture, balance	Vestibular nucleus	Anterior horn of spinal cord	Uncrossed
Reticulospinal	Posture adjustment, especially during movement	Reticular formation	Anterior horn of spinal cord	Some uncrossed; some cross at level of termination
Tectospinal	Movement of head and neck in response to visual reflexes	Superior colliculus	Cranial nerve nucleus in medulla oblongata and anterior horn of upper levels of spinal cord (lower motor neurons that turn head and neck)	Midbrain

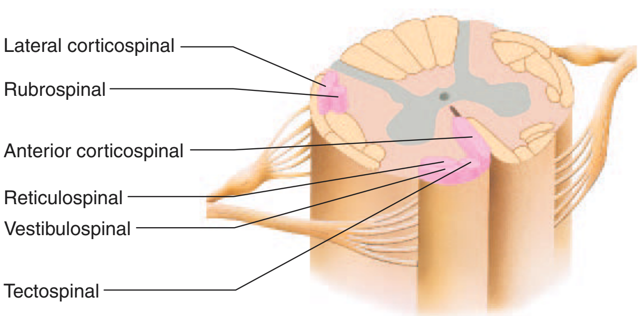


Figure 14.12 Cross Section of the Spinal Cord at the Cervical Level Depicting the Descending Pathways

Descending pathways are labeled on the left side of the figure only (*pink*), though they exist on both sides.

The descending motor fibers are divided into two groups: direct pathways and indirect pathways (figure 14.13). The **direct pathways,** also called the **pyramidal** (pi-ram′i-dal) **system,** are involved in the maintenance of muscle tone and in controlling the speed and precision of skilled movements, primarily fine movements involved in dexterity. Most of the **indirect pathways,** sometimes called the **extrapyramidal system,** are involved in less precise control of motor functions, especially those associated with overall body coordination and cerebellar function such as posture. Many of the indirect pathways are phylogenetically older and control more "primitive" movements of the trunk and proximal portions of the limbs. The direct pathways, which exist only in mammals, may be thought of as overlying the indirect pathways and are more involved in finely controlled movements of the face and distal portions of the limbs. Some indirect pathways, such as those from the basal nuclei and cerebellum, help in fine control of the direct pathways.

Direct Pathways

Direct pathways are so named because upper motor neurons in the cerebral cortex, whose axons form these pathways, synapse directly with lower motor neurons in the brainstem or spinal cord. They are also called the pyramidal system because the fibers of these pathways primarily pass through the medullary **pyramids.** They include groups of nerve fibers arrayed into two tracts: the **corticospinal tract,** which is involved in direct cortical control of movements below the head, and the **corticobulbar tract,** which is involved in direct cortical control of movements in the head and neck.

The corticospinal tracts consist of axons of upper motor neurons located in the primary motor and premotor areas of the frontal lobes and the somatic sensory parts of the parietal lobes. They descend through the **internal capsules** and the cerebral peduncles of the midbrain to the pyramids of the medulla oblongata. At the inferior end of the medulla 75%–85% of the corticospinal fibers cross to the opposite side of the CNS through the **pyramidal decussation,** which is visible on the anterior surface of the inferior medulla. The crossed fibers descend in the **lateral corticospinal tracts** of the spinal cord (figure 14.14). The remaining 15%–25% descend uncrossed in the **anterior corticospinal tracts** and decussate near the level where they synapse with lower motor neurons. The anterior corticospinal tracts supply the neck and upper limbs, and the lateral corticospinal tracts supply all levels of the body.

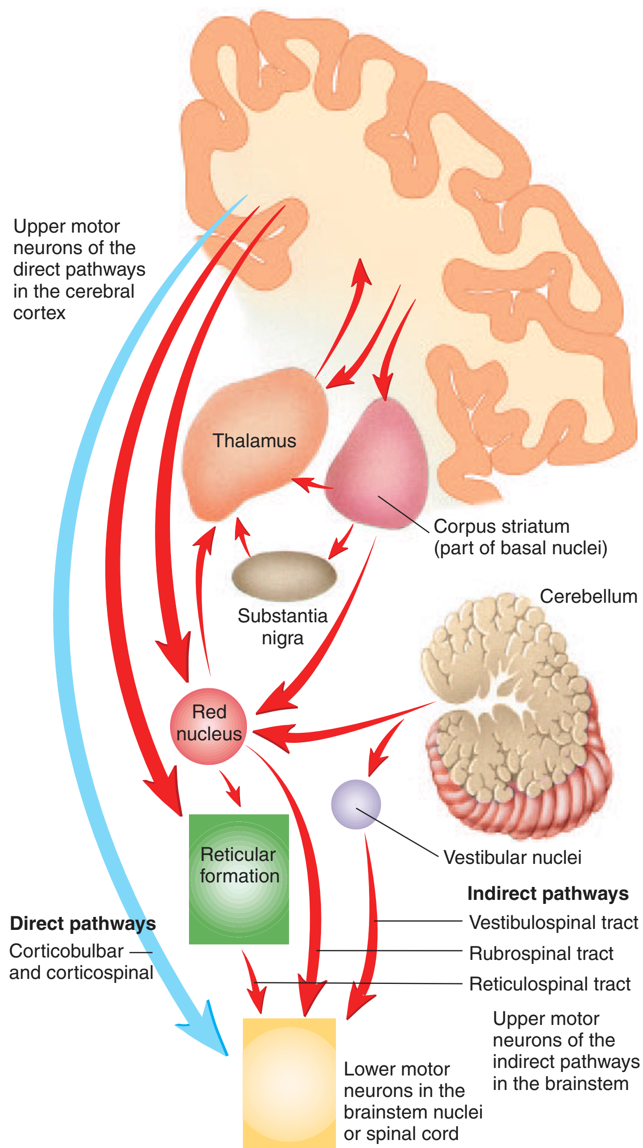


Figure 14.13 Descending Pathways

The direct pathways (corticobulbar and corticospinal) are indicated by the *blue arrow.* The indirect pathways and their interconnections are indicated by the *red arrows.*

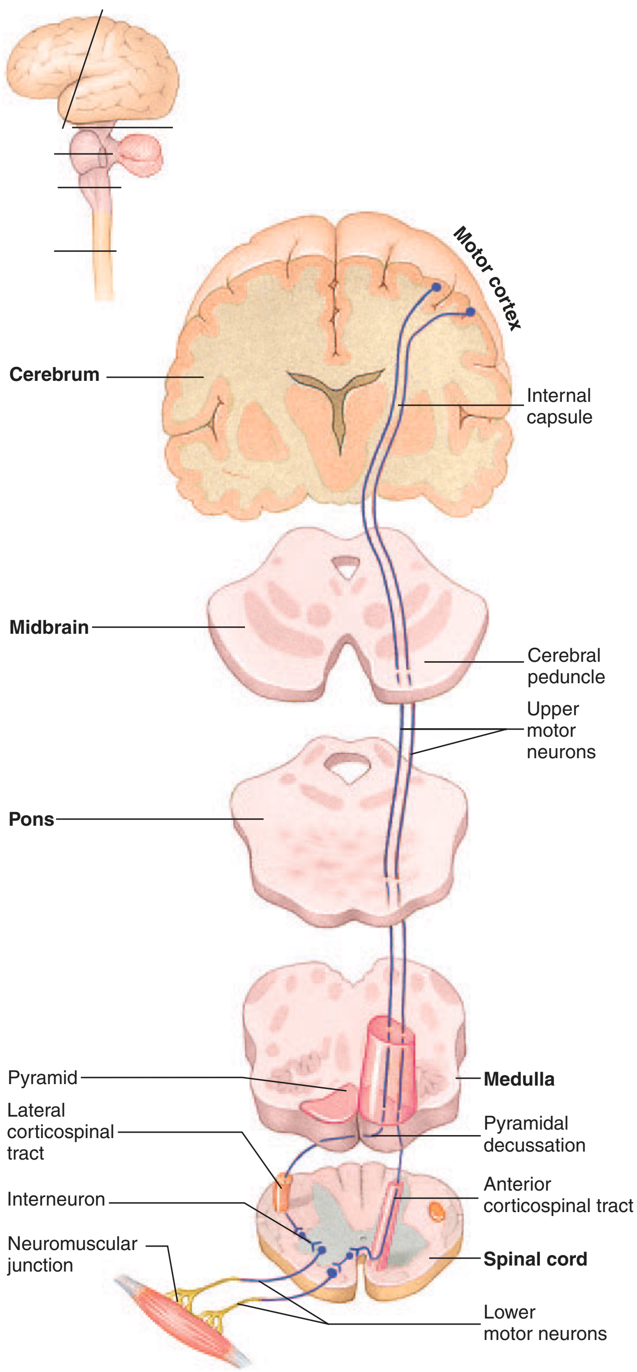


Figure 14.14 Direct Pathways

Lateral and anterior corticospinal tract, which are responsible for movement below the head. Lines on the inset indicate levels of section.

Most of the corticospinal fibers synapse with interneurons in the lateral portions of the spinal cord central gray matter. The interneurons, in turn, synapse with the lower motor neurons of the anterior horn that innervate primarily distal limb muscles.

Damage to the corticospinal tracts results in reduced muscle tone, clumsiness, and weakness but not in complete paralysis, even if the damage is bilateral. Experiments with monkeys have demonstrated that bilateral sectioning of the medullary pyramids results in (1) loss of contact-related activities such as tactile placing of the foot and grasping, (2) defective fine movements, and (3) hypotonia (reduced tone). These and other experimental data, support the conclusion that the corticospinal system is superimposed over the older indirect pathways and that it has many parallel functions. It is proposed that the main function of the direct pathways is to add speed and agility to conscious movements, especially of the hands, and to provide a high degree of fine motor control such as in movements of individual fingers. Spinal cord lesions that affect both the direct and indirect pathways result in complete paralysis.

The **corticobulbar tracts** are analogous to the corticospinal tracts. The former innervate the head, and the latter innervate the rest of the body. Cells that contribute to the corticobulbar tracts are in regions of the cortex similar to those of the corticospinal tracts, except that they are more laterally and inferiorly located. Corticobulbar tracts follow the same basic route as the corticospinal system down to the level of the brainstem. At that point, most corticobulbar fibers terminate in the reticular formation near the **cranial nerve nuclei.** Interneurons from the reticular formation then enter the cranial nerve nuclei, where they synapse with lower motor neurons. These nuclei give rise to nerves that control eye and tongue movements, mastication, facial expression, and palatine, pharyngeal, and laryngeal movements.

12. Distinguish between upper and lower motor neurons.

13. What two tracts form the direct pathways? What area of the body is supplied by each tract? Describe the location of the neurons in each tract, where they cross over, and where they synapse.

Indirect Pathways

The indirect pathways (figure 14.15) originate in upper motor neurons of the cerebrum and cerebellum whose axons synapse in some intermediate nucleus rather than directly with lower motor neurons. Axons from the upper motor neurons in these nuclei form the indirect pathways. They do not pass through the pyramids or through the corticobulbar tracts and, therefore, are sometimes called extrapyramidal. The major tracts are the rubrospinal, vestibulospinal, and reticulospinal tracts. Many interconnections and feedback loops are present in this system.

Upper motor neurons of the **rubrospinal tract** begin in the red nucleus, which is located at the boundary between the diencephalon and midbrain. The tract decussates in the midbrain, and descends in the lateral column of the spinal cord. The red nucleus receives input from both the motor cortex and the cerebellum. Lesions in the red nucleus result in intention, or action, tremors similar to those seen in cerebellar lesions (see the Clinical Focus on

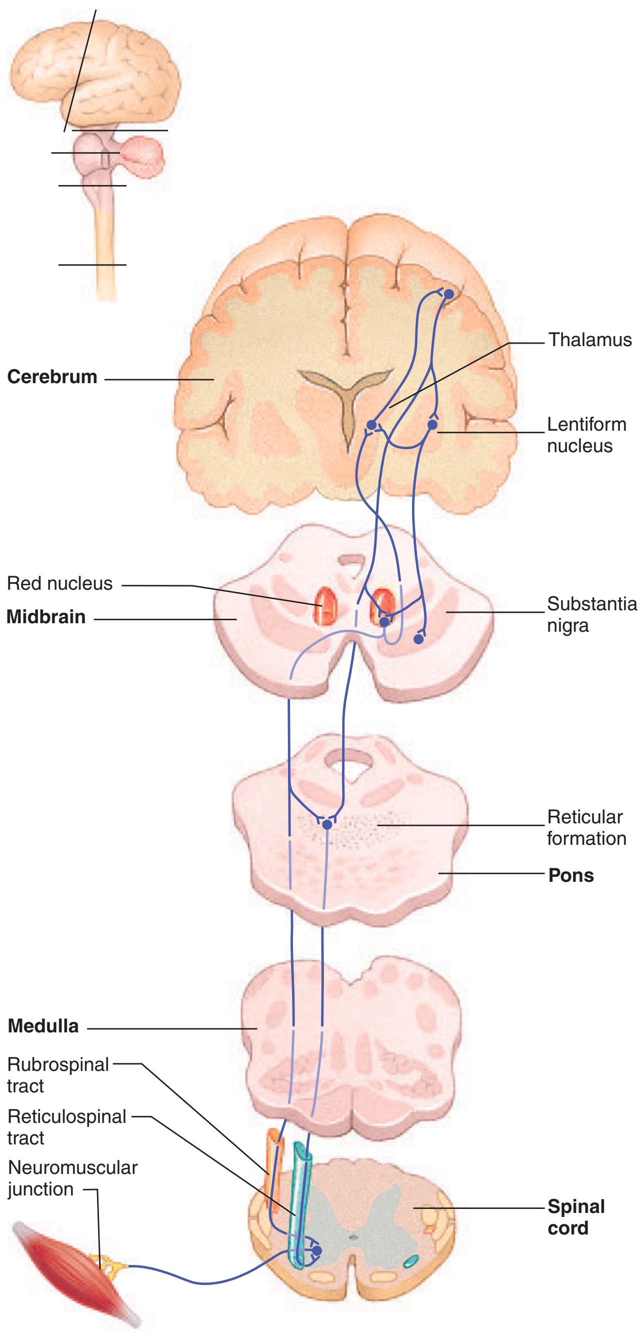


Figure 14.15 **Indirect Pathways**

Examples of indirect pathways: rubrospinal and reticulospinal tracts. Lines on the inset indicate levels of section.

"Dyskinesias"; p. 485). The function of the red nucleus therefore is related closely to cerebellar function. Damage to the rubrospinal tract impairs forearm and hand movements but doesn't greatly affect general body movements. The rubrospinal tract is the one indirect tract that is very closely related to the direct, corticospinal tract. It terminates in the lateral portion of the spinal cord central gray matter with the corticospinal tract, and it transmits action potentials involved in the comparator function of the cerebellum (see p. 484). It plays a major role in regulating fine motor control of muscles in the distal part of the upper limbs.

The **vestibulospinal tracts** (see figure 14.12) originate in the vestibular nuclei, descend in the anterior column, and synapse with lower motor neurons in the ventromedial portion of the spinal cord central gray matter. Their fibers preferentially influence neurons innervating extensor muscles in the trunk and proximal portion of the lower limbs and are involved primarily in the maintenance of upright posture. The vestibular nuclei receive major input from the vestibular nerve (see chapter 15) and the cerebellum.

Neuron cell bodies of the **reticulospinal tract** (see figure 14.12) are in the reticular formation of the pons and medulla oblongata. Their axons descend in the anterior portion of the lateral column and synapse with lower motor neurons in the ventromedial portion of the spinal cord central gray matter. The function of this tract involves the maintenance of posture through the action of trunk and proximal upper and lower limb muscles during certain movements. For example, when a person who is standing lifts one foot off the ground, the weight of the body is shifted over to the other limb. The reticulospinal tract apparently enhances the functions of the alpha motor neurons in the crossed extensor reflex during this type of movement so that balance is maintained.

Another major portion of the indirect pathways involves the basal nuclei (see figure 14.13). They have a number of connections with each other, as well as the thalamus and cerebrum. They interact with other indirect pathways, like the rubrospinal tract, by which they modulate motor functions.

14. Name the structures and the tracts that form the indirect pathways. What functions do they control? Contrast them with the functions of the direct pathways.

Modifying and Refining Motor Activities

Basal Nuclei

The **basal nuclei** (see figure 13.8) are important in planning, organizing, and coordinating motor movements and posture. Complex neural circuits link the basal nuclei with each other, with the thalamus, and with the cerebral cortex. These connections form several feedback loops, some of which are stimulatory and others inhibitory. The stimulatory circuits facilitate muscle activity, especially at the beginning of a voluntary movement like rising from a sitting position or beginning to walk. The inhibitory circuits facilitate the actions of the stimulatory circuits by inhibiting muscle activity in antagonist muscles. Inhibitory circuits also decrease muscle tone when the body, limbs, and head are at rest. Disorders of the basal nuclei result in difficulty in rising from a sitting position and difficulty in initiating walking. People with basal nuclei disorders exhibit increased muscle tone and exaggerated, uncontrolled movements when they are at rest. A specific feature of some basal nuclei disorders is a "resting tremor," a slight shaking of the hands when a person is not performing a task. Parkinson's disease and cerebral palsy are basal nuclei disorders. They are discussed in the Clinical Focus on "Dyskinesias" (p. 485).

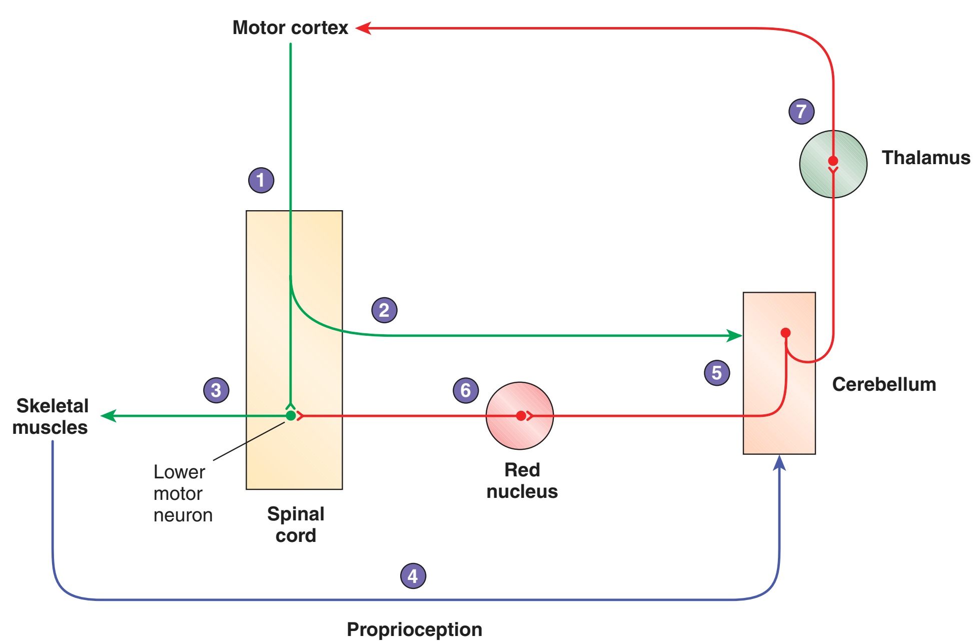
Cerebellum

The **cerebellum** (see figure 13.4) consists of three functional parts: the **flocculonodular lobe** is called the **vestibulocerebellum.** It receives direct input from the vestibular structures, especially the semicircular canals (see chapter 15), and sends axons to the vestibular nuclei of the brainstem. It helps maintain muscle tone in postural muscles. It also helps control balance, especially during movements, and it helps coordinate eye movement.

The **vermis** and medial portion of the **lateral hemisphere,** referred to jointly as the **spinocerebellum,** helps accomplish fine motor coordination of simple movements by means of its **comparator** function. Action potentials from the motor cortex descend into the spinal cord to initiate voluntary movements. At the same time, action potentials are carried from the motor cortex to the cerebellum to give the cerebellar neurons information representing the intended movement (figure 14.16). Simultaneously, action potentials from proprioceptive neurons ascend through the spinocerebellar tracts to the cerebellum. Proprioceptive neurons innervate the joints and tendons of the structure being moved, such as the elbow or knee, and provide information about the position of the body or body parts. These action potentials give the cerebellar neurons information from the periphery about the actual movements. The cerebellum compares the action potentials from the motor cortex to those from the moving structures. That is, it compares the intended movement with the actual movement. If a difference is detected, the cerebellum sends action potentials through the thalamus to the motor cortex and to the spinal cord to correct the discrepancy. The result is smooth and coordinated movements.

The comparator function works to coordinate simple movements like touching your nose. Rapid, complex movements, however, require much greater coordination and training. The **cerebrocerebellum** consists of the lateral two-thirds of the lateral hemispheres. It communicates with the motor, premotor, and prefrontal portions of the cerebral cortex to help in planning and practicing rapid, complex motor actions. The connections from the cerebrum to the cerebellum constitute a large portion of the axons in the cerebral peduncles. Because of the cerebrocerebellum, with training, a person can learn highly skilled and rapid movements that are accomplished more rapidly than can be accounted for by the comparator function of the cerebellum. In these cases, the cerebellum participates with the cerebrum in learning highly specialized movements like playing the piano or swinging a baseball bat. The cerebrocerebellum is also involved in cognitive functions such as rhythm, conceptualizing time intervals, some word associations, and solving pegboard puzzles—tasks once thought to occur only in the cerebrum.

1. The motor cortex sends action potentials to lower motor neurons in the spinal cord.
2. Action potentials from the motor cortex inform the cerebellum of the intended movement.
3. Lower motor neurons in the spinal cord send action potentials to skeletal muscles, causing them to contract.
4. Proprioceptive signals from the skeletal muscles and joints to the cerebellum convey information concerning the status of the muscles and the structure being moved during contraction.
5. The cerebellum compares the information from the motor cortex to the proprioceptive information from the skeletal muscles and joints.
6. Action potentials from the cerebellum to the spinal cord modify the stimulation from the motor cortex to the lower motor neurons.
7. Action potentials from the cerebellum are sent to the motor cortex, which modify its motor activity.



Process Figure 14.16 Cerebellar Comparator Function

Clinical Focus Dyskinesias

Dyskinesias (dis-ki-nē′zē-ăs) are a group of disorders often involving the basal nuclei in which unwanted, superfluous movements occur. Defects in the basal nuclei may result in brisk, jerky, purposeless movements that resemble fragments of voluntary movements. **Sydenham's chorea** (kōr-ē′ă; also called St. Vitus' dance) is a disease usually associated with a toxic or infectious disorder that apparently causes temporary dysfunction of the corpus striatum. It usually affects children. **Huntington's chorea** is a dominant hereditary disorder that begins in middle life and causes mental deterioration and progressive degeneration of the corpus striatum in affected individuals.

Cerebral palsy (pawl′zē) is a general term referring to defects in motor functions or coordination resulting from several types of brain damage, which may be caused by abnormal brain development or birth-related injury. Some symptoms of cerebral palsy, such as increased muscle tension, are related to basal nuclei dysfunction. **Athetosis** (ath-ĕ-tō′sis), often one of the features of cerebral palsy, is characterized by slow, sinuous, aimless movements. When the face, neck, and tongue muscles are involved, grimacing, protrusion, and writhing of the tongue and difficulty in speaking and swallowing are characteristics.

Damage to the subthalamic nucleus can result in **hemiballismus** (hem-ē-bal-iz′mŭs), an uncontrolled, purposeless, and forceful throwing or flailing of the arm. Forceful twitching of the face and neck may also result from subthalamic nuclear damage.

Parkinson's disease, characterized by muscular rigidity, loss of facial expression, tremor, a slow, shuffling gait, and general lack of movement, is caused by a dysfunction in the substantia nigra. The disease usually occurs after age 55 and is not contagious or inherited. A resting tremor called "pill-rolling" is characteristic of Parkinson's disease and consists of circular movement of the opposed thumb and index fingertips. The increased muscular rigidity in Parkinson's disease results from defective inhibition of some of the basal nuclei by the substantia nigra. In this disease, dopamine, an inhibitory neurotransmitter produced by the substantia nigra is deficient. The melanin-containing cells of the substantia nigra degenerate, resulting in a loss of pigment.

Parkinson's disease can be treated with levodopa (lē-vō-dō′pă, L-dopa), a precursor to dopamine, or, more effectively, with Sinemet, a combination of L-dopa and carbidopa (kar-bi-dō′pă). Carbidopa prevents L-dopa from being absorbed by tissues other than the brain. Because of long-term side effects, including dyskinesias, associated with levodopa, other dopamine agonists, such as ropinirole and pramipexole, are being examined. A protein called **glial cell line–derived neurotrophic factor (GDNF)** has been discovered that selectively promotes the survival of dopamine-secreting neurons. Chronic stimulation of the globus pallidus (part of the lentiform nucleus) with an electrical pulse generator has shown some success. Experimental treatment of the disorder by transplanting fetal tissues, or stem cells from adult tissues, capable of producing dopamine is also under investigation.

Cerebellar lesions result in a spectrum of characteristic functional disorders. Movements tend to be **ataxic** (jerky) and **dysmetric** (overshooting—for example, pointing past or deviating from a mark that one tries to touch with the finger). Alternating movements such as supination and pronation of the hand are performed in a clumsy manner. **Nystagmus** (nis-tag′mŭs), which is a constant motion of the eyes, may also occur. A cerebellar tremor is an intention tremor (i.e., the more carefully one tries to control a given movement, the greater the tremor becomes). For example, when a person with a cerebellar tremor attempts to drink a glass of water, the closer the glass comes to the mouth, the shakier the movement becomes. This type of tremor is in direct contrast to basal nuclei tremors described previously, in which the resting tremor largely or completely disappears during purposeful movement.

15. *What are the functions of the basal nuclei?*
16. *Explain the comparator activities of the spinocerebellum.*
17. *Describe the role of the cerebrocerebellum in rapid and skilled motor movements such as playing the piano.*

Cerebellar Dysfunction

Cerebellar dysfunction results in (1) decreased muscle tone, (2) balance impairment, (3) a tendency to overshoot when reaching for or touching an object, and (4) an intention tremor, which is a shaking in the hands that occurs only while attempting to perform a task. Notice that although the cerebellum and basal nuclei both control motor functions, they have opposite effects, and exhibit opposite symptoms when injured. For example, cerebellar dysfunction results in decreased muscle tone and an intention tremor, whereas basal nuclear dysfunction results in increased muscle tone and a resting tremor.

Brainstem Functions

Objectives

- *Name the cranial nerves that have their nuclei in the brainstem. Describe the functions of the reticular formation.*
- *Describe the major features of the brainstem related to its sensory, motor, and reflex functions.*

The major ascending and descending pathways project through the brainstem. In addition, the brainstem contains nuclei, including the nuclei of cranial nerves II–XII nuclei and nuclei of the reticular formation. Only cranial nerve I (olfactory nerve) does not have axons that pass through the brainstem or nuclei in the brainstem.

The brainstem receives sensory input from collateral branches of ascending spinal cord pathways and from the axons of cranial nerves II (vision), V (tactile sensation from the face, nasal cavity, and oral cavity), VII (taste), VIII (hearing and balance), IX (taste; tactile sensation in the throat), and X (taste; tactile sensation in the larynx; visceral sensation in the thorax and abdomen). These cranial nerves all have sensory nuclei in the brainstem. Many of these nuclei are involved in the special senses and are discussed in chapter 15. The brainstem nuclei associated with cranial nerve II are involved in visual reflexes.

As noted earlier, fibers of the spinothalamic tracts passing through the brainstem, are joined by fibers of the trigeminothalamic tract (trigeminal nerve, or cranial nerve V). This tract carries tactile sensations, such as pain and temperature, two-point discrimination, proprioception, and light touch from the face, nasal cavity, and oral cavity, including the teeth. This input is much like that from the spinal nerves in that primary neurons from one side of the face synapse with secondary neurons, which cross to the opposite side of the brainstem. A difference is that the brainstem contains a different nucleus for each of the four tactile sensory modes; pain and temperature, light touch, two point discrimination, and proprioception from the trigeminal nerve. The secondary neurons synapse with tertiary neurons in the thalamus. Tertiary neurons from the thalamus project to the somatic sensory cortex. Collateral branches of trigeminothalamic tract neurons project to the reticular formation where they stimulate wakefulness and consciousness. This part of the reticular formation and its connections constitute the **reticular activating system (RAS),** which is involved in the sleep–wake cycle.

P R E D I C T 7

Describe an effective technique for arousing a sleeping person.

Collateral branches of cranial nerves II (optic) and VIII (vestibulocochlear), ascending tactile sensory pathways, and descending neurons from the cerebrum also project to the RAS. Visual and acoustic stimuli, as well as mental activities, stimulate the RAS to help maintain alertness and attention. Ringing alarm clocks, sudden flashes of bright lights, or cold water being splashed on the face can all arouse consciousness. Removal of visual, auditory, and other stimuli may lead to drowsiness or sleep. For example, consider what happens to many students during a monotonous lecture in a dark lecture hall.

Damage to RAS cells of the reticular formation can result in coma.

Drugs and the Reticular Activating System

Certain drugs can either stimulate or depress the RAS. General anesthetics suppress this system, and many tranquilizers depress it. On the other hand, ammonia (smelling salts) and other irritants stimulate trigeminal nerve endings in the nose. As a result, action potentials are sent to the reticular formation and the cerebral cortex to arouse an unconscious patient.

Several important reflexes are integrated by nuclei in the brainstem. For example, sensory input from cranial nerve IX (glossopharyngeal) conveys tactile information from the back of the tongue, the soft palate, and the throat (pharynx) to the brainstem. Mechanical stimulation of these areas can initiate a gag reflex, whereas other stimulation of the throat can initiate a cough reflex. Sensory input from cranial nerve X conveys tactile information from the larynx (voicebox) and thoracic and abdominal viscera. Tactile input from the larynx can also initiate a cough reflex. In addition, cranial nerve X (vagus nerve) is involved in many complex reflexes associated with vital functions like heart rate, respiration, and digestion. Many of these involve the reticular formation and are discussed in later chapters.

Several critical functions like heart rate, blood pressure, respiration, sleep, swallowing, vomiting, coughing, and sneezing are regulated by nuclei of the brainstem. When a person is involved in a serious accident or is extremely ill, most of the vital functions assessed by medical personnel, such as blood pressure, heart rate, respiration, and dilation of the pupils, are controlled by the brainstem; so many emergency evaluations involve evaluations of brainstem function.

Descending pathways in the brainstem pass to the spinal cord, pass into the cerebellum, or synapse with cranial nerve motor nuclei and other nuclei in the brainstem. Some of the descending pathways originate in the cerebral cortex and pass directly through the brainstem (direct pathways). Others synapse with brainstem nuclei, which, in turn, send descending fibers into the spinal cord (indirect pathways). Descending fibers from the reticular formation constitute one of the body's most important motor pathways. Fibers from the reticular formation are critical in controlling many vital functions, such as respiratory movements and cardiac rhythms. Cranial nerves III, IV, V, VI, VII, IX, X, XI, and XII all have motor nuclei in the brainstem.

Cranial nerves III, IV, and VI control the eye muscles. Collateral branches from the optic nerve tract (II) synapse in the superior colliculi of the midbrain (see figure 13.7). Axons from the superior colliculi project to cranial nerve nuclei II (oculomotor), IV (trochlear), and VI (abducens) and to the cervical part of the spinal cord, spinal nucleus of XI, where they stimulate motor neurons involved in turning the eyes and head toward a visual stimulus. The superior colliculi also receive input from auditory pathways, which can initiate a reflex that turns the eyes and head toward a sudden noise. Action potentials reaching the superior colliculi from the cerebrum are involved in the visual tracking of moving objects. The visual tracking with both eyes to the right involves the lateral rectus muscle and abducens (VI) nerve of the right eye and the medial rectus muscle and oculomotor (III) nerve of the left eye. Coordination of these two nerves and muscles requires nuclei of the reticular formation. Constriction of the pupil involves parasympathetic stimulation through the oculomotor (III) nerve. The visual reflexes resulting in pupil constriction are coordinated through nuclei in the reticular formation. These reflexes are also coordinated by a nuclear region in the diencephalon called the pretectal area (in front of the tectum, the roof of the midbrain).

The Brain's Canary

Function of the pretectal area is critical for normal pupillary constriction in response to light. This area of the brain can be thought of as the "brain's canary." For many years, miners carried caged canaries with them into deep mine shafts to detect poison gas. An unconscious or dead canary would warn the miners of methane gas before enough accumulated to kill them. Like a canary, the pretectal area is more sensitive to brain damage, or symptoms of the damage are more easily observed, than many other parts of the brain. Fixed, dilated pupils in a patient is a sign that the patient may have experienced damage to the brain in addition to the pretectal area.

Motor fibers from the trigeminal nerve (V) innervate the muscles of mastication. Tactile sensory input from the same nerve informs the brainstem and cerebrum of the presence of food or some other object in the mouth. The presence of an object in the mouth, even a nonfood item like a marble, stimulates a reflex between the trigeminal sensory nuclei and the motor nuclei of VII and IX, which innervate the salivary glands to stimulate salivation. A reflex between the trigeminal sensory nuclei and the motor nucleus of V initiates the chewing cycle, which is regulated by the reticular formation. Other reflexes in the trigeminal nerve system detect how hard or soft an item is in the mouth and adjusts the bite accordingly. The motor nucleus of XII innervates the tongue muscles. Reflexes between the trigeminal sensory nuclei and the motor nucleus of XII control the tongue to help place food between the teeth for chewing, while, at the same time, keep the tongue out of harm's way.

18. *List the motor nuclei of the brainstem.*
19. *Describe some of the reflexes that occur in the brainstem.*
20. *What are some of the vital functions that are regulated in the brainstem?*

Other Brain Functions

Objectives

- *Describe the brain activity involved in speech.*
- *Name the pathways that connect the right and left cerebral hemispheres.*
- *Describe the basic brain waves, and correlate them with brain function.*
- *Describe how sensory, short-term, and long-term memory work.*
- *Describe the basic functions of the limbic system.*

The human brain is capable of many functions besides awareness of sensory input and the control of skeletal muscles. Speech, mathematical and artistic abilities, sleep, memory, emotions, and judgment are functions of the brain.

Speech

In most people, the speech area is in the left cerebral cortex. Two major cortical areas are involved in speech: **Wernicke's area** (sensory speech area), a portion of the parietal lobe, and **Broca's area** (motor speech area) in the inferior part of the frontal lobe (see figure 14.9). Wernicke's area is necessary for understanding and formulating coherent speech. Broca's area initiates the complex series of movements necessary for speech.

For someone to repeat a word that he or she hears, the following sequence of events must take place. Action potentials from the ear reach the primary auditory cortex, where the word is heard. The word is then recognized in the auditory association area and comprehended in parts of Wernicke's area. Then action potentials representing the word are conducted through association fibers that connect Wernicke's and Broca's areas. In Broca's area, the word is formulated as it will be repeated. Action potentials are then propagated to the premotor area, where the movements are programmed, and finally to the primary motor cortex, where the proper movements are triggered (figure 14.17).

To speak a written word is similar. The information passes from the eyes to the visual cortex and then passes to the visual association area, where the word is recognized, and continues to Wernicke's area, where the word is understood and formulated as it will be spoken. From Wernicke's area, it follows the same route as followed for repeating words that are heard.

Aphasia

Aphasia (ă-fā′zē-ă), absent or defective speech or language comprehension, results from a lesion in the language areas of the cortex. The several types of aphasia depend on the site of the lesion. **Receptive aphasia** (Wernicke's aphasia), which includes defective auditory and visual comprehension of language, defective naming of objects, and repetition of spoken sentences, is caused by a lesion in Wernicke's area. Both **jargon aphasia,** in which a person may speak fluently but unintelligibly, and **conduction aphasia,** in which a person has poor repetition but relatively good comprehension, can result from a lesion in the tracts between Wernicke's and Broca's areas. **Anomic** (ă-nō′mik) **aphasia,** caused by the isolation of Wernicke's area from the parietal or temporal association areas, is characterized by fluent but circular speech resulting from poor word-finding ability. **Expressive aphasia** (Broca's aphasia), caused by a lesion in Broca's area, is characterized by hesitant and distorted speech.

21. *List the necessary sequence of events that must occur for a person to repeat a word that he or she hears.*

P R E D I C T 8

Propose the sequence needed for a blindfolded person to name an object placed in her right hand.

Right and Left Cerebral Cortex

The cortex of the right cerebral hemisphere controls muscular activity in and receives sensory input from the left half of the body. The left cerebral hemisphere controls muscles in and receives sensory input from the right half of the body. Sensory information received by the cortex of one hemisphere is shared with the other through connections between the two hemispheres called **commissures** (kom′i-shūrz; a joining together). The largest of these commissures is the **corpus callosum** (kōr′pūs kă-lō′sŭm;

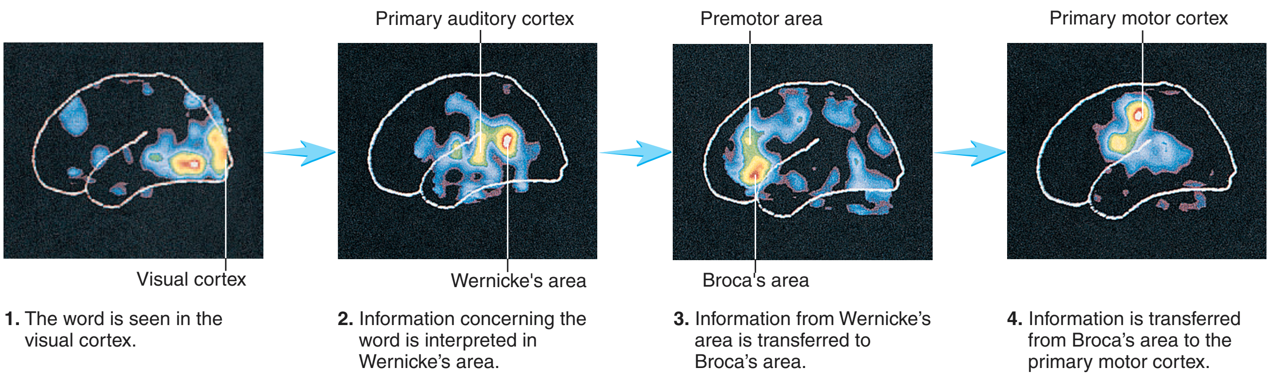


Figure 14.17 Demonstration of Cortical Activities During Speech

The figures show the pathway for reading and naming something that is seen, such as reading aloud. PET scans show the areas of the brain that are most active during various phases of speech. *Red* indicates the most active areas; *blue* indicates the least active areas.

callous body), which is a broad band of nerve tracts at the base of the longitudinal fissure (see figure 13.1).

Language and perhaps other functions, such as artistic activities, are not shared equally between the left and right cerebral hemispheres. The left hemisphere is more involved in such skills as mathematics and speech. The right hemisphere is involved in activities like three-dimensional or spatial perception, recognition of faces, and musical ability.

22. Name the largest pathway that connects the right and left cerebral hemispheres.

23. What are the functions localized in the left cerebral hemisphere? In the right cerebral hemisphere?

Hemisphere Dominance and Amorphosynthesis

Dominance of one cerebral hemisphere over the other, for most functions, is probably not very important in most people because the two hemispheres are in constant communication through the corpus callosum, literally allowing the right hand to know what the left hand is doing. Surgical cutting of the corpus callosum has been successful in treating a limited number of epilepsy cases. Under certain conditions, however, interesting functional defects develop in people who have had their corpus callosum severed. For example, if a patient with a severed corpus callosum is asked to reach behind a screen to touch one of several items with one hand without being able to see it and then is asked to point out the same object with the other hand, the person cannot do it. Tactile information from the left hand enters the right somatic sensory cortex but that information is not transferred to the left hemisphere, which controls the right hand. As a result, the left hemisphere cannot direct the right hand to the correct object.

A person suffering a stroke in the right parietal lobe may lose the ability to recognize faces while retaining essentially all other brain functions. A more severe lesion can cause a person to lose the ability to identify simple objects. This defect is called **amorphosynthesis** (ă-mōr′fō-sin′thĕ-sis). Some people with a similar lesion in the right cerebral hemisphere may tend to ignore the left half of the world, including the left half of their own bodies. These people may completely ignore a person who is to their left but react normally when the person moves to their right. They may also fail to dress the left half of their bodies or eat the food on the left half of their plates.

Brain Waves and Sleep

Electrodes placed on a person's scalp and attached to a recording device can record the electrical activity of the brain, producing an **electroencephalogram** (ē-lek′trō-en-sef′ă-lō-gram; **EEG;** figure 14.18). These electrodes are not sensitive enough to detect individual action potentials, but they can detect the simultaneous action potentials in large numbers of neurons. As a result, the EEG displays wavelike patterns known as **brain waves.** Brain waves are produced continuously, but their intensity and frequency differ from time to time based on the state of brain activity.

Most of the time, EEG patterns from a given individual are irregular with no particular pattern because, although the normal brain is active, most of its electrical activity is not synchronous. At other times, however, specific patterns can be detected. These regular patterns are classified as alpha, beta, theta, or delta waves (see figure 14.18). **Alpha waves** are observed in a normal person who is awake but in a quiet, resting state with the eyes closed. **Beta waves** have a higher frequency than alpha waves and occur during intense mental activity. **Theta waves** usually occur in children, but they can also occur in adults who are experiencing frustration or who have certain brain disorders. **Delta waves** occur in deep sleep, in infancy, and in patients with severe brain disorders.

Brain wave patterns vary during the four stages of sleep (see figure 14.18) A sleeping person arouses several times during a period of sleep. Dreaming occurs during periods when eye movement can be observed in a sleeping person, called rapid eye movement (REM) sleep.

Distinct types of EEG patterns can be detected in patients with specific brain disorders, such as epileptic seizures. Neurologists use these patterns to diagnose the disorders and determine the appropriate treatment.

24. What is an EEG? What four conditions produce alpha, beta, theta, and delta waves, respectively?

Memory

Memory is divided into three major types: sensory, short term (or primary), and long term (figure 14.19). **Sensory memory** is the very short-term retention of sensory input received by the brain

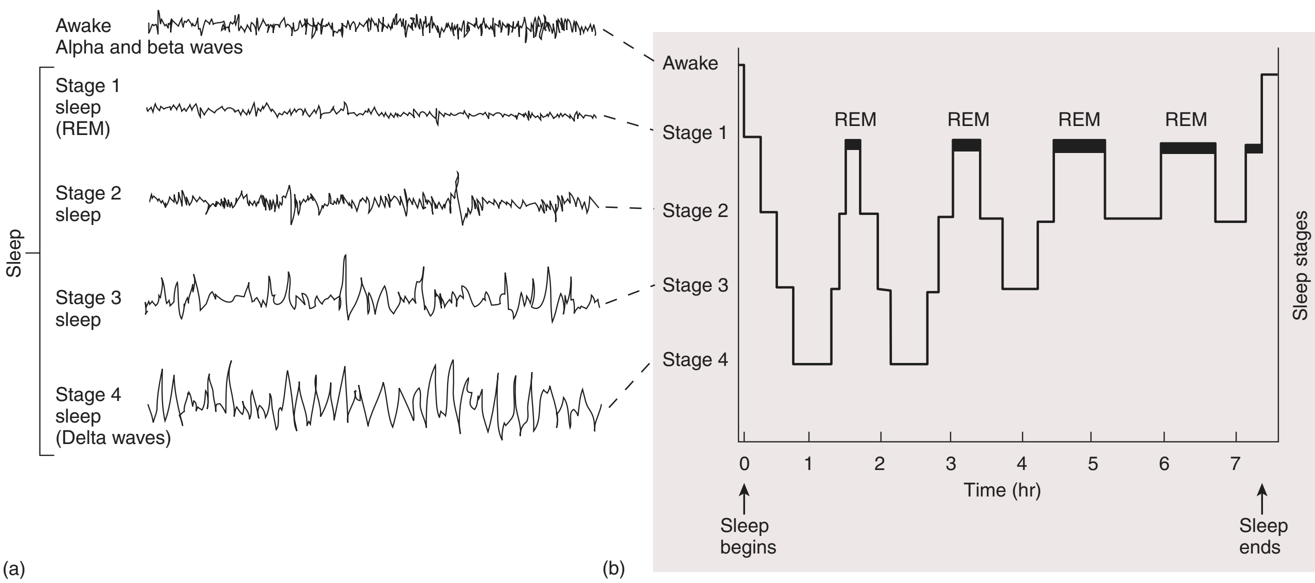


Figure 14.18 **Electroencephalograms (EEGs) Showing Brain Waves**

(*a*) EEG tracings when a person is awake and during four stages of sleep. (*b*) A typical night's sleep pattern in a young adult. The time spent in REM sleep is labeled and shown by *dark bars*.

while something is scanned, evaluated, and acted on. This type of memory lasts less than a second and apparently involves transient changes in membrane potentials.

If a given piece of data held in sensory memory is considered valuable enough, it is moved into **short-term memory,** where information is retained for a few seconds to a few minutes. This memory is limited primarily by the number of bits of information (usually about seven) that can be stored at any one time, although the amount varies from person to person. Have you ever wondered why telephone numbers are seven digits long? More bits can be stored when the numbers are grouped into specific segments separated by spaces, such as when adding an area code. When new information is presented, or when the person is distracted, old information previously stored in short-term memory is eliminated; therefore, if a person is given a second telephone number or if the person's attention is drawn to something else, the first number usually is forgotten.

Two types of **long-term memory** (memory that may last a lifetime) exist: explicit or declarative and implicit or procedural. **Explicit** or **declarative memory** involves the retention of facts, such as names, dates, and places. Explicit memory is accessed by part of the temporal lobe called the **hippocampus** (hip-ō-kam′pŭs; shaped like a seahorse) and the **amygdaloid** (ă-mig′dă-loyd; almond-shaped) **nucleus.** The hippocampus is involved in retrieving the actual memory, such as recalling a person's name; and the amygdala is involved in the emotional overtones of that memory, such as feelings of like or dislike, and the recollection of good or bad memories associated with that person. A lesion in the temporal lobe affecting the hippocampus can prevent the brain from moving information from short-term to long-term memory. Emotion and mood apparently serve as gates in the brain and determine what is or is not stored in long-term explicit memory. The amygdaloid nucleus is also a key to the development of fear, which also involves the prefrontal cortex and the hypothalamus.

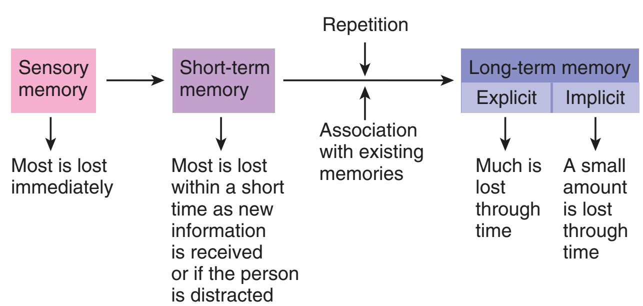


Figure 14.19 **Memory Processing**

Fear

Some aspects of fearful responses appear to be "hardwired" in the brain and don't require learning. For example, infant rodents are terrified when exposed to a cat, even though they have never seen a cat. Loud sounds seem to be particularly effective in eliciting fear responses. A direct collateral branch runs from the auditory pathway to the amygdala, which does not involve the cerebral cortex. Fear can be evoked by a loud sound acting directly on the amygdala. Overcoming fear, however, requires the involvement of the cerebral cortex; therefore, the stimulation of fear appears to involve one process, and its suppression another. Flaws in either process could result in fear-related disorders, such as anxiety, depression, panic, phobias, and posttraumatic stress disorder.

Parts of explicit memory appear to be stored separately in various parts of the cerebrum, especially in the parietal lobe, much like storing items in separate "pigeonholes." Memories of people appear to be stored separately from memories of places. People's faces may be stored in yet other pigeonholes. Family members appear to be stored together. Items that are recognized by sight, such as an animal, are stored separately from items that are recognized by feel, such as tools. Damage, such as a stroke, to one part of the brain can remove certain memories without affecting others.

Retrieval of a complete memory requires accessing parts of the memory from different pigeonholes. A complex memory requires accessing and reassembling segments of memory each time the memory is recalled. The memory of an experience, for example, may be stored in at least four different pigeonholes. Where you were is stored in one place, who you were with in another, what happened in another, and how you felt in yet another place. The complexity of this process my be responsible for the changes in what is recalled over time. On occasion, parts of unrelated different memories may be pulled out and put together incorrectly to create a "false memory." Much of what is stored as explicit memory is gradually lost through time.

Implicit or **procedural memory,** also called **reflexive memory,** involves the development of skills like riding a bicycle or playing a piano. Implicit memory is stored primarily in the cerebellum and the premotor area of the cerebrum. Conditioned, or Pavlovian, reflexes are also implicit and can be eliminated in experimental animals by producing cerebellar lesions in the animals. The most famous example of a conditioned reflex is that of Ivan Pavlov's experiments with dogs. Each time he fed the dogs, a bell was rung; soon the dogs would salivate when the bell rang, even if no food was presented. Only a small amount of implicit memory is lost through time.

Several physiologic explanations have been proposed for short-term memory, most of which involve short-term changes in membrane potentials. The changes in membrane potentials are transitory but are longer than those involved in sensory memory, and they can be eliminated by new information reaching the cells.

Certain pieces of information are transferred from short-term to long-term memory. Long-term memory involves changes in neurons, called **long-term potentiation,** which facilitates future transmission of action potentials (figure 14.20). The amount of the neurotransmitter glutamate produced and released by the presynaptic neuron increases. The number of glutamate receptors in the postsynaptic neuron also increases, and the reaction of the postsynaptic neuron to glutamate is potentiated. Long-term memory storage in a single neuron also involves calcium influx into the postsynaptic cell. Calcium ions associate with and activate **calmodulin** (kal-mod′ū-lin) inside the cell. Calmodulin, through a cAMP mechanism, stimulates the synthesis of specific proteins. These proteins are involved in changing the shape of the cell. The change in shape is stabilized by the creation of a new cytoskeleton, and the memory becomes more or less permanent.

A whole series of neurons and their pattern of activity, called a **memory engram,** or memory trace, probably are involved in the long-term retention of information, a thought, or an idea. Repetition of the information and association of the new information with existing memories assist in the transfer of information from short-term to long-term memory.

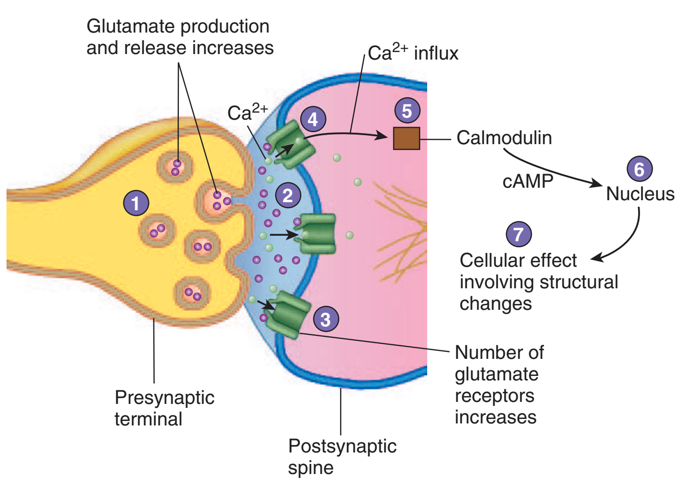
25. Name the three different types of memory, and describe the processes that result in the transfer of information from short-term to long-term memory.

26. Distinguish between implicit and explicit memory.

Limbic System

The limbic system (see figure 13.9) influences emotions, the visceral responses to emotions, motivation, mood, and the sensations of pain and pleasure. This system is associated with basic survival instincts: the acquisition of food and water, as well as reproduction. One of the major sources of sensory input into the limbic system is the olfactory nerves. The smell or thought of food stimulates the sense of hunger in the hypothalamus, which motivates us to seek food. Many animals can also smell water, even over great distances. In animals such as dogs and cats, olfactory detection of **pheromones** (fer′ō-mōnz) is

1. The amount of the neurotransmitter glutamate produced by the presynaptic neuron increases.
2. The amount of glutamate released by the presynaptic neuron also increases.
3. The number of glutamate receptors on the postsynaptic neuron membrane increases.
4. Ca^{2+} channels in the postsynaptic membrane open, allowing Ca^{2+} to enter the cell.
5. The Ca^{2+} that enters the cell associates with the intracellular molecule calmodulin.
6. Activated calmodulin activates a cAMP second messenger, which stimulates synthesis of specific proteins.
7. The cellular effect may involve structural changes in the cell.



Process Figure 14.20 Cellular Mechanisms of Long-Term Potentiation

Clinical Focus General CNS Disorders

Infections

Encephalitis (en-sef-ă-lī′tis) is an inflammation of the brain most often caused by a virus and less often by bacteria or other agents. A large variety of symptoms may result, including fever, paralysis, coma, or even death.

Myelitis (mī-ĕ-lī′tis) is an inflammation of the spinal cord caused by trauma, multiple sclerosis, or a number of infectious agents, including viruses, bacteria, or other agents. A large variety of symptoms may result depending on the extent and level of injury or infection.

Meningitis (men-in-jī′tis) is an inflammation of the meninges. It may be virally induced but is more often bacterial. Symptoms usually include stiffness in the neck, headache, and fever. Pus may accumulate in the subarachnoid space, block CSF flow, and result in hydrocephalus. In severe cases, meningitis may also cause paralysis, coma, or death.

Reye's syndrome may develop in children following a viral infection, especially influenza or chickenpox. The use of aspirin in cases of viral infection has been linked to development of the syndrome in the United States. A predisposing disorder in fat metabolism may also be present in some cases. In children affected by the syndrome, the brain cells swell, and the liver and kidneys accumulate fat. Symptoms include vomiting, lethargy, and loss of consciousness and may progress to coma and death or to permanent brain damage.

Rabies is a viral disease transmitted by the bite of an infected mammal. The rabies virus infects the brain, salivary glands (through which it is transmitted), muscles, and connective tissue. When the patient attempts to swallow, the effort can produce pharyngeal muscle spasms; sometimes even the thought of swallowing water or the sight of water can induce pharyngeal spasms. Thus the term *hydrophobia,* fear of water, is applied to the disease. The virus also infects the brain and results in abnormal excitability, aggression, and, in later stages, paralysis and death.

Tabes dorsalis (tā′bēz dōr-sā′lis) is a progressive disorder occurring as a result of untreated syphilis. Tabes means a wasting away, and dorsalis refers to a degeneration of the dorsal roots and dorsal columns of the spinal cord. The symptoms include ataxia, resulting from lack of proprioceptive input; anesthesia, resulting from dorsal root damage; and eventually paralysis as the infection spreads.

Multiple sclerosis (MS), although of unknown cause, possibly involves an autoimmune response to a viral infection. It results in localized brain lesions and demyelination of neurons in the brain and spinal cord, in which the myelin sheaths become sclerotic, or hard—thus the name—causing poor conduction of action potentials. Symptomatic periods of MS are separated by periods of apparent remission. With each recurrence, however, many neurons are permanently damaged so that the progressive symptoms of the disease include exaggerated reflexes, tremor, nystagmus (rhythmic oscillation of the eyes), and speech defects.

Other Disorders

Tumors of the brain develop from neuroglial cells. Symptoms vary widely, depending on the location of the tumor, but may include headaches, neuralgia (pain along the distribution of a peripheral nerve), paralysis, seizures, coma, and death. **Meningiomas** (mĕ-nin′jē-ō′măz), tumors of the meninges, account for 25% of all primary intracranial tumors.

Stroke is a term meaning a blow or sudden attack, suggesting the speed with which this type of defect can occur. It is also referred to clinically as a **cerebrovascular accident (CVA)** and is caused by hemorrhage, thrombosis, embolism, or vasospasm of the cerebral blood vessels, which result in an infarct, a local area of neuronal cell death caused by a lack of blood supply. Symptoms depend on the location but include anesthesia or paralysis on the side of the body opposite the cerebral infarct. Each year 75,000 Americans suffer strokes. Cigarette smokers are 2.5 times more likely to suffer strokes than are nonsmokers. A daily dose of aspirin may reduce a person's risk of stroke by 50%–80% through its ability to interfere with blood clotting.

An **aneurysm** (an′ū-rizm) is a dilation, or ballooning, of an artery. The arteries around the brain are common sites for aneurysms, and hypertension can cause one of these "balloons" to burst or leak, causing a hemorrhage around the brain. With hemorrhaging, blood may enter the epidural space (epidural hematoma), subdural space (subdural hematoma), subarachnoid space, or the brain tissue. Blood in the subdural or subarachnoid space can apply pressure to the brain, causing damage to brain tissue. Blood is toxic to brain tissue, so that blood entering the brain can directly damage brain tissue.

Cerebral compression may occur as a result of hematomas, hydrocephalus, tumors, or edema of the brain, which can occur as the result of a severe blow to the head. The intracranial pressure increases, which may directly damage brain tissue. The cerebellum may compress the fourth ventricle, blocking the foramina and causing internal hydrocephalus, which further increases intracranial pressure. The greatest problem comes from compression of the brainstem. Compression of the midbrain can kink the oculomotor nerves, resulting in dilation of the pupils with no light response. Compression of the medulla oblongata may disrupt cardiovascular and respiratory centers, which can cause death. Compression of any part of the CNS that results in ischemia for as little as 3–5 minutes can result in local neuronal cell death. This is a major problem in spinal cord injuries.

Syringomyelia (sĭ-ring′gō-mī-ē′lē-ă) is a degenerative cavitation of the central canal of the spinal cord, often caused by a cord tumor. Symptoms include neuralgia, paresthesia (increased sensitivity to pain), specific loss of pain and temperature sensation, and paresis. This defect is unusual in that it occurs in a distinct band that includes both sides of the body because commissural tracts are destroyed.

Alzheimer's disease is a severe type of mental deterioration, or dementia, usually affecting older people but occasionally affecting people younger than 60. It accounts

Continued

Continued

for half of all dementias; the other half result from drug and alcohol abuse, infections, or CVAs. Alzheimer's disease is estimated to affect 10% of all people older than 65 and nearly half of those older than 85.

Alzheimer's disease involves a general decrease in brain size resulting from loss of neurons in the cerebral cortex. The gyri become narrower, and the sulci widen. The frontal lobes and specific regions of the temporal lobes are affected most severely. Symptoms include general intellectual deficiency, memory loss, short attention span, moodiness, disorientation, and irritability.

Amyloid plaques and neurofibrillary tangles, which may contain aluminum accumulations, form in the cortex of patients with Alzheimer's disease. **Amyloid** (am′i-loyd) **plaques** are localized axonal enlargements of degenerating nerve fibers, containing large amounts of β-amyloid protein, and **neurofibrillary tangles,** which are filaments inside the cell bodies of the dead or dying neurons.

Some evidence exists that Alzheimer's disease may have characteristics of a chronic inflammatory disease, similar to arthritis, and anti-inflammatory drug therapy has had some affect in slowing its progress. Estrogen treatment may decrease or postpone symptoms in women.

The gene for β-amyloid protein has been mapped to chromosome 21; however, it is thought that only the rare, inherited, early-onset (beginning before age 60) form of Alzheimer's maps to chromosome 21. The more common late-onset form (beginning after age 65), which makes up more than three-fourths of all cases, maps to chromosome 19. It is noteworthy that people with Down's syndrome, or trisomy 21, which means that a person has three copies of chromosome 21, exhibit the cortical and other changes associated with Alzheimer's disease.

Another protein, **apolipoprotein E** (ap′ō-lip-ō-prō′tēn; **apo E**), which binds to β-amyloid protein and is known to transport cholesterol in the blood, has also been associated with Alzheimer's disease. The protein has been found in the plaques and tangles and has been mapped to the same region of chromosome 19 as the late-onset form of Alzheimer's. People with two copies of the apo E-IV gene are eight times more likely to develop the disease than people with no copies of the defective gene. Apo E-IV apparently binds to β-amyloid more rapidly and more tightly than does apo E-III, which is the normal form of the protein.

Apo E may also be involved with regulating phosphorylation of another protein, called τ (tau), which, in turn, is involved in microtubule formation inside neurons. If τ is overphosphorylated, microtubules are not properly constructed, and the τ proteins intertwine to form neurofibrillary tangles. It has been demonstrated that apo E-III interacts with τ but that apo E-IV does not. It may be that the less stable microtubules, formed with a decreased τ involvement, begin to eventually break down, resulting in neuronal dysfunction. The neurofibrillary tangles of τ proteins may also clog up the cell, further decreasing cell function.

Alzheimer's may be treated with the monoamine oxidase-B inhibitor L-deprenyl. The drug may stimulate nitric oxide production, which could stimulate vasodilation of cerebral blood vessels.

Tay-Sachs disease is a hereditary disorder of infants involving abnormal sphingolipid (lipids with long base chains) metabolism that results in severe brain dysfunction. Symptoms include paralysis, blindness, and death, usually before age 5.

Chronic mercury poisoning can cause brain disorders, such as intention tremor, exaggerated reflexes, and emotional instability.

Lead poisoning is a serious problem, particularly among urban children. Lead is taken into the body from contaminated air, food, and water. Flaking lead paint in older houses and soil contamination can be major sources of lead poisoning in children. Lead usually accumulates slowly in the body until toxic levels are reached.

Brain damage caused by lead poisoning in children includes edema, demyelination, and cortical neuron necrosis with astrocyte proliferation. This damage appears to be permanent and can result in reduced intelligence, learning disabilities, poor psychomotor development, and blindness. In severe cases, psychoses, seizures, coma, or death may occur. Adults exhibit more mild PNS symptoms, including demyelination with decreased neuromuscular function. Other symptoms include abdominal pain and renal disease.

Epilepsy is a group of brain disorders that have seizure episodes in common. The seizure, a sudden massive neuronal discharge, can be either partial or complete,

important in reproduction. Pheromones are molecules released into the air by one animal that attract another animal of the same species, usually of the opposite sex. Pheromones released by human females can influence the menstrual cycles of other women.

Apparently the cingulate gyrus is a "satisfaction center" for the brain and is associated with the feeling of satisfaction after a meal or after sexual intercourse. The relationship of the hippocampus with the limbic system and with memory is probably important to survival. For example, it's very important for an animal to remember where to obtain food. Once a person has eaten, the satiety center in the hypothalamus is stimulated, the hunger center is inhibited, and the person feels satiated. The hypothalamus interacts with the cingulate gyrus and other parts of the limbic system, causing a sense of satisfaction associated with the satiation.

Lesions in the limbic system can result in a voracious appetite, increased sexual activity, which is often inappropriate, and docility, including the loss of normal fear and anger responses. Because the hippocampus is part of the temporal lobe, damage to that portion can also result in a loss of memory formation.

27. What are the functions of the limbic system? Which of the special senses has a major input into the limbic system?
28. Define pheromones.

depending on the amount of brain involved and whether or not consciousness is impaired. Normally a balance exists between excitation and inhibition in the brain. When this balance is disrupted by increased excitation or decreased inhibition, a seizure may result. The neuronal discharges may stimulate muscles innervated by the neurons involved, resulting in involuntary muscle contractions, or convulsions.

Depression may cause more "grief and misery" than any other single disease. Although the illness has been known for over 2000 years, its medical status is still uncertain. Is depression a disease state caused by some chemical excess or deficiency, or is it a psychologic condition that a person can decide to snap out of? The answer is probably that both types of depression exist. Depression is a complex multifacited group of disorders. Some types of "endogenous" depression can be treated with antidepressants, of which there are five groups: tricyclic antidepressesants, nontricyclic compounds, MAO inhibitors, serotonin agonists, and lithium. Many people with depression also have epilepsy. Recent research in which "pacemaker-like" stimulation of the vagus nerve to treate epilepsy has shown some promise in treating depression that does not respond to drugs.

Headaches have a variety of causes that can be grouped into two basic classes: extracranial and intracranial. Extracranial headaches can be caused by inflammation of the sinuses, dental irritations, temperomandibular joint disorders, ophthalmologic disorders, or tension in the muscles moving the head and neck. Intracranial headaches may result from inflammation of the brain or meninges, vascular problems, mechanical damage, or tumors.

Tension headaches are extracranial muscle tension, stress headaches, consisting of a dull, steady pain in the forehead, temples, neck, or throughout the head. Tension headaches are associated with stress, fatigue, and posture.

Migraine headaches (migraine means half a skull) occur in only one side of the head and appear to involve the abnormal dilation and constriction of blood vessels. They often start with distorted vision, shooting spots, and blind spots. Migraines consist of severe throbbing, pulsating pain. About 80% of migraine sufferers have a family history of the disorder, and women are affected four times more often than men. Those suffering migraines are usually women younger than 35. The severity and frequency usually decrease with age.

A **concussion** is a blow to the head producing momentary loss of consciousness without immediate detectable damage to the brain. Often no more problems occur after the person regains consciousness; however, in some cases, **postconcussion syndrome** may occur a short time after the injury. The syndrome includes increased muscle tension or migraine headaches, reduced alcohol tolerance, difficulty in learning new things, reduction in creativity, and motivation, fatigue, and personality changes. The symptoms may be gone in a month or may persist for as much as a year. In some cases, postconcussion syndrome may be the result of a slowly occurring subdural hematoma that may be missed by an early examination. The blood may accumulate from small leaks in the dural sinuses.

Alexia (ă-lek′sē-ă), loss of the ability to read, may result from a lesion in the visual association cortex. **Dyslexia** (dīs-lek′sē-ă) is a defect in which the reading level is below that expected on the basis of an individual's overall intelligence. Most people with dyslexia have normal or above-normal intelligence quotients. The term means reading deficiency and is also called partial alexia. It is three times more common in males than females. As many as 10% of males in the United States suffer from the disorder. The symptoms vary considerably from person to person and include transposition of letters in a word, confusion between the letters *b* and *d,* and lack of orientation in three-dimensional space. The brains of some dyslexics have abnormal cellular arrangements, including cortical disorganization and the appearance of bits of gray matter in medullary areas. Dyslexia apparently results from abnormal brain development.

Children with **attention deficit disorder (ADD)** are easily distractible, have short attention spans, and may shift from one uncompleted task to another. Children with **attention deficit/hyperactivity disorder (ADHD)** exhibit the characteristics of ADD, but they are also fidgety, have difficulty remaining seated and waiting their turn, engage in excessive talking, and commonly interrupt others. About 3% of all children exhibit ADHD, more so in boys than girls. Symptoms usually occur before age 7. The neurologic basis of both ADD and ADHD is as yet unknown.

Effects of Aging on the Nervous System

Objective

- ***Describe the age-related effects of aging on the nervous system.***

As a person ages, there's a gradual decline in sensory function because the number of sensory neurons declines, the function of remaining neurons decreases, and CNS processing decreases. In the skin, free nerve endings and hair follicle receptors remain largely unchanged with age. Meissner's corpuscles and pacinian corpuscles, however, decrease in number. The capsules of those that remain become thicker and structurally distorted and, therefore, exhibit reduced function. As a result of these changes in Meissner's corpuscles and pacinian corpuscles, elderly people are less conscious of something touching or pressing on the skin, have a decreased sense of two-point discrimination, and have a more difficult time identifying objects by touch. These functional changes leave elderly people more prone to skin injuries and with a greater sense of isolation.

Systems Pathology

Stroke

Mr. S, who is approaching middle age, is somewhat overweight and has high blood pressure. He was seated on the edge of his couch, at least most of the time, when he was not jumping to his feet and shouting at the referees for an obviously bad call. He was surrounded by empty pizza boxes, bowls of chips and salsa, empty beer cans, and full ashtrays. As Mr. S cheered on his favorite team in a hotly contested big game, which they would be winning easily if it weren't for the lousy officiating, he noticed that he felt drowsy and that the television screen seemed blurry. He began to feel dizzy. As he tried to stand up, he suddenly vomited and collapsed to the floor, unconscious.

Mr. S was rushed to the local hospital, where the following signs and symptoms were observed. He exhibited weakness in his limbs, especially on the right, and ataxia (inability to walk). He had loss of pain and temperature sensation in his right lower limb and the left side of his face. The dizziness persisted and he appeared disoriented and lacked attentiveness. He also exhibited dysphagia (the inability to swallow) and hoarseness. He had nystagmus (rhythmic oscillation of the eyes). His pupils were slightly dilated, his respiration was short and shallow, and his pulse rate and blood pressure were elevated.

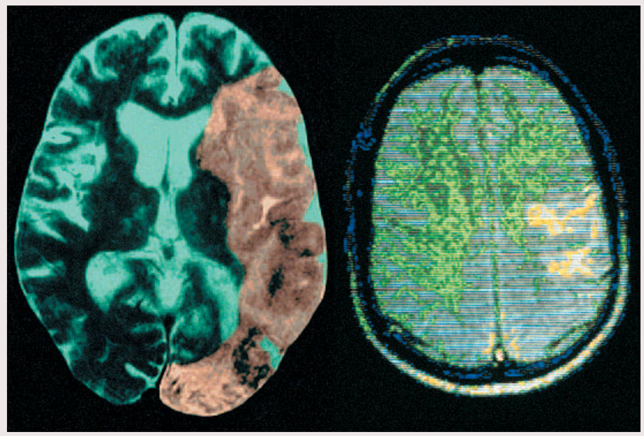


Figure B MRI of a massive stroke in the brain (left). Colorized NMR showing disruption of blood flow to the right side of the brain (yellow). This disruption could cause a stroke (right).

Background Information

Mr. S suffered a "stroke," also referred to as a cerebrovascular accident (CVA). The term *stroke* describes a heterogeneous group of conditions involving death of brain tissue resulting from disruption of its vascular supply. Two types of stroke exist: **hemorrhagic stroke,** which results from bleeding of arteries supplying brain tissue, and **ischemic stroke,** which results from blockage of arteries supplying brain tissue (figure B). The blockage in ischemic stroke can result from a thrombus (a clot that develops in place within an artery) or an embolism (a plug, composed of a detached thrombus or other foreign body, such as a fat globule or gas bubble, that becomes lodged in an artery, blocking it).

Mr. S was at high risk for developing a stroke. He was approaching middle age, was overweight, did not exercise enough, smoked, was under stress, and had a poor diet.

The combination of motor loss, which was seen as weakness in his limbs, and sensory loss, seen as loss of pain and temperature sensation in his right lower limb and loss of all sensation in the left side of his face; along with the ataxia, dizziness, nystagmus, and hoarseness, suggest that the stroke affected the brainstem and cerebellum.

Loss of pacinian corpuscles also results in a decreased sense of position of the limbs and in the joints, which can affect balance and coordination. The functions of Golgi tendon organs and muscle spindles also decline with increasing age. As a result, information on the position, tension, and length of tendons and muscles decreases, resulting in additional reduction in the senses of movement, posture, and position, as well as reduced control and coordination of movement.

Other sensory neurons with reduced function include those that monitor blood pressure, thirst, objects in the throat, the amount of urine in the urinary bladder, and the amount of feces in the rectum. As a result, elderly people are more prone to high blood pressure, dehydration, swallowing and choking problems, urinary incontinence, and constipation or bowel incontinence.

There's also a general decline in the number of motor neurons. As many as 50% of the lower motor neurons in the lumbar region of the spinal cord may be lost by age 60. Muscle fibers innervated by the lost motor neurons are also lost, resulting in a general decline in muscle mass. The remaining motor units can compensate for some of the lost function. This, however, often results in a feeling that one must work harder to perform activities that were previously not so difficult. Loss of motor units also leads to more rapid fatigue as the remaining units must perform compensatory work.

Reflexes slow as people age because both the generation and conduction of action potentials and synaptic functions slow. The number of neurotransmitters and receptors declines. Age-related

System Interactions Effect of Stroke on Other Systems

System	Interactions
Integumentary	Decubitus ulcers (bedsores) from immobility; loss of motor function following a stroke leads to immobility.
Skeletal	Loss of bone mass, if muscles are dysfunctional for a prolonged time; in the absence of muscular activity, the bones to which those muscle are attached begin to be resorbed by osteoclasts.
Muscular	Major area of effect; absence of stimulation due to damaged pathways or neurons leads to decreased motor function and may result in muscle atrophy.
Endocrine	Strokes in other parts of the brain could involve the hypothalamus, pineal body, or pituitary gland functions.
Cardiovascular	Risks: Phlebothrombosis (blood clot in a vein) can occur from inactivity. Edema around the brain could apply pressure to the cardioregulatory and vasomotor centers of the brain. This pressure could stimulate these centers, which would result in elevated blood pressure, and congestive heart failure could result. If the cardioregulatory center in the brain is damaged, death may occur rapidly. Bleeding is due to the use of anticoagulants. Hypotension results from use of antihypertensives.
Respiratory	Pneumonia from aspiration of the vomitus or hypoventilation results from decreased function in the respiratory center. If the respiratory center is severely damaged, death may occur rapidly.
Digestive	Vomiting, dysphagia (difficulty swallowing); hypovolemia (decreased blood volume) result from decreased fluid intake; occurs because of dysphagia; may be a loss of bowel control.
Urinary	Control of the micturition reflex may be inhibited. Urinary tract infection results from catheter implantation or from urinary bladder distension.
Reproductive	Loss of libido; innervation of the reproductive organs is often affected.

Blockage of the vertebral artery, a major artery supplying the brain, or its branches can result in what is called a lateral medullary infarction (an area of dead tissue resulting from a loss of blood supply to an area). Damage to the descending motor pathways in that area, above the medullary decussation, results in muscle weakness. Damage to ascending pathways can result in loss of pain and temperature sensation (or other sensory modalities depending on the affected tract). Damage to cranial nerve nuclei results in the loss of pain and temperature sensation in the face, dizziness, blurred vision, nystagmus, vomiting, and hoarseness. These signs and symptoms are not observed unless the lesion is in the brainstem, where these nuclei are located. Some damage to the cerebellum, also supplied by branches of the vertebral artery, can account for the ataxia.

Drowsiness, disorientation, inattentiveness, and loss of consciousness are examples of generalized neurologic response to damage. Seizures may also result from severe neurologic damage. Depression from neurologic damage or from discouragement is also common. Slight dilation of the pupils; short, shallow respiration; and increased pulse rate and blood pressure are all signs of Mr. S's anxiety, not about the outcome of the game but about his current condition and his immediate future. With a loss of consciousness, Mr. S would not remember the last few minutes of what he saw in the game he was watching. People in these circumstances are often worried about how they are going to deal with work tomorrow. They often have no idea that the motor and sensory losses may be permanent, or that they will have a long period of therapy ahead.

PREDICT 9

Given that Mr. S exhibited weakness in his right limbs and loss of pain and temperature sensation in his right lower limb and the left side of his face, state which side of the brainstem was most severely affected by the stroke. Explain your answer.

changes in the CNS also slow reflexes. The more complicated the reflex, the more it's affected by age. As reflexes slow, older people are less able to react automatically, quickly, and accurately to changes in internal and external conditions.

The size and weight of the brain decrease as a person ages. At least part of these changes result from the loss of neurons within the cerebrum. The remaining neurons can apparently compensate for much of this loss. In addition to loss of neurons, structural changes occur in the remaining neurons. Neuron plasma membranes become more rigid, the endoplasmic reticulum becomes more irregular in structure, neurofibrillar tangles develop in the cells, and amyloid plaques form in synapses. All of these changes decrease the ability of neurons to function. Age-related changes in brain function include decreased voluntary movement, conscious sensations, reflexes, memory, and sleep. Short-term memory is decreased in most older people. This change varies greatly among individuals, but, in general, such changes are slow until about age 60 and then become more rapid, especially after age 70. However, the total amount of memory loss is normally not great for most people. The most difficult information for older people to assimilate is that which is unfamiliar and presented verbally and rapidly. Some of these problems may occur as older people are required to deal with new information in the face of existing, contradictory memories. Long-term memory appears to be unaffected or even improved in older people.

As with short-term memory, thinking, which includes problem solving, planning, and intelligence, in general, declines slowly to age 60 but more rapidly thereafter. These changes, however, are slight and quite variable. Many older people show no change and about 10% show an increase in thinking ability. Many of these changes are impacted by a person's background, education, health, motivation, and experience.

Among older people, more time is required to fall asleep, there are more periods of waking during the night, and the wakeful periods are of greater duration. Factors that can affect sleep include pain, indigestion, rhythmic leg movements, sleep apnea, decreased urinary bladder capacity, and circulatory problems. There is, on the average, an increase in stage 1 sleep, which is the least restful, and less time spent in stage 4 and REM sleep, which are the most restful.

29. How does aging affect sensory function? How does loss of motor neurons affect muscle mass?
30. Does aging always produce memory loss?

S U M M A R Y

Sensation (p. 466)

1. The senses include general senses and special senses.
2. Somatic senses include touch, pressure, temperature, proprioception, and pain.
3. Visceral senses are primarily pain and pressure.
4. Special senses are smell, taste, sight, hearing, and balance.
5. Sensation, or perception, is the conscious awareness of stimuli received by sensory receptors.
6. Sensation requires a stimulus, a receptor, conduction of an action potential to the CNS, translation of the action potential, and processing of the action potential in the CNS so that the person is aware of the sensation.

Sensory Receptors

1. Receptors include mechanoreceptors, chemoreceptors, thermoreceptors, photoreceptors, and nociceptors.
2. Free nerve endings detect light touch, pain, itch, tickle, and temperature.
3. Merkel's disks respond to light touch and superficial pressure.
4. Hair follicle receptors wrap around the hair follicle and are involved in the sensation of light touch when the hair is bent.
5. Pacinian corpuscles, located in the dermis and hypodermis, detect pressure. In joints, they serve a proprioceptive function.
6. Meissner's corpuscles, located in the dermis, are responsible for two-point discriminative touch.
7. Ruffini's end organs are involved in continuous touch or pressure.
8. Muscle spindles, located in skeletal muscle, are proprioceptors.
9. Golgi tendon organs, embedded in tendons, respond to changes in tension.
10. A stimulus produces a receptor potential in a sensory receptor. Primary receptors have axons that transmit action potentials toward the CNS. Secondary receptors have no axons but release neurotransmitters.
11. Adaptation is decreased sensitivity to a continued stimulus. Tonic receptors accommodate slowly, phasic receptors accommodate rapidly.

Sensory Nerve Tracts

1. Ascending pathways carry conscious and unconscious sensations.
2. Spinothalamic system
   - The lateral spinothalamic tract carries pain and temperature sensations. The anterior spinothalamic tract carries light touch, pressure, tickle, and itch sensations.
   - Both tracts are formed by primary neurons that enter the spinal cord and synapse with secondary neurons. The secondary neurons cross the spinal cord and ascend to the thalamus, where they synapse with tertiary neurons that project to the somatic sensory cortex.
   - Primary neurons enter the spinal cord and ascend to the medulla, where they synapse with secondary neurons. The secondary neurons cross over and project to the thalamus, where they synapse with tertiary neurons that extend to the somatic sensory cortex.
3. The dorsal-column/medial-lemniscal system carries the sensations of two-point discrimination, proprioception, pressure, and vibration. Primary neurons enter the spinal cord and ascend to the medulla, where they synapse with secondary neurons. Secondary neurons cross over and project to the thalamus. Tertiary neurons extend from there to the somatic sensory cortex.
4. The trigeminothalamic tract carries sensory information from the face, nose, and mouth.
5. Spinocerebellar system and other tracts
   - The spinocerebellar tracts carry unconscious proprioception to the cerebellum from the same side of the body.
   - Neurons of the dorsal-column/medial-lemniscal system synapse with the neurons that carry proprioception information to the cerebellum.
   - The spinoolivary tract contributes to coordination of movement, the spinotectal tract to eye reflexes, and the spinoreticular tract to arousing consciousness.
6. Descending pathways can reduce conscious perception of sensations.

Sensory Areas of the Cerebral Cortex

1. Sensory pathways project to primary sensory areas in the cerebral cortex. Association areas interpret input from the primary sensory areas.
2. Sensory areas are organized topographically in the somatic sensory cortex.

Control of Skeletal Muscles (p. 478)

1. Upper motor neurons are located in the cerebral cortex, cerebellum, and brainstem. Lower motor neurons are found in the cranial nuclei or the anterior horn of the spinal cord gray matter.
2. Upper motor neurons in the cerebral cortex and other brain areas project to lower motor neurons in the brainstem and spinal cord.

Motor Areas of the Cerebral Cortex

1. The primary motor cortex is the precentral gyrus. The premotor and prefrontal areas are staging areas for motor function.
2. The motor cortex is organized topographically.

Motor Nerve Tracts

1. The direct pathways maintain muscle tone and control fine, skilled movements in the face and distal limbs. The indirect pathways control conscious and unconscious muscle movements in the trunk and proximal limbs.
2. The corticospinal tracts control muscle movements below the head.
   - About 75%–85% of the upper motor neurons of the corticospinal tracts cross over in the medulla to form the lateral corticospinal tracts in the spinal cord.
   - The remaining upper motor neurons pass through the medulla to form the anterior corticospinal tracts, which cross over in the spinal cord.
   - The upper motor neurons of both tracts synapse with interneurons that then synapse with lower motor neurons in the spinal cord.

3. The corticobulbar tracts innervate the head muscles. Upper motor neurons synapse with interneurons in the reticular formation that, in turn, synapse with lower motor neurons in the cranial nerve nuclei.
4. The indirect pathways include the rubrospinal, vestibulospinal, and reticulospinal tracts and fibers from the basal nuclei.
5. The indirect pathways are involved in conscious and unconscious trunk and proximal limb muscle movements, posture, and balance.

Modifying and Refining Motor Activities

1. Basal nuclei are important in planning, organizing, and coordinating motor movements and posture.
2. The cerebellum has three parts.
   - The vestibulocerebellum controls balance and eye movement.
   - The spinocerebellum functions to correct discrepancies between intended movements and actual movements.
   - The cerebrocerebellum can "learn" highly specific complex motor activities.

Brainstem Functions (p. 485)

1. The brainstem contains nuclei of cranial nerves II–XII.
2. Sensory and motor pathways pass through the brainstem.
3. Some sensory pathways synapse in the brainstem.
4. Many important reflexes, some of which are critical to survival, are controlled in the brainstem.

Other Brain Functions (p. 487)

Speech

1. Speech is located only in the left cortex in most people.
2. Wernicke's area comprehends and formulates speech.
3. Broca's area receives input from Wernicke's area and sends impulses to the premotor and motor areas, which cause the muscle movements required for speech.

Right and Left Cerebral Cortex

1. Each cerebral hemisphere controls and receives input from the opposite side of the body.
2. The right and left hemispheres are connected by commissures. The largest commissure is the corpus callosum, which allows sharing of information between hemispheres.
3. In most people the left hemisphere is dominant, controlling speech and analytic skills. The right hemisphere controls spatial and musical abilities.

Brain Waves and Sleep

1. Electroencephalograms (EEGs) record the electrical activity of the brain as alpha, beta, theta, and delta waves.
2. Some brain disorders can be detected with EEGs.
3. Sleep patterns are characterized by specific EEGs.

Memory

At least three kinds of memory exist: sensory, short term, and long term.

Limbic System

1. The limbic system includes parts of the cerebral cortex, basal nuclei, thalamus, hypothalamus, and the olfactory cortex.
2. The limbic system controls visceral functions through the autonomic nervous system and the endocrine system and is also involved in emotions and memory.

Effects of Aging on the Nervous System (p. 493)

1. There is a general decline in sensory and motor functions as a person ages.
2. Short-term memory is decreased in most older people.
3. Thinking ability does not decrease in most older people.

R E V I E W A N D C O M P R E H E N S I O N

1. Nociceptors respond to
   a. changes in temperature at the site of the receptor.
   b. compression, bending, or stretching of cells.
   c. painful mechanical, chemical, or thermal stimuli.
   d. light striking a receptor cell.
2. Which of these types of nerve endings responds to pain, itch, tickle, and temperature?
   a. Merkel's disks
   b. Meissner's corpuscles
   c. Ruffini's end organs
   d. free nerve endings
   e. pacinian corpuscles
3. Which of these types of nerve endings are involved with proprioception?
   a. free nerve endings
   b. Golgi tendon organs
   c. muscle spindles
   d. pacinian corpuscle
   e. all of the above
4. The sensory nerve ending in the dermis and hypodermis responsible for sensing deep continuous touch or pressure are
   a. Merkel's disks.
   b. Meissner's corpuscles.
   c. Ruffini's end organs.
   d. free nerve endings.
   e. pacinian corpuscles.
5. Decreased sensitivity to a continued stimulus is called
   a. adaptation.
   b. projection.
   c. translation.
   d. conduction.
   e. phantom pain.
6. Secondary neurons in the spinothalamic tracts synapse with tertiary neurons in the
   a. medulla oblongata.
   b. gray matter of the spinal cord.
   c. cerebellum.
   d. thalamus.
   e. midbrain.
7. If the lateral spinothalamic tract on the right side of the spinal cord is severed,
   a. pain sensations below the damaged area on the right side are eliminated.
   b. pain sensations below the damaged area on the left side are eliminated.
   c. temperature sensations are unaffected.
   d. neither pain sensations nor temperature sensations are affected.
8. Fibers of the dorsal-column/medial-lemniscal system
   a. carry the sensations of two-point discrimination, proprioception, pressure, and vibration.
   b. cross to the opposite side in the medulla oblongata.
   c. are divided into the fasciculus gracilis and fasciculus cuneatus in the spinal cord.
   d. include secondary neurons that exit the medulla and synapse in the thalamus.
   e. all of the above.

9. Tertiary neurons in both the spinothalamic tracts and dorsal-column/medial-lemniscal tracts
   a. project to the somatic sensory cortex.
   b. cross to the opposite side in the medulla oblongata.
   c. are found in the spinal cord.
   d. connect to quaternary neurons in the thalamus.
   e. are part of a descending pathway.
10. Unlike the spinothalamic and dorsal-column/medial-lemniscal systems, the spinocerebellar tracts
   a. are descending tracts.
   b. transmit information from the same side of the body as the side of the brain to which they project.
   c. have four neurons in each pathway.
   d. carry only pain sensations.
   e. have primary neurons that synapse in the thalamus.
11. General sensory inputs (pain, pressure, temperature) to the cerebrum end in the
   a. precentral gyrus.
   b. postcentral gyrus.
   c. central sulcus.
   d. corpus callosum.
   e. arachnoid mater.
12. Neurons from which of these areas of the body occupy the greatest area of the somatic sensory cortex?
   a. foot
   b. leg
   c. torso
   d. arm
   e. face
13. A cutaneous nerve to the hand is severed at the elbow. The distal end of the nerve at the elbow is then stimulated. The subject reports
   a. no sensation because the receptors are gone.
   b. a sensation only in the region of the elbow.
   c. a sensation "projected" to the hand.
   d. a vague sensation on the side of the body containing the cut nerve.
14. Which of these areas of the cerebral cortex is involved in the motivation and foresight to plan and initiate movements?
   a. primary motor cortex
   b. somatic sensory cortex
   c. prefrontal area
   d. premotor area
   e. basal nuclei
15. Which of these pathways is *not* an ascending (sensory) pathway?
   a. anterior spinothalamic tract
   b. corticospinal tract
   c. dorsal column/medial lemniscal tract
   d. trigeminothalamic tract
   e. spinocerebellar tract
16. The ______________ tracts innervate the head muscles.
   a. corticospinal
   b. rubrospinal
   c. vestibulospinal
   d. corticobulbar
   e. dorsal-column/medial-lemniscal
17. Most fibers of the direct (pyramidal) system
   a. decussate in the medulla oblongata.
   b. synapse in the pons.
   c. descend in the rubrospinal tract.
   d. begin in the cerebellum.
18. A person with a spinal cord injury is suffering from paresis (partial paralysis) in the right lower limb. Which of these pathways is probably involved?
   a. left lateral corticospinal tract
   b. right lateral corticospinal tract
   c. left dorsal column/medial lemniscal system
   d. right dorsal column/medial lemniscal system
19. Which of these pathways is *not* an indirect (extrapyramidal) pathway?
   a. reticulospinal tract
   b. corticobulbar tract
   c. rubrospinal tract
   d. vestibulospinal tract
20. The indirect (extrapyramidal) system is concerned with
   a. posture
   b. trunk movements
   c. proximal limb movements
   d. all of the above
21. The major effect of the basal nuclei is
   a. to act as a comparator for motor coordination.
   b. to decrease muscle tone and inhibit unwanted muscular activity.
   c. affect emotions and emotional responses to odors.
   d. modulate pain sensations.
22. Which of the parts of the cerebellum is correctly matched with its function?
   a. vestibulocerebellum—planning and learning rapid, complex movements
   b. spinocerebellum—comparator function
   c. cerebrocerebellum—balance
   d. none of the above
23. Given the following events:
   1. Action potentials from the cerebellum go to the motor cortex and spinal cord.
   2. Action potentials from the motor cortex go to lower motor neurons and the cerebellum.
   3. Action potentials from proprioceptors go to the cerebellum.

   Arrange the events in the order they occur in the cerebellar comparator function.
   a. 1, 2, 3
   b. 1, 3, 2
   c. 2, 1, 3
   d. 2, 3, 1
   e. 3, 2, 1
24. The brainstem
   a. consists of ascending and descending pathways.
   b. contains cranial nerve nuclei II–XII.
   c. has nuclei and connections that form the reticular activating system.
   d. has many important reflexes, some of which are necessary for survival.
   e. has all of the above.
25. Given these areas of the cerebral cortex:
   1. Broca's area
   2. premotor area
   3. primary motor cortex
   4. Wernicke's area

   If a person hears and understands a word and then says the word out loud, in what order are the areas used?
   a. 1,4,2,3
   b. 1,4,3,2
   c. 3,1,4,2
   d. 4,1,2,3
   e. 4,1,3,2

26. The main connection between the right and left hemispheres of the cerebrum is the
    a. intermediate mass.
    b. corpus callosum.
    c. vermis.
    d. unmyelinated nuclei.
    e. thalamus.
27. Which of these activities is mostly associated with the left cerebral hemisphere in most people?
    a. sensory input from the left side of the body
    b. mathematics and speech
    c. spatial perception
    d. recognition of faces
    e. musical ability
28. The limbic system is involved in the control of
    a. sleep and wakefulness.
    b. maintaining posture.
    c. higher intellectual processes.
    d. emotion, mood, and sensations of pain or pleasure.
    e. hearing.
29. Long-term memory involves
    a. a change in the cytoskeleton of neurons.
    b. movement of calcium into the neuron.
    c. increase in glutamate release by presynaptic neurons.
    d. activation of the enzyme calpains.
    e. all of the above.
30. Concerning long-term memory,
    a. explicit (declarative) memory involves the development of skills, such as riding a bicycle.
    b. implicit (procedural) memory involves the retention of facts, such as names, dates, or places.
    c. much of explicit (declarative) memory is lost through time.
    d. explicit (declarative) memory is stored primarily in the cerebellum and premotor area of the cerebrum.
    e. all of the above.

Answers in Appendix F

CRITICAL THINKING

1. Describe all the sensations involved when a woman picks up an apple and bites into it. Explain which of those sensations are special and which are general. What types of receptors are involved? Which aspects of the taste of the apple are actually taste and which are olfaction?
2. Some student nurses are at a party. Because they love anatomy and physiology so much, they are discussing adaptation of the special senses. They make the following observations:
    a. When entering a room, an odor like brewing coffee is easily noticed. A few minutes later, the odor might be barely, if at all, detectable, no matter how hard one tries to smell it.
    b. When entering a room, the sound of a ticking clock can be detected. Later the sound is not noticed until a conscious effort is made to hear it. Then it is easily heard. Explain the basis for each of these observations.
3. A patient is suffering from the loss of two-point discrimination and proprioceptive sensations on the right side of the body resulting from a lesion in the pons. What tract is affected, and which side of the pons is involved?
4. A patient suffers a lesion in the central core of the spinal cord. It is suspected that the fibers that decussate and that are associated with the lateral spinothalamic tracts are affected in the area of the lesion. What observations would be consistent with that diagnosis?
5. A person in a car accident exhibits the following symptoms: extreme paresis on the right side, including the arm and leg, reduction of pain sensation on the left side, and normal tactile sensation on both sides. Which nerve tracts are damaged? Where did the patient suffer nerve tract damage?
6. If the right side of the spinal cord is completely transected, what symptoms do you expect to observe with regard to motor function, two-point discrimination, light touch, and pain perception?
7. A patient with a cerebral lesion exhibits a loss of fine motor control of the left hand, arm, forearm, and shoulder. All other motor and sensory functions appeared to be intact. Describe the location of the lesion as precisely as possible.
8. A patient suffers brain damage in an automobile accident. It is suspected that the cerebellum is the part of the brain that is affected. On the basis of what you know about cerebellar function, how could you determine that the cerebellum is involved?
9. Woody Knothead was accidentally struck in the head with a baseball bat. He fell to the ground unconscious. Later, when he regains consciousness, he is not able to remember any of the events that happened 10 minutes before the accident. Explain. What complications might be looked for at a later time?

Answers in Appendix G

ANSWERS TO PREDICT QUESTIONS

1. Because hot and cold objects may not be perceived any differently for temperatures of 0°–12°C or above 47°C (both temperature ranges stimulate pain fibers), the nervous system may not be able to discriminate between the two temperatures. At low temperatures, both cold and pain receptors are stimulated; thus, after the object has been in the hand for a very short time, it's possible to discriminate between cold and pain. If, however, the CNS has been preprogrammed to think that the object to be placed in the hand is hot, a cold object can elicit a rapid withdrawal reflex.
2. Collateral branches in the anterior spinothalamic tracts result in increased light-touch sensitivity because collaterals from a number of sensory nerve endings can converge onto one ascending neuron and enhance its sensory conduction. As a result, light touch requires less peripheral stimulation to produce action potentials in the ascending pathway. Collateral, converging pathways, however, result in less discriminative information because sensory receptors from more than one point of the skin have input onto the same ascending neuron, and the neuron cannot distinguish one small area of skin from another within the zone where its sensory receptors are located.

3. The damage to Bill's spinal cord would be on the left side. The fasciculus gracilis conveys sensations of proprioception, fine touch, and vibration through the spinal cord on the same side of the body as the sensory nerve endings. The damage to Mary's brainstem would be on the right side if the damage occurred above the medulla oblongata or on the left if it occurred in the inferior part of the medulla oblongata. The secondary neurons in the nucleus gracilis cross over in the medulla through the decussations of the medial lemniscus, and once crossed, are on the opposite side of the body from the nerve endings where the sensations would be initiated.
4. Most proprioception from the lower limbs is unconscious, whereas that from the upper limbs is mostly conscious. This difference is valuable because walking and standing (balance) are not activities on which we want to focus our attention, whereas proprioceptive activities of the arms and hands are essential for gaining information about the environment.
5. In the visual cortex the brain "sees" an object. Without a functional visual cortex, a person is blind. The visual association areas allow us to relate objects seen to previous experiences and to interpret what has been seen. Similarly, other association areas allow us to relate the sensory information integrated in the primary sensory areas with previous experiences and to make judgments about the information.
6. Constipation, with painful distention and cramping of the colon, results in the sensation of diffuse pain. Deep, visceral pain is not highly localized because few mechanoreceptors are present in deeper structures such as the colon. The pain is perceived as occurring in the skin over the lower central portion of the abdomen (in the hypogastric region) because it is referred to that location because of converging CNS pathways.
7. A sleeping person can be aroused by tactile stimulation, especially to the face, so touching the person on the face can arouse the person. Water on the face also works.
8. If a person holds an object in her right hand, tactile sensations of various types travel up the spinal cord to the brain, where they reach the somatic sensory cortex of the left hemisphere and the object is recognized. Action potentials then travel to Wernicke's area (probably on both sides of the cerebrum), where the object is given a name. From there action potentials travel to Broca's area, where the spoken word is initiated. Action potentials from Broca's area travel to the premotor area and primary motor cortex, where action potentials are initiated that stimulate the muscles necessary to form the word.
9. The stroke was on the left side of the brainstem. Both the motor and sensory neurons to the right side of the body are located in the left cerebral cortex. At the level of the upper medulla oblongata, neither the motor nor sensory pathways to the limbs have yet crossed over to the left side of the CNS. Most of the motor fibers cross at the inferior end of the medulla oblongata, whereas sensory pain and temperature fibers cross over at the level where they enter the CNS. Loss of pain and temperature to the left side of the face indicates that the lesion occurred at a level where the nerve fibers from the face had entered the CNS but had not yet crossed.

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