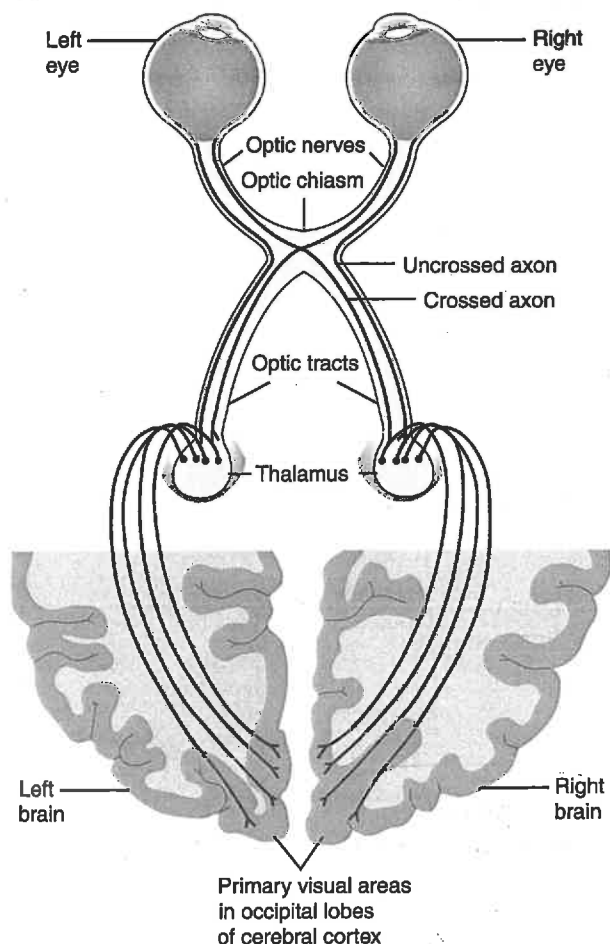


Figure 12.11 Visual pathway.

At the optic chiasm, half of the retinal ganglion cell axons from each eye cross to the opposite side of the brain.



? What is the correct order of structures that carry nerve impulses from the retina to the occipital lobe?

primary visual areas in the occipital lobes of the cerebral cortex (see Figure 10.13 on page 259). Because of crossing at the optic chiasm, the right side of the brain receives signals from both eyes for interpretation of visual sensations from the left side of an object, and the left side of the brain receives signals from both eyes for interpretation of visual sensations from the right side of an object.

CHECKPOINT

10. How does the shape of the lens change during accommodation?
11. How do photopigments respond to light?
12. By what pathway do nerve impulses triggered by an object in the left half of the visual field of the left eye reach the primary visual area of the cerebral cortex?

HEARING AND EQUILIBRIUM

OBJECTIVES • Describe the structures of the outer, middle, and inner ear.

- Describe the receptors for hearing and equilibrium and their pathways to the brain.

The ear is a marvelously sensitive structure. Its sensory receptors can convert sound vibrations into electrical signals 1000 times faster than photoreceptors can respond to light. Beside receptors for sound waves, the ear also contains receptors for equilibrium (balance).

Structure of the Ear

The ear is divided into three main regions: the outer ear, which collects sound waves and channels them inward; the middle ear, which conveys sound vibrations to the oval window; and the inner ear, which houses the receptors for hearing and equilibrium.

Outer Ear

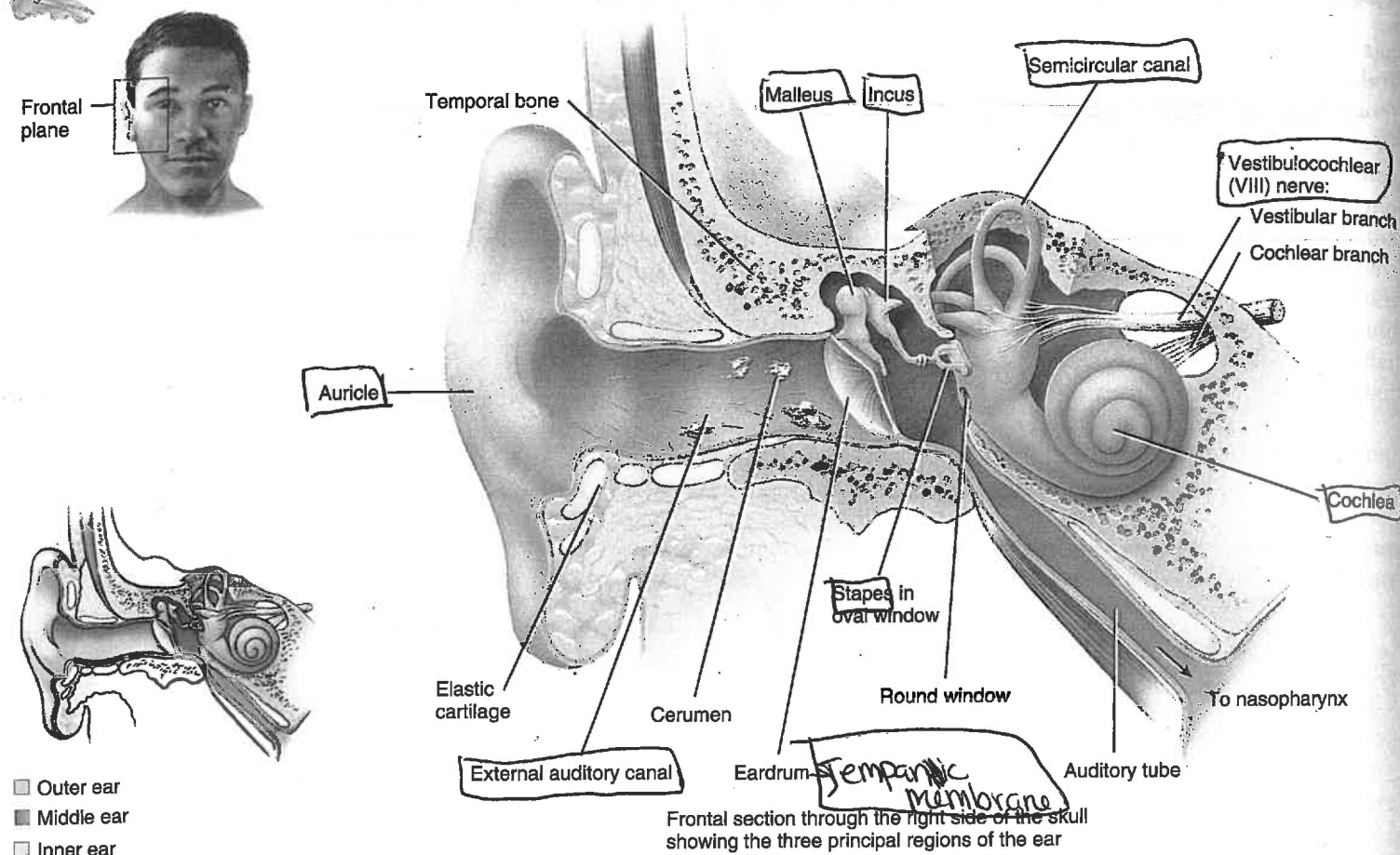
The **outer ear** collects sound waves and passes them inward (Figure 12.12). It consists of an auricle, external auditory canal, and eardrum. The **auricle**, the part of the ear that you can see, is a skin-covered flap of elastic cartilage shaped like the flared end of a trumpet. It plays a small role in collecting sound waves and directing them toward the **external auditory canal** (*audit-* = hearing), a curved tube that extends from the auricle and directs sound waves toward the eardrum. The canal contains a few hairs and **ceruminous glands** (se-ROO-mi-nus; *cer-* = wax), which secrete **cerumen** (se-ROO-men) (earwax). The hairs and cerumen help prevent foreign objects from entering the ear. The **eardrum**, also called the **tympanic membrane** (tim-PAN-ik; *tympan-* = adrum), is a thin, semitransparent partition between the external auditory canal and the middle ear. Sound waves cause the eardrum to vibrate. Tearing of the tympanic membrane, due to trauma or infection, is called a **perforated eardrum**.

Middle Ear

The **middle ear** is a small, air-filled cavity between the eardrum and inner ear (Figure 12.12). An opening in the anterior wall of the middle ear leads directly into the **auditory tube**, commonly known as the **eustachian tube**, which connects the middle ear with the upper part of the throat. When the auditory tube is open, air pressure can equalize on both sides of the eardrum. Otherwise, abrupt changes in air pressure on one side of the eardrum might cause it to rupture. During swallowing and yawning, the tube opens, which explains why yawning can help equalize the pressure changes that occur while flying in an airplane.

Figure 12.12 Structure of the ear.

The ear has three principal regions: the outer ear, the middle ear, and the inner ear.



? Where are the receptors for hearing and equilibrium located?

Extending across the middle ear and attached to it by means of ligaments are three tiny bones called **auditory ossicles** (OS-si-kuls) that are named for their shapes: the **malleus** (MAL-ē-us), **incus** (ING-kus), and **stapes** (STĀ-pēz), commonly called the hammer, anvil, and stirrup (Figure 12.12). Equally tiny skeletal muscles control the amount of movement of these bones to prevent damage by excessively loud noises. The stapes fits into a small opening in the thin bony partition between the middle and inner ear called the **oval window**, where the inner ear begins.

Inner Ear

The **inner ear** is divided into the outer bony labyrinth and inner membranous labyrinth (Figure 12.13). The **bony labyrinth** (LAB-i-rinth) is a series of cavities in the temporal bone, including the cochlea, vestibule, and semicircular canals. The cochlea is the sense organ for hearing, and the vestibule and semicircular canals are the sense organs for

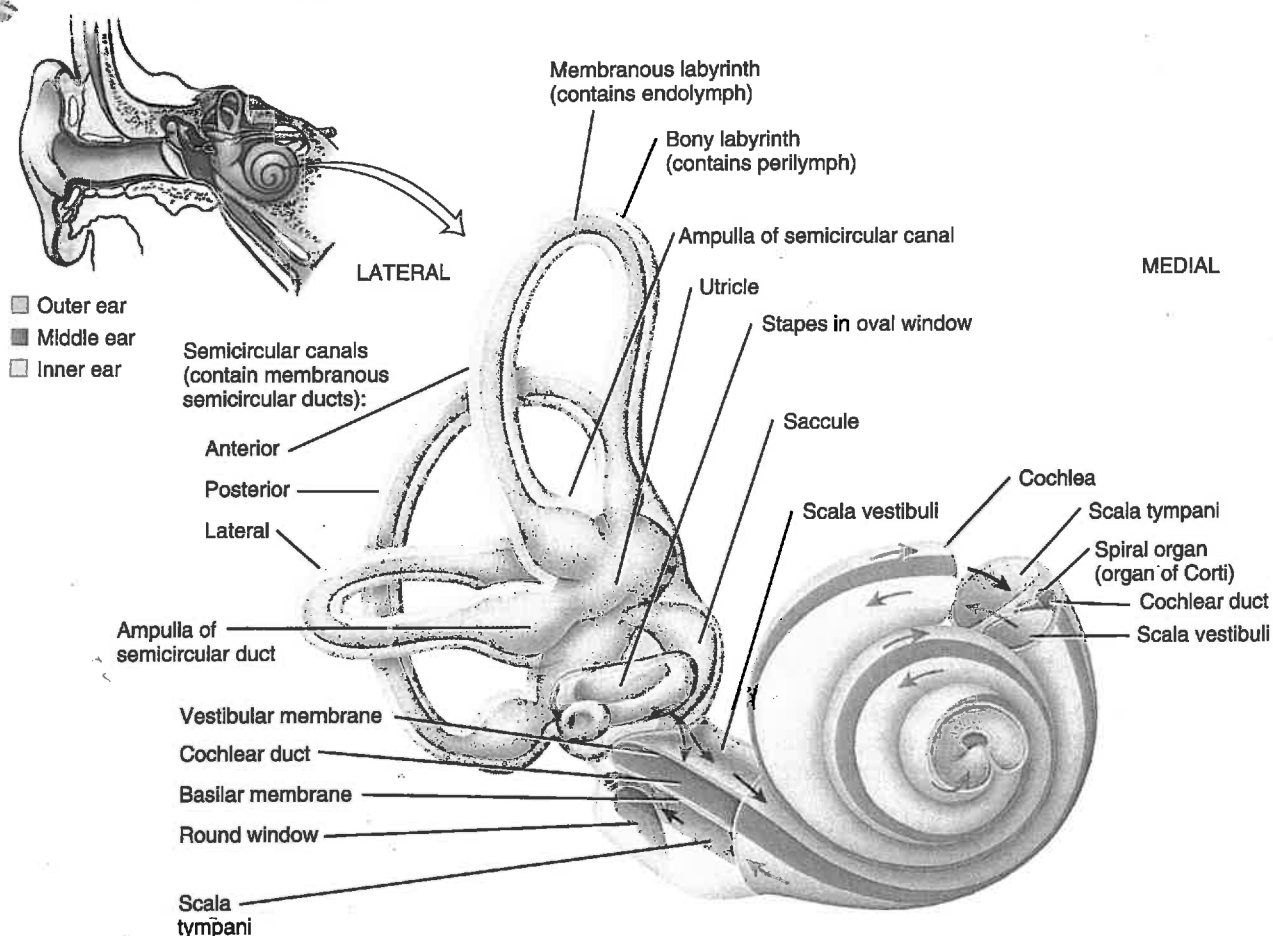
equilibrium and balance. The bony labyrinth contains a fluid called **perilymph**. This fluid surrounds the inner **membranous labyrinth**, a series of sacs and tubes with the same general shape as the bony labyrinth. The membranous labyrinth contains a fluid called **endolymph**.

The **vestibule** (VES-ti-būl) is the oval-shaped middle part of the bony labyrinth. The membranous labyrinth in the vestibule consists of two sacs called the **utricle** (Ū-tri-kl = little bag) and **saccul** (SAK-ūl = little sac). Behind the vestibule are the three bony **semicircular canals**. The anterior and posterior semicircular canals are both vertical, and the lateral canal is horizontal. One end of each canal enlarges into a swelling called the **ampulla** (am-POOL-la = little jar). The portions of the membranous labyrinth that lie inside the bony semicircular canals are called the **semicircular ducts**, which connect with the utricle of the vestibule.

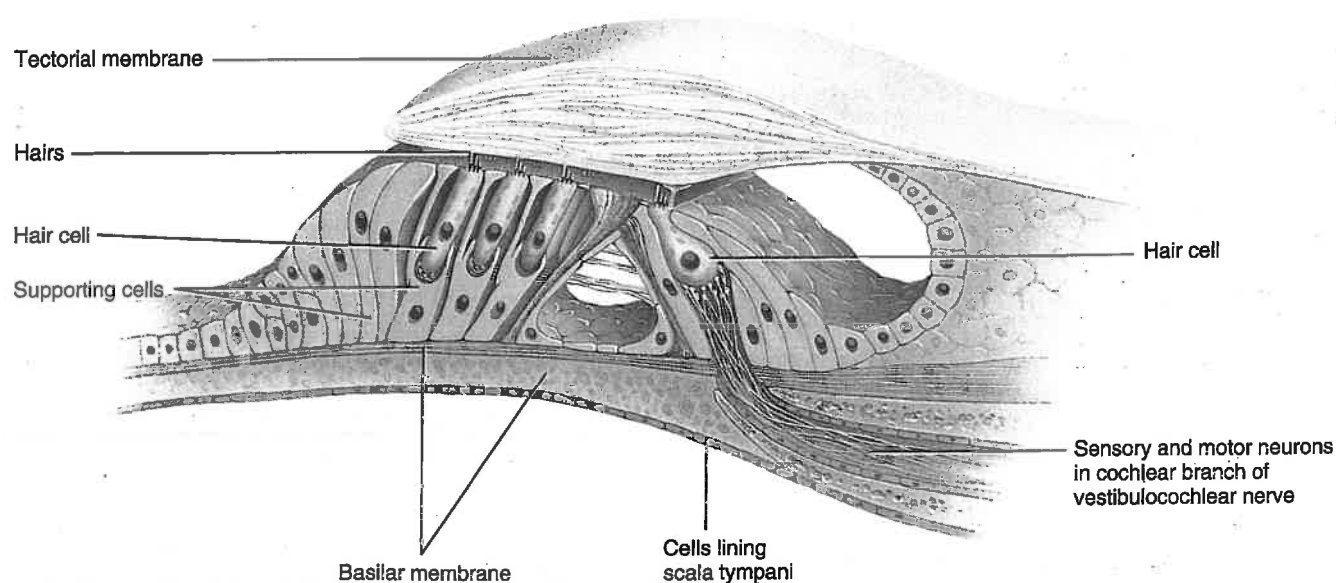
A transverse section through the **cochlea** (KOK-lē-a = snail's shell), a bony spiral canal that resembles a snail's shell,

Figure 12.13 Details of the right inner ear. (a) Relationship of the scala tympani, cochlear duct, and scala vestibuli. The arrows indicate the transmission of sound waves. (b) Details of the spiral organ (organ of Corti).

The three channels in the cochlea are the scala vestibuli, scala tympani, and cochlear duct.



(a) Sections through the cochlea



(b) Enlargement of spiral organ (organ of Corti)

? What structures separate the outer ear from the middle ear? The middle ear from the inner ear?

shows that it is divided into three channels: cochlear duct, scala vestibuli, and scala tympani. The *cochlear duct* is a continuation of the membranous labyrinth into the cochlea; it is filled with endolymph. The channel above the cochlear duct is the *scala vestibuli*, which ends at the oval window. The channel below the cochlear duct is the *scala tympani*, which ends at the *round window* (a membrane-covered opening directly below the oval window). Both the scala vestibuli and scala tympani are part of the bony labyrinth of the cochlea and are filled with perilymph. The scala vestibuli and scala tympani are completely separated, except for an opening at the apex of the cochlea. Between the cochlear duct and the scala vestibuli is the *vestibular membrane*. Between the cochlear duct and scala tympani is the *basilar membrane*.

Resting on the basilar membrane is the *spiral organ* (*organ of Corti*), the organ of hearing (Figure 12.13b). The spiral organ consists of *supporting cells* and *hair cells*. The hair cells, the receptors for auditory sensations, have long processes at their free ends that extend into the endolymph of the cochlear duct. The hair cells form synapses with sensory and motor neurons in the cochlear branch of the

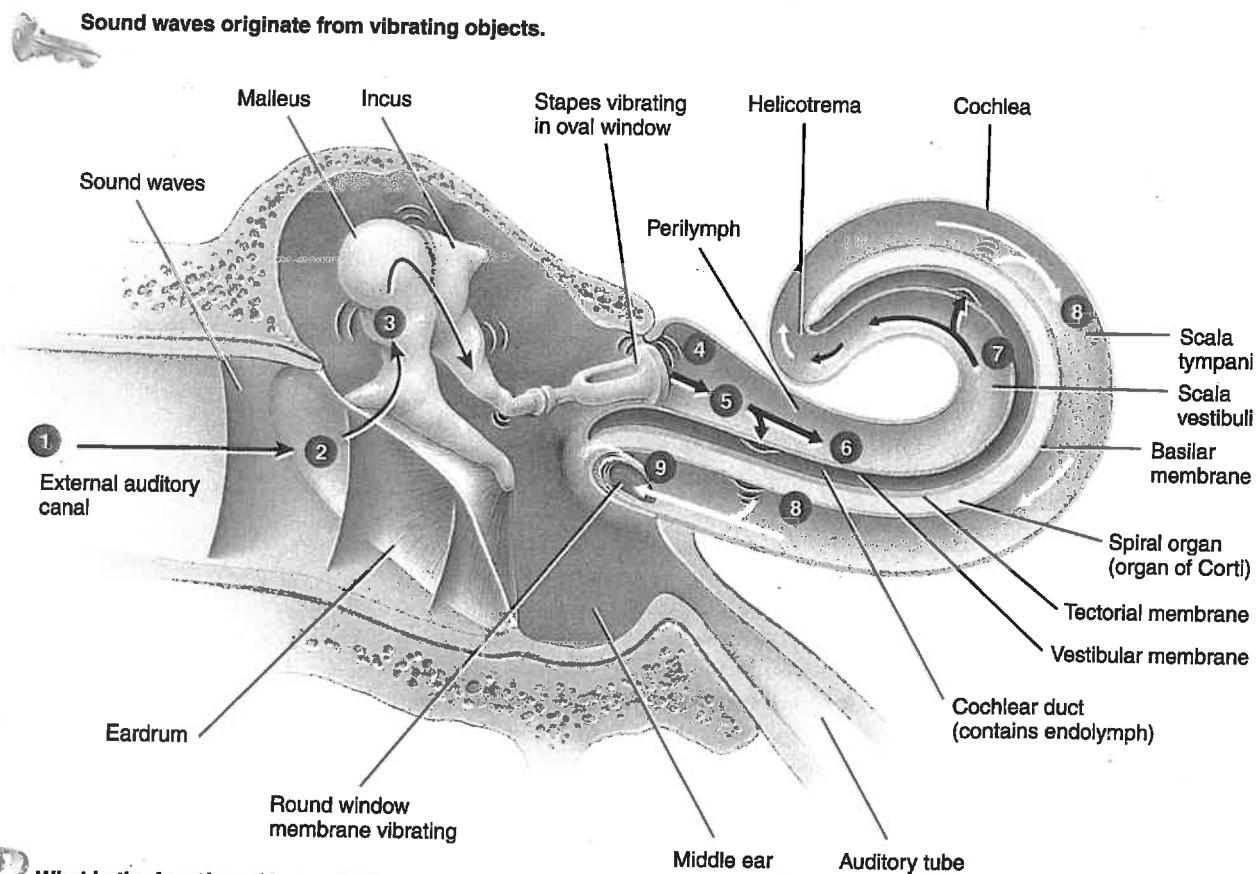
vestibulocochlear (VIII) nerve. The *tectorial membrane*, a flexible gelatinous membrane, covers the hair cells.

Physiology of Hearing

The events involved in stimulation of hair cells by sound waves are as follows (Figure 12.14):

- 1 The auricle directs sound waves into the external auditory canal.
- 2 Sound waves striking the eardrum cause it to vibrate. The distance and speed of its movement depend on the intensity and frequency of the sound waves. More intense (louder) sounds produce larger vibrations. The eardrum vibrates slowly in response to low-frequency (low-pitched) sounds and rapidly in response to high-frequency (high-pitched) sounds.
- 3 The central area of the eardrum connects to the malleus, which also starts to vibrate. The vibration is transmitted from the malleus to the incus and then to the stapes.
- 4 As the stapes moves back and forth, it pushes the oval window in and out.

Figure 12.14 Physiology of hearing shown in the right ear. The numbers correspond to the events listed in the text. The cochlea has been uncoiled in order to more easily visualize the transmission of sound waves and their subsequent distortion of the vestibular and basilar membranes of the cochlear duct.



What is the function of hair cells?

- 5 The movement of the oval window sets up fluid pressure waves in the perilymph of the cochlea. As the oval window bulges inward, it pushes on the perilymph of the scala vestibuli.
- 6 The fluid pressure waves are transmitted from the scala vestibuli to the scala tympani and eventually to the membrane covering the round window, causing it to bulge outward into the middle ear. (See 8 in the figure.)
- 7 As the pressure waves deform the walls of the scala vestibuli and scala tympani, they also push the vestibular membrane back and forth, creating pressure waves in the endolymph inside the cochlear duct.
- 8 The pressure waves in the endolymph cause the basilar membrane to vibrate, which moves the hair cells of the spiral organ against the tectorial membrane. Bending of their hairs stimulates the hair cells to release neurotransmitter molecules at synapses with sensory neurons that are part of the vestibulocochlear (VIII) nerve (see Figure 12.13b). Then, the sensory neurons generate nerve impulses that conduct along the vestibulocochlear (VIII) nerve.

Sound waves of various frequencies cause certain regions of the basilar membrane to vibrate more intensely than other regions. Each segment of the basilar membrane is “tuned” for a particular pitch. Because the membrane is narrower and stiffer at the base of the cochlea (closer to the oval window), high-frequency (high-pitched) sounds induce maximal vibrations in this region. Toward the apex of the cochlea, the basilar membrane is wider and more flexible; low-frequency (low-pitched) sounds cause maximal vibration of the basilar membrane there. Loudness is determined by the intensity of sound waves. High-intensity sound waves cause larger vibrations of the basilar membrane, which leads to a higher frequency of nerve impulses reaching the brain. Louder sounds also may stimulate a larger number of hair cells.

Besides its role in detecting sounds, the cochlea has the surprising ability to *produce* sounds, which are called **otoacoustic emissions**. These sounds arise from vibrations of the hair cells themselves, caused in part by signals from *motor* neurons that synapse with the hair cells. A sensitive microphone placed next to the eardrum can pick up these very-low-volume sounds. Detection of otoacoustic emissions is a fast, inexpensive, and noninvasive way to screen newborns for hearing defects. In deaf babies, otoacoustic emissions are not produced or are greatly reduced in size.

Auditory Pathway

Sensory neurons in the cochlear branch of each vestibulocochlear (VIII) nerve terminate in the medulla oblongata on

the same side of the brain. From the medulla, axons ascend to the midbrain, then to the thalamus, and finally to the primary auditory area in the temporal lobe (see Figure 10.13 on page 259). Because many auditory axons cross to the opposite side, the right and left primary auditory areas receive nerve impulses from both ears.

Physiology of Equilibrium

You learned about the anatomy of the inner ear structures for equilibrium in the previous section. In this section we will cover the physiology of balance, or how you are able to stay on your feet after tripping over your roommate’s shoes. There are two types of **equilibrium** (balance). One kind, called **static equilibrium**, refers to the maintenance of the position of the body (mainly the head) relative to the force of gravity. The second kind, **dynamic equilibrium**, is the maintenance of body position (mainly the head) in response to sudden movements such as rotation, acceleration, and deceleration. Collectively, the receptor organs for equilibrium, which include the saccule, utricle, and membranous semicircular ducts, are called the **vestibular apparatus** (ves-TIB-ū-lar).

Static Equilibrium

The walls of both the utricle and the saccule contain a small, thickened region called a **macula** (MAK-ū-la; *macula* = spot). The two maculae (plural), which are perpendicular to one another, are the receptors for static equilibrium. The maculae provide sensory information on the position of the head in space and help maintain appropriate posture and balance. The maculae also contribute to some aspects of dynamic equilibrium by detecting linear acceleration and deceleration, such as the sensations you feel while in an elevator or a car that is speeding up or slowing down.

The two maculae consist of two kinds of cells: **hair cells**, which are the sensory receptors, and **supporting cells** (Figure 12.15). The hairs of the hair cells protrude into a thick, jellylike substance called the **otolithic membrane**. A layer of dense calcium carbonate crystals, called **otoliths** (*oto-* = ear; *-liths* = stones), extends over the entire surface of the otolithic membrane. If you tilt your head forward, gravity pulls the membrane (and the otoliths) so it slides over the hair cells in the direction of the tilt. This stimulates the hair cells and triggers nerve impulses that conduct along the **vestibular branch** of the vestibulocochlear (VIII) nerve (see Figure 12.12).

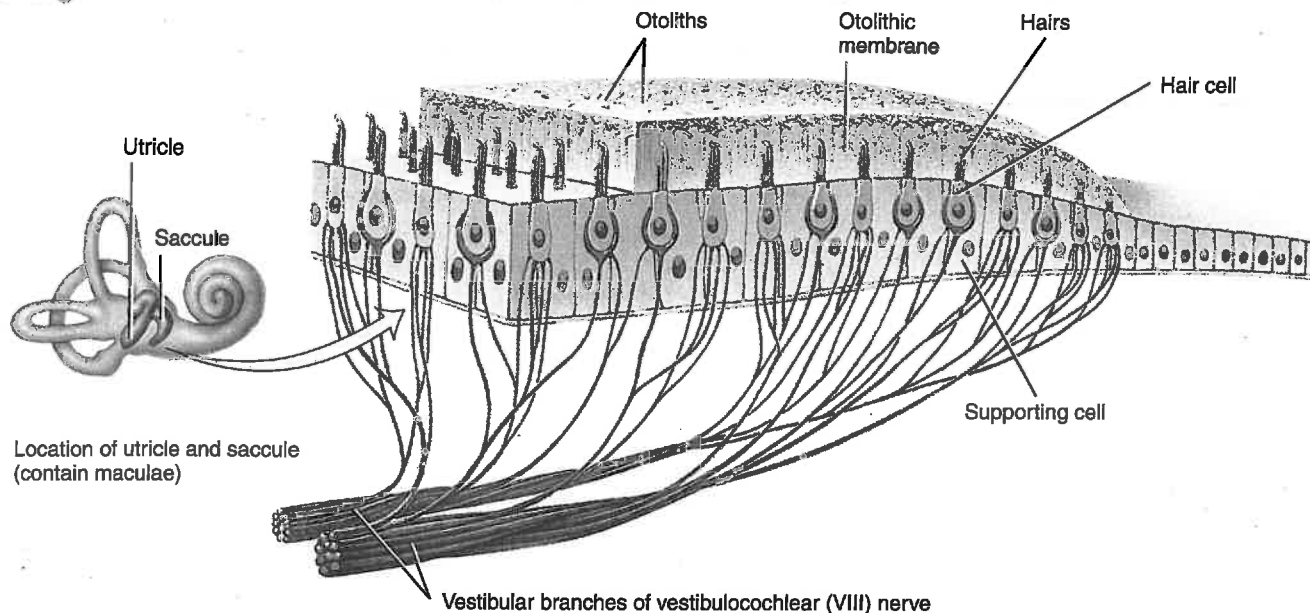
Dynamic Equilibrium

The three membranous semicircular ducts lie at right angles to one another in three planes (see Figure 12.13a). The positioning permits detection of rotational acceleration or deceleration. The dilated portion of each duct, the ampulla, contains a small elevation called the **crista** (KRIS-ta = crest;

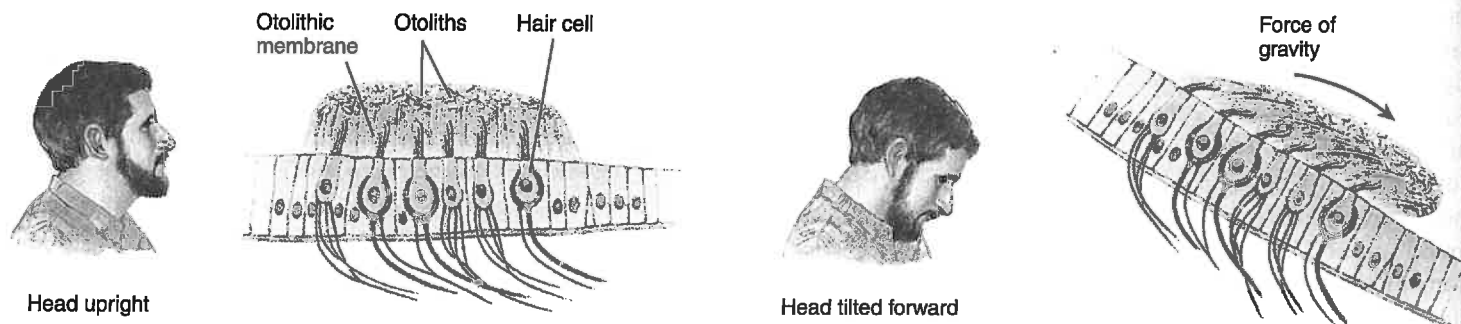
Figure 12.15 Location and structure of receptors in the maculae of the right ear. Both sensory neurons (blue) and motor neurons (red) synapse with the hair cells.



Movements of the otolithic membrane stimulate the hair cells.



(a) Overall structure of a section of the macula



(b) Position of macula with head upright (left) and tilted forward (right)



What is the function of the maculae?

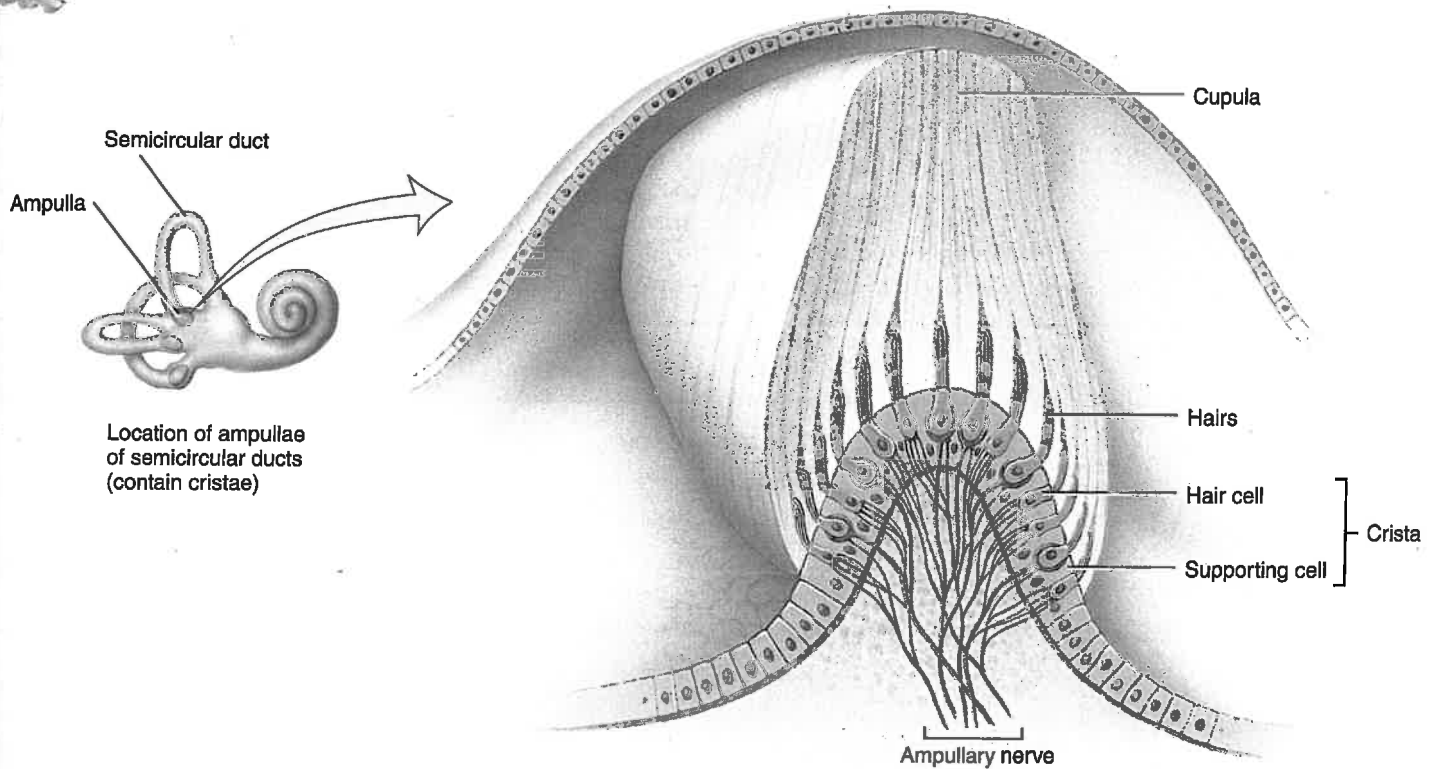
plural is *cristae*) (Figure 12.16). Each *crista* contains a group of **hair cells** and **supporting cells**. Covering the crista is a mass of gelatinous material called the **cupula** (KŪ-pū-la). When the head moves, the attached membranous semicircular ducts and hair cells move with it. However, the endolymph within the membranous semicircular ducts is not attached and lags behind due to its inertia. As the moving hair cells drag along the stationary endolymph, the hairs bend. Bending of the hairs causes electrical signals in the hair cells. In turn, these signals trigger nerve impulses in sensory neurons that are part of the vestibular branch of the vestibulocochlear (VIII) nerve.

Equilibrium Pathways

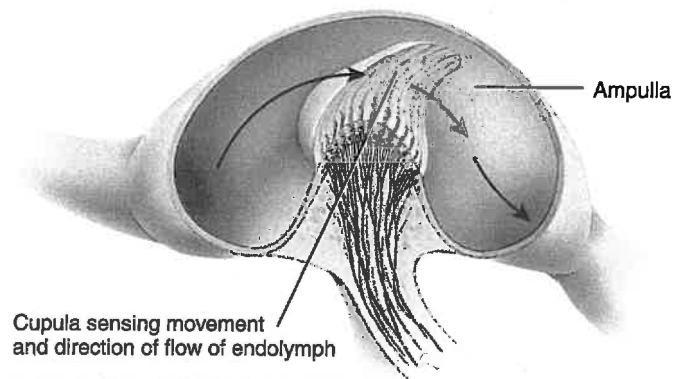
Most of the vestibular branch axons of the vestibulocochlear (VIII) nerve enter the brain stem and then extend to the medulla or the cerebellum, where they synapse with the next neurons in the equilibrium pathways. From the medulla, some axons conduct nerve impulses along the cranial nerves that control eye movements and head and neck movements. Other axons form a spinal cord tract that conveys impulses for regulation of muscle tone in response to head movements. Various pathways among the medulla, cerebellum, and cerebrum enable the cerebellum to play a key role in maintaining equilibrium. The cerebellum continuously re-

Figure 12.16 Location and structure of the membranous semicircular ducts of the right ear. Both sensory neurons (blue) and motor neurons (red) synapse with the hair cells. The ampullary nerves are branches of the vestibular division of the vestibulocochlear (VIII) nerve.

The positions of the membranous semicircular ducts permit detection of rotational movements.



(a) Details of a crista



Head rotating

? With which type of equilibrium are the membranous semicircular ducts associated?

ceives sensory information from the utricle and saccule. In response, the cerebellum makes adjustments to the signals going from the motor cortex to specific skeletal muscles to maintain equilibrium.

Table 12.3 summarizes the structures of the ear related to hearing and equilibrium.

■ CHECKPOINT

13. What is the pathway for auditory impulses from the cochlea to the cerebral cortex?

14. Compare the function of the maculae in maintaining static equilibrium with the role of the cristae in maintaining dynamic equilibrium.

• • •

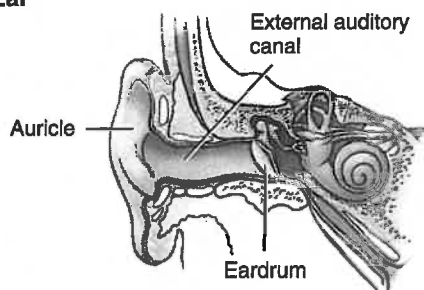
Now that our exploration of the nervous system and sensations is completed, you can appreciate the many ways that the nervous system contributes to homeostasis of other body systems by examining Focus on Homeostasis: The Nervous System on page 309. Next, in Chapter 13, we will see how the hormones released by the endocrine system also help maintain homeostasis of many body processes.

Table 12.3 Summary of Structures of the Ear Related to Hearing and Equilibrium

Regions of the Ear and Key Structures

Functions

Outer Ear

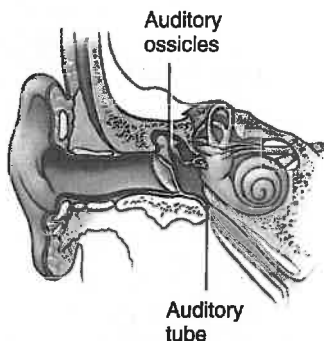


Auricle: Collects sound waves.

External auditory canal: Directs sound waves to the eardrum.

Eardrum (tympanic membrane): Sound waves cause it to vibrate, which, in turn, causes the malleus to vibrate.

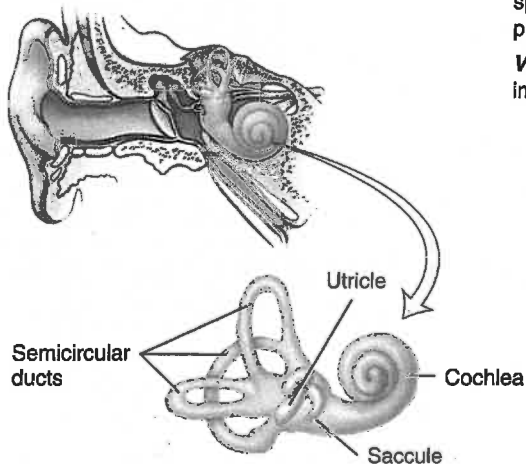
Middle Ear



Auditory ossicles: Transmit and amplify vibrations from tympanic membrane to oval window.

Auditory (eustachian) tube: Equalizes air pressure on both sides of the tympanic membrane.

Inner Ear



Cochlea: Contains a series of fluids, channels, and membranes that transmit vibrations to the spiral organ (organ of Corti), the organ of hearing; hair cells in the spiral organ trigger nerve impulses in the cochlear branch of the vestibulocochlear (VIII) nerve.

Vestibular apparatus: Includes semicircular ducts, utricle, and saccule, which generate nerve impulses that propagate along the vestibular branch of the vestibulocochlear (VIII) nerve.

Semicircular ducts: Contain cristae, sites of hair cells for dynamic equilibrium.

Utricle: Contains macula, site of hair cells for static and dynamic equilibrium.

Saccule: Contains macula, site of hair cells for static and dynamic equilibrium.

FOCUS ON HOMEOSTASIS



THE NERVOUS SYSTEM

BODY SYSTEM

CONTRIBUTION OF THE NERVOUS SYSTEM

For all body systems



Together with hormones from the endocrine system, nerve impulses provide communication and regulation of most body tissues.

Integumentary system



Sympathetic nerves of the autonomic nervous system (ANS) control contraction of smooth muscles attached to hair follicles and secretion of perspiration from sweat glands.

Skeletal system



Nociceptors (pain receptors) in bone tissue warn of bone trauma or damage.

Muscular system



Somatic motor neurons receive instructions from motor areas of the brain and stimulate contraction of skeletal muscles to bring about body movements. The basal ganglia and reticular formation set the level of muscle tone. The cerebellum coordinates skilled movements.

Endocrine system



The hypothalamus regulates secretion of hormones from the anterior and posterior pituitary. The ANS regulates secretion of hormones from the adrenal medulla and pancreas.

Cardiovascular system



The cardiovascular center in the medulla oblongata provides nerve impulses to the ANS that govern heart rate and the forcefulness of the heartbeat. Nerve impulses from the ANS also regulate blood pressure and blood flow through blood vessels.

Lymphatic system and immunity



Certain neurotransmitters help regulate immune responses. Activity in the nervous system may increase or decrease immune responses.

Respiratory system



Respiratory areas in the brain stem control breathing rate and depth. The ANS helps regulate the diameter of airways.

Digestive system



The ANS and enteric nervous system (ENS) help regulate digestion. The parasympathetic division of the ANS stimulates many digestive processes.

Urinary system



The ANS helps regulate blood flow to kidneys, thereby influencing the rate of urine formation; brain and spinal cord centers govern emptying of urinary bladder.

Reproductive systems



The hypothalamus and limbic system govern a variety of sexual behaviors; the ANS brings about erection of the penis in males and the clitoris in females and ejaculation of semen in males. The hypothalamus regulates release of anterior pituitary hormones that control the gonads (ovaries and testes). Nerve impulses elicited by touch stimuli from suckling infant cause release of oxytocin and milk ejection in nursing mothers.



COMMON DISORDERS

Cataracts

A common cause of blindness is a loss of transparency of the lens known as a **cataract** (CAT-a-rakt). The lens becomes cloudy (less transparent) due to changes in the structure of the lens proteins. Cataracts often occur with aging but may also be caused by injury, excessive exposure to ultraviolet rays, certain medications (such as long-term use of steroids), or complications of other diseases (for example, diabetes). People who smoke also have increased risk of developing cataracts. Fortunately, sight can usually be restored by surgical removal of the old lens and implantation of an artificial one.

Glaucoma

In **glaucoma** (glaw-KŌ-ma), the most common cause of blindness in the United States, a buildup of aqueous humor within the anterior cavity causes an abnormally high intraocular pressure. Persistent pressure results in a progression from mild visual impairment to irreversible destruction of the retina, damage to the optic nerve, and blindness. Because glaucoma is painless, and because the other eye initially compensates to a large extent for the loss of vision, a person may experience considerable retinal damage and loss of vision before the condition is diagnosed.

Deafness

Deafness is significant or total hearing loss. **Sensorineural deafness** is caused by either impairment of hair cells in the cochlea or damage

of the cochlear branch of the vestibulocochlear nerve. This type of deafness may be caused by atherosclerosis, which reduces blood supply to the ears; repeated exposure to loud noise, which destroys hair cells of the spiral organ; or certain drugs such as aspirin and streptomycin. **Conduction deafness** is caused by impairment of the outer and middle ear mechanisms for transmitting sounds to the cochlea. It may be caused by otosclerosis, the deposition of new bone around the oval window; impacted cerumen; injury to the eardrum; or aging, which often results in thickening of the eardrum and stiffening of the joints of the auditory ossicles.

Ménière's Disease

Ménière's disease (men'-ē-ĀRZ) results from an increased amount of endolymph that enlarges the membranous labyrinth. Among the symptoms are fluctuating hearing loss (caused by distortion of the basilar membrane of the cochlea) and roaring tinnitus (ringing). Vertigo (a sensation of spinning or whirling) is characteristic of Ménière's disease. Almost total destruction of hearing may occur over a period of years.

Otitis Media

Otitis media is an acute infection of the middle ear caused primarily by bacteria and associated with infections of the nose and throat. Symptoms include pain; malaise (discomfort or uneasiness); fever; and a reddening and outward bulging of the eardrum, which may rupture unless prompt treatment is received (this may involve draining pus from the middle ear). Bacteria from the nasopharynx passing into the auditory tube is the primary cause of all middle ear infections. Children are more susceptible than adults to middle ear infections because their auditory tubes are almost horizontal, which decreases drainage.

MEDICAL TERMINOLOGY AND CONDITIONS

Age-related macular disease (AMD) Degeneration of the macula lutea of the retina in persons 50 years of age and older.

Anosmia (an-OZ-mē-a; a- = without; -osmi = smell, odor) Total lack of the sense of smell.

Cochlear implant A device that translates sounds into electrical signals that can be interpreted by the brain. It is especially useful for people with deafness caused by damage to hair cells in the cochlea.

Conjunctivitis (pinkeye) An inflammation of the conjunctiva; when caused by bacteria such as pneumococci, staphylococci, or *Hemophilus influenzae*, it is very contagious and more common in children. May also be caused by irritants, such as dust, smoke, or pollutants in the air, in which case it is not contagious.

Detached retina Detachment of the neural portion of the retina from the pigment epithelium due to trauma, disease, or age-related degeneration. The result is distorted vision and blindness.

LASIK Surgery with a laser to correct the curvature of the cornea for conditions such as nearsightedness, farsightedness, and astigmatism.

Nystagmus (nis-TAG-mus; nystagm- = nodding or drowsy) A rapid involuntary movement of the eyeballs, possibly caused by a disease of the central nervous system. It is associated with conditions that cause vertigo.

Otalgia (ō-TAL-jē-a; ot- = ear; -algia = pain) Earache.

Retinoblastoma (ret-i-nō-blas-TŌ-ma; -oma = tumor) A tumor arising from immature retinal cells; it accounts for 2% of childhood cancers.

Scotoma (skō-TŌ-ma = darkness) An area of reduced or lost vision in the visual field.

Strabismus (stra-BIZ-mus) An imbalance in the extrinsic eye muscles that causes a misalignment of one eye so that its line of vision is not parallel with that of the other eye (cross-eyes) and both eyes are not pointed at the same object at the same time; the condition produces a squint.

Tinnitus (ti-NĪ-tus) A ringing, roaring, or clicking in the ears.

Trachoma (tra-KŌ-ma) A serious form of conjunctivitis and the greatest single cause of blindness in the world. It is caused by the bacterium *Chlamydia trachomatis*. The disease produces an excessive growth of subconjunctival tissue and invasion of blood vessels into the cornea, which progresses until the entire cornea is opaque, causing blindness.

Vertigo (VER-ti-gō = dizziness) A sensation of spinning or movement in which the world seems to revolve or the person seems to revolve in space.

STUDY OUTLINE

Overview of Sensations (p. 285)

1. Sensation is the conscious or subconscious awareness of external and internal stimuli.
2. Two general classes of senses are (1) general senses, which include somatic senses and visceral senses, and (2) special senses, which include smell, taste, vision, hearing, and equilibrium (balance).
3. The conditions for a sensation to occur are reception of a stimulus by a sensory receptor, conversion of the stimulus into one or more nerve impulses, conduction of the impulses to the brain, and integration of the impulses by a region of the brain.
4. Sensory impulses from each part of the body arrive in specific regions of the cerebral cortex.
5. Adaptation is a decrease in sensation during a prolonged stimulus. Some receptors are rapidly adapting; others are slowly adapting.
6. Receptors can be classified structurally by their microscopic features as free nerve endings, encapsulated nerve endings, or separate cells. Functionally, receptors are classified by the type of stimulus they detect as mechanoreceptors, thermoreceptors, nociceptors, photoreceptors, osmoreceptors, and chemoreceptors.

Somatic Senses (p. 286)

1. Somatic sensations include tactile sensations (touch, pressure, vibration, itch, and tickle), thermal sensations (heat and cold), pain sensations, and proprioceptive sensations (joint and muscle position sense and movements of the limbs). Receptors for these sensations are located in the skin, mucous membranes, muscles, tendons, and joints.
2. Receptors for touch include corpuscles of touch (Meissner corpuscles), hair root plexuses, type I cutaneous mechanoreceptors (Merkel discs), and type II cutaneous mechanoreceptors (Ruffini corpuscles). Receptors for pressure and vibration are lamellated (pacinian) corpuscles. Tickle and itch sensations result from stimulation of free nerve endings.
3. Thermoreceptors, free nerve endings in the epidermis and dermis, adapt to continuous stimulation.
4. Nociceptors are free nerve endings that are located in nearly every body tissue; they provide pain sensations.
5. Proprioceptors inform us of the degree to which muscles are contracted, the amount of tension present in tendons, the positions of joints, and the orientation of the head.

Olfaction: Sense of Smell (p. 290)

1. The olfactory epithelium in the upper portion of the nasal cavity contains olfactory receptors, supporting cells, and basal stem cells.
2. Individual olfactory receptors respond to hundreds of different odorant molecules by producing an electrical signal that triggers one or more nerve impulses. Adaptation (decreasing sensitivity) to odors occurs rapidly.
3. Axons of olfactory receptors form the olfactory nerves, which convey nerve impulses to the olfactory bulbs. From there,

impulses conduct via the olfactory tracts to the limbic system, hypothalamus, and cerebral cortex (temporal lobe).

Gustation: Sense of Taste (p. 291)

1. The receptors for gustation, the gustatory receptor cells, are located in taste buds.
2. To be tasted, substances must be dissolved in saliva.
3. The five primary tastes are salty, sweet, sour, bitter, and umami.
4. Gustatory receptor cells trigger impulses in cranial nerves VII (facial), IX (glossopharyngeal), and X (vagus). Impulses for taste conduct to the medulla oblongata, limbic system, hypothalamus, thalamus, and the primary gustatory area in the parietal lobe of the cerebral cortex.

Vision (p. 293)

1. Accessory structures of the eyes include the eyebrows, eyelids, eyelashes, the lacrimal apparatus (which produces and drains tears), and extrinsic eye muscles (which move the eyes).
2. The eyeball has three layers: (a) fibrous tunic (sclera and cornea), (b) vascular tunic (choroid, ciliary body, and iris), and (c) retina.
3. The retina consists of a neural layer (photoreceptor layer, bipolar cell layer, and ganglion cell layer) and a pigmented layer (a sheet of melanin-containing epithelial cells).
4. The anterior cavity contains aqueous humor; the vitreous chamber contains the vitreous body.
5. Image formation on the retina involves refraction of light rays by the cornea and lens, which focus an inverted image on the central fovea of the retina.
6. For viewing close objects, the lens increases its curvature (accommodation), and the pupil constricts to prevent light rays from entering the eye through the periphery of the lens.
7. Improper refraction may result from myopia (nearsightedness), hypermetropia (farsightedness), or astigmatism (irregular curvature of the cornea or lens).
8. Movement of the eyeballs toward the nose to view an object is called convergence.
9. The first step in vision is the absorption of light rays by photopigments in rods and cones (photoreceptors). Stimulation of the rods and cones then activates bipolar cells, which in turn activate the ganglion cells.
10. Nerve impulses arise in ganglion cells and conduct along the optic nerve, through the optic chiasm and optic tract to the thalamus. From the thalamus, the optic radiations extend to the primary visual area in the occipital lobe of the cerebral cortex.

Hearing and Equilibrium (p. 301)

1. The outer ear consists of the auricle, external auditory canal, and eardrum.
2. The middle ear consists of the auditory (eustachian) tube, auditory ossicles, oval window, and round window.

3. The inner ear consists of the bony labyrinth and membranous labyrinth. The inner ear contains the spiral organ (organ of Corti), the organ of hearing.
4. Sound waves enter the external auditory canal, strike the eardrum, pass through the ossicles, strike the oval window, set up pressure waves in the perilymph, strike the vestibular membrane and scala tympani, increase pressure in the endolymph, vibrate the basilar membrane, and stimulate hair cells in the spiral organ.
5. Hair cells release neurotransmitter molecules that can initiate nerve impulses in sensory neurons.
6. Sensory neurons in the cochlear branch of the vestibulocochlear nerve terminate in the medulla oblongata. Auditory signals then pass to the midbrain, thalamus, and temporal lobes.
7. Static equilibrium is the orientation of the body relative to the pull of gravity. The maculae of the utricle and saccule are the sense organs of static equilibrium.
8. Dynamic equilibrium is the maintenance of body position in response to rotation, acceleration, and deceleration. The maculae of the utricle and saccule and the cristae in the membranous semicircular ducts are the sense organs of dynamic equilibrium.
9. Most vestibular branch axons of the vestibulocochlear nerve enter the brain stem and terminate in the medulla and pons, other axons extend to the cerebellum.

Q SELF-QUIZ

1. You enter a sauna and it feels awfully hot, but soon the temperature feels comfortably warm. What have you have experienced?
 - a. damage to your thermoreceptors
 - b. sensory adaptation
 - c. a change in the temperature of the sauna
 - d. inactivation of your thermoreceptors
 - e. damage to the parietal lobe
2. The lacrimal glands produce _____, which drain(s) into the _____.
 - a. tears; anterior cavity
 - b. tears; nasal cavity
 - c. aqueous humor; anterior chamber
 - d. aqueous humor; anterior cavity
 - e. aqueous humor; scleral venous sinus
3. The spiral organ (organ of Corti)
 - a. contains hair cells
 - b. is responsible for equilibrium
 - c. is filled with perilymph
 - d. is another name for the auditory (eustachian) tube
 - e. transmits auditory nerve impulses to the brain
4. Equilibrium and the activities of muscles and joints are monitored by
 - a. olfactory receptors
 - b. nociceptors
 - c. tactile receptors
 - d. proprioceptors
 - e. thermoreceptors
5. In the retina, cone photoreceptors
 - a. are more numerous than rods
 - b. contain the photopigment rhodopsin
 - c. are more sensitive to low light level than are rods
 - d. reform their photopigments more slowly than do rods
 - e. provide higher acuity vision than do rods
6. Which of the following is NOT required for a sensation to occur?
 - a. the presence of a stimulus
 - b. a receptor specialized to detect a stimulus
 - c. the presence of slowly adapting receptors
 - d. a sensory neuron to conduct impulses
 - e. a region of the brain for integration of the nerve impulse
7. Match each receptor with its function.

___ a. color vision	A. lamellated (pacinian) corpuscle
___ b. taste	B. type I cutaneous mechanoreceptor
___ c. smell	C. rod photoreceptor
___ d. dynamic equilibrium	D. nociceptor
___ e. vision in dim light	E. gustatory receptor cell
___ f. stretch in a muscle	F. olfactory receptor
___ g. static equilibrium	G. muscle spindle
___ h. pressure	H. maculae
___ i. touch	I. cristae
___ j. detection of pain	J. cone photoreceptors
8. For taste to occur
 - a. the mouth must be dry
 - b. the chemical must be in contact with the basal cells
 - c. filiform papillae must be stimulated
 - d. the limbic system needs to be activated
 - e. the gustatory hair must be stimulated by the dissolved chemical
9. Which of the following characteristics of taste is NOT true?
 - a. Olfaction can affect taste.
 - b. Three cranial nerves conduct the impulses for taste to the brain.

- c. Taste adaptation occurs quickly.
 d. Humans can recognize about 10 primary tastes.
 e. Taste receptors are located in taste buds on the tongue, on the roof of the mouth, in the throat, and in the epiglottis.
10. You are seated at your desk and drop your pencil. As you lean over to retrieve it, what is occurring in your inner ear?
 a. The hair cells on the macula are responding to changes in static equilibrium.
 b. The hair cells in the cochlea are responding to changes in dynamic equilibrium.
 c. The cristae of each semicircular duct are responding to changes in dynamic equilibrium.
 d. The cochlear branch of the vestibulocochlear (VIII) nerve begins to transmit nerve impulses to the brain.
 e. The auditory (eustachian) tube makes adjustments for varying air pressures.
11. Kinesthesia is the
 a. perception of body movements
 b. ability to identify an object by feeling it
 c. sensation of weightlessness that occurs in outer space
 d. decrease in sensitivity of receptors to a prolonged stimulus
 e. movement of body parts in a rhythmic manner
12. Which of the following is NOT true about nociceptors?
 a. They respond to stimuli that may cause tissue damage.
 b. They consist of free nerve endings.
 c. They can be activated by excessive stimuli from other sensations.
 d. They are found in virtually every body tissue except the brain.
 e. They adapt very rapidly.
13. Which of the following is NOT a function of tears?
 a. moisten the eye b. wash away eye irritants
 c. destroy certain bacteria d. lubricate the eye
 e. provide nutrients to the cornea
14. Transmission of vibrations (sound waves) from the tympanic membrane to the oval window is accomplished by
 a. neurons b. the tectorial membrane
 c. the auditory ossicles d. the endolymph
 e. the auditory (Eustachian) tube
15. Match the following:
- | | |
|---|--------------------|
| — a. focuses light rays onto the retina | A. sclera |
| — b. regulates the amount of light entering the eye | B. choroid |
| — c. contains aqueous humor | C. lacrimal glands |
| — d. contains blood vessels that help nourish the retina | D. lens |
| — e. produce tears | E. retina |
| — f. dense connective tissue that provides shape to the eye | F. iris |
| — g. contains photoreceptors | G. anterior cavity |
16. Which of the following structures refracts light rays entering the eye?
 a. cornea b. sclera c. pupil d. retina
 e. conjunctiva
17. Your 45-year-old neighbor has recently begun to have difficulty reading the morning newspaper. You explain that this condition is known as _____ and is due to _____.
 a. myopia, inability of his eyes to properly focus light on his retinas
 b. night blindness, a vitamin A deficiency
 c. binocular vision, the eyes focusing on two different objects
 d. astigmatism, an irregularity in the curvature of the lens
 e. presbyopia, the loss of elasticity in the lens
18. Damage to cells in the central fovea would interfere with
 a. dynamic equilibrium b. accommodation
 c. visual acuity d. ability to see in dim light
 e. intraocular pressure
19. Place the following events concerning the visual pathway in the correct order:
 1. Nerve impulses exit the eye via the optic nerve.
 2. Optic tract axons terminate in the thalamus.
 3. Light reaches the retina.
 4. Rods and cones are stimulated.
 5. Synapses occur in the thalamus and continue to the primary visual area in the occipital lobe.
 6. Ganglion cells generate nerve impulses.
 a. 4, 1, 2, 5, 6, 3 b. 5, 4, 1, 3, 2, 6 c. 3, 4, 6, 1, 5, 2
 d. 3, 4, 6, 1, 2, 5 e. 3, 4, 5, 6, 1, 2
20. Place the following events of the auditory pathway in the correct order:
 1. Hair cells in the spiral organ bend as they rub against the tectorial membrane.
 2. Movement in the oval window begins movement in the perilymph.
 3. Nerve impulses exit the ear via the vestibulocochlear (VIII) nerve.
 4. The eardrum and auditory ossicles transmit vibrations from sound waves.
 5. Pressure waves from the perilymph cause bulging of the round window and formation of pressure waves in the endolymph.
 a. 4, 2, 5, 1, 3 b. 4, 5, 2, 3, 1 c. 5, 3, 2, 4, 1
 d. 3, 4, 5, 1, 2 e. 2, 4, 1, 5, 3

 CRITICAL THINKING APPLICATIONS

1. When you first enter a coffee shop, the aroma of fresh java is wonderfully strong and full-bodied. After several minutes waiting in line, the odor is barely noticeable. Has something happened to the coffee or has something happened to you?
2. Cliff works the night shift and sometimes falls asleep in A&P class. What is the effect on the structures in his internal ear when his head falls backward as he slumps in his seat?
3. A medical procedure used to improve visual acuity involves shaving of a thin layer off the cornea. How could this procedure improve vision?
4. The optometrist put drops in Latasha's eyes during her eye exam. When Latasha looked in the mirror after the exam, her pupils were very large and her eyes were sensitive to the bright light. How did the eye drops produce this effect on Latasha's eyes?



ANSWERS TO FIGURE QUESTIONS

- 12.1 Corpuscles of touch (Meissner corpuscles) are abundant in the fingertips, palms, and soles.
- 12.2 The kidneys have the broadest area for referred pain.
- 12.3 Basal stem cells undergo cell division to produce new olfactory receptors.
- 12.4 The gustatory pathway: gustatory receptor cells → cranial nerves VII, IX, and X → medulla oblongata → thalamus → primary gustatory area in the parietal lobe of the cerebral cortex.
- 12.5 Tears clean, lubricate, and moisten the eyeball.
- 12.6 The fibrous tunic consists of the cornea and sclera; the vascular tunic consists of the choroid, ciliary body, and iris.
- 12.7 The parasympathetic division of the autonomic nervous system causes pupillary constriction; the sympathetic division causes pupillary dilation.
- 12.8 The two types of photoreceptors are rods and cones. Rods provide black-and-white vision in dim light; cones provide high visual acuity and color vision in bright light.
- 12.9 During accommodation, the ciliary muscle contracts, zonular fibers slacken, and the lens becomes more rounded (convex) and refracts light more.
- 12.10 Presbyopia is the loss of elasticity in the lens that occurs with aging.
- 12.11 Structures carrying visual impulses from the retina: axons of ganglion cells → optic (II) nerve → optic chiasm → optic tract → thalamus → primary visual area in occipital lobe of the cerebral cortex.
- 12.12 The receptors for hearing and equilibrium are located in the inner ear: cochlea (hearing) and semicircular ducts (equilibrium).
- 12.13 The eardrum (tympanic membrane) separates the outer ear from the middle ear. The oval and round windows separate the middle ear from the inner ear.
- 12.14 Hair cells convert a mechanical force (stimulus) into an electrical signal (depolarization and repolarization of the hair cell membrane).
- 12.15 The maculae are the receptors for static equilibrium and also contribute to dynamic equilibrium.
- 12.16 The membranous semicircular ducts function in dynamic equilibrium.