CHAPTER 10

The Sensory System

Learning Outcomes

After careful study of this chapter, you should be able to:

1. Describe the function of the sensory system
2. Differentiate between the special and general senses and give examples of each
3. Describe the structure of the eye
4. List and describe the structures that protect the eye
5. Define *refraction* and list the refractive parts of the eye
6. Differentiate between the rods and the cones of the eye
7. Compare the functions of the extrinsic and intrinsic muscles of the eye
8. Describe the nerve supply to the eye
9. Describe the three divisions of the ear
10. Describe the receptor for hearing and explain how it functions
11. Compare static and dynamic equilibrium and describe the location and function of these receptors
12. Explain the function of proprioceptors
13. List several methods for treatment of pain
14. Describe sensory adaptation and explain its value
15. Show how word parts are used to build words related to the sensory system (see Word Anatomy at the end of the chapter)

Selected Key Terms

The following terms and other boldface terms in the chapter are defined in the Glossary

accommodation
choroid
cochlea
conjunctiva
convergence
cornea
gustation
lacrimal apparatus
lens (crystalline lens)
olfaction
organ of Corti
ossicle
proprioceptor
refraction
retina
sclera
semicircular canal
sensory adaptation
sensory receptor
tympanic membrane
vestibule
vitreous body

PASSport to Success

Visit ***thePoint*** or see the Student Resource CD in the back of this book for definitions and pronunciations of key terms as well as a pretest for this chapter.

A&P in Action

Paul's Second Case: Seeing More of the Sun's Effects

Paul glanced once again at the postcard sitting on his entranceway table as he arrived home in the evening. He knew it said he was due for a checkup with his ophthalmologist, but after his run-in with skin cancer 6 months earlier, he was in no hurry to see the inside of a medical office. *Well, it's just routine, and I may need a slight change in my prescription, so I'll make the call*, he thought.

At the office, Dr. Gilbert greeted Paul and asked how he was feeling in general and if he thought there had been any change in his vision. "My vision sometimes seems a little blurry, especially when my eyes are tired, but no major changes," Paul replied. Dr. Gilbert proceeded with the eye exam, testing his visual acuity and checking on his astigmatism.

"You're right; not much change," said the ophthalmologist. "But, we'll give you a new prescription for your glasses. At 42, you're a little young for presbyopia—far-sightedness that develops with age—but we'll do the routine check for glaucoma. I know your father developed that condition, and it does have a hereditary factor." The doctor dilated Paul's eyes with drops and examined the fundus of each eye with an ophthalmoscope. In answer to Paul's query, he explained that in this way he could examine the health of the retina and the optic nerve and also look at the vessels at the back of the eye for any signs of diabetes or circulatory problems. In addition, he used a tonometer to test for glaucoma, a condition that can damage the eye with high fluid pressure. "I need to check on another patient," he told Paul. "Then I'll be back to explain what I've found. Just sit in the waiting room for a few minutes, please."

Dr. Gilbert uses his knowledge of the structure and function of the eye to diagnose medical conditions. In this chapter, you will learn about the eye and other sensory system organs. As well, we'll examine the consequences of Paul's sun-loving youth on his eyes and vision.

The Senses

The sensory system protects a person by detecting changes in the environment. An environmental change becomes a *stimulus* when it initiates a nerve impulse, which then travels to the central nervous system (CNS) by way of a sensory (afferent) neuron. A stimulus becomes a sensation—something we experience—only when a specialized area of the cerebral cortex interprets the nerve impulse received. Many stimuli arrive from the external environment and are detected at or near the body surface. Others, such as stimuli from the viscera, originate internally and help to maintain homeostasis.

Sensory Receptors

The part of the nervous system that detects a stimulus is the **sensory receptor.** In structure, a sensory receptor may be one of the following:

- The free dendrite of a sensory neuron, such as the receptors for pain and temperature
- A modified ending, or **end-organ,** on the dendrite of an afferent neuron, such as those for touch
- A specialized cell associated with an afferent neuron, such as the rods and cones of the eye's retina and the receptors in the other special sense organs

Receptors can be classified according to the type of stimulus to which they respond:

- Chemoreceptors, such as receptors for taste and smell, detect chemicals in solution.
- Photoreceptors, located in the retina of the eye, respond to light.
- Thermoreceptors detect change in temperature. Many of these receptors are located in the skin.
- Mechanoreceptors respond to movement, such as stretch, pressure, or vibration. These include pressure receptors in the skin, receptors that monitor body position, and the receptors of hearing and equilibrium in the ear, which are activated by the movement of cilia on specialized receptor cells.

Any receptor must receive a stimulus of adequate intensity, that is, at least a **threshold stimulus**, in order to respond and generate a nerve impulse.

Special and General Senses

Another way of classifying the senses is according to the distribution of their receptors. A **special sense** is localized in a special sense organ; a **general sense** is widely distributed throughout the body.

- Special senses
  - > **Vision** from receptors in the eye
  - > **Hearing** from receptors in the internal ear
  - > **Equilibrium** from receptors in the internal ear
  - > **Taste** from receptors in the tongue
  - > **Smell** from receptors in the upper nasal cavities
- General senses
  - > **Pressure, temperature, pain,** and **touch** from receptors in the skin and internal organs
  - > Sense of **position** from receptors in the muscles, tendons, and joints

The Eye and Vision

In the embryo, the eye develops as an outpocketing of the brain. It is a delicate organ, protected by a number of structures:

- The skull bones form the walls of the eye orbit (cavity) and protect the posterior part of the eyeball.
- The upper and lower eyelids aid in protecting the eye's anterior portion (Fig. 10-1). The eyelids can be closed to keep harmful materials out of the eye, and blinking helps to lubricate the eye. A muscle, the levator palpebrae, is attached to the upper eyelid. When this muscle contracts, it keeps the eye open. If the muscle becomes weaker with age, the eyelids may droop and interfere with vision, a condition called *ptosis*.

PASSport to Success: Visit ***thePoint*** or see the Student Resource CD in the back of this book for an image of *ptosis*.

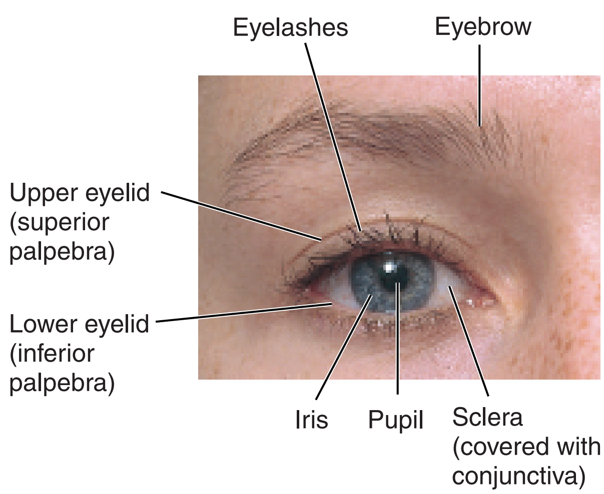

Figure 10-1 The eye's protective structures. (Reprinted with permission from Bickley LS. *Bates' Guide to Physical Examination and History Taking*, 8th ed. Philadelphia: Lippincott Williams & Wilkins, 2003.)

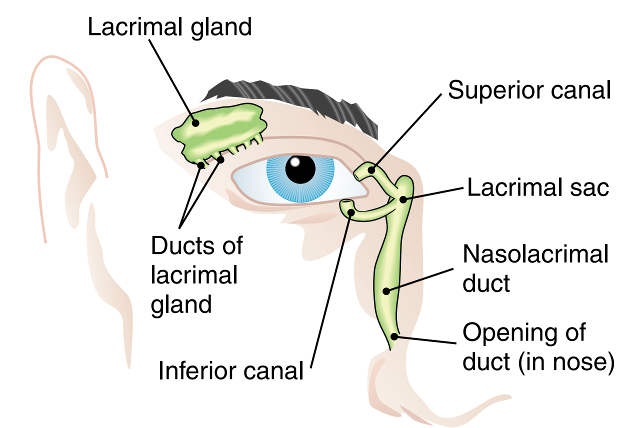

Figure 10-2 The lacrimal apparatus. The lacrimal (tear) gland and its associated ducts are shown.

- The eyelashes and eyebrow help to keep foreign matter out of the eye.
- A thin membrane, the **conjunctiva** (kon-junk-TI-vah), lines the inner surface of the eyelids and covers the visible portion of the white of the eye (sclera). Cells within the conjunctiva produce mucus that aids in lubricating the eye. Where the conjunctiva folds back from the eyelid to the eye's anterior surface, a sac is formed. The lower portion of the conjunctival sac can be used to instill medication drops. With age, the conjunctiva often thins and dries, resulting in inflammation and enlarged blood vessels.
- Tears, produced by the **lacrimal** (LAK-rih-mal) **glands** (Fig. 10-2), lubricate the eye and contain an enzyme that protects against infection. As tears flow across the eye from the lacrimal gland, located in the orbit's upper lateral part, they carry away small particles that may have entered the eye. The tears then flow into ducts near the eye's nasal corner where they drain into the nose by way of the **nasolacrimal** (na-zo-LAK-rih-mal) **duct** (see Fig. 10-2). An excess of tears causes a "runny nose"; a greater overproduction of them results in the tears spilling onto the cheeks. With age, the lacrimal glands produce less secretion, but tears still may overflow onto the cheek if the nasolacrimal ducts become plugged.

CHECKPOINT 10-1 ➤ What are some structures that protect the eye?

Coats of the Eyeball

The eyeball has three separate coats, or tunics (Fig. 10-3).

1. The outermost tunic, called the **sclera** (SKLE-rah), is made of tough connective tissue. It is commonly referred to as the *white of the eye*. It appears white because of the collagen it contains and because it has no blood vessels to add color. (Reddened or "bloodshot" eyes result from inflammation and swelling of blood vessels in the conjunctiva).
2. The second tunic of the eyeball is the **choroid** (KO-royd). This coat is composed of a delicate network of connective tissue interlaced with many blood vessels. It also contains much dark brown pigment. The choroid may be compared to the dull black lining of a camera in that it prevents incoming light rays from scattering and reflecting off the eye's inner surface. The blood vessels at the posterior, or fundus, of the eye can reveal signs of disease, and visualization of these vessels with an **ophthalmoscope** (of-THAL-mo-skope) is an important part of a medical examination.
3. The innermost tunic, the **retina** (RET-ih-nah), is the eye's actual receptor layer. It contains light-sensitive cells known as **rods** and **cones**, which generate the nerve impulses associated with vision.

CHECKPOINT 10-2 ➤ What are the names of the tunics of the eyeball?

Pathway of Light Rays and Refraction

As light rays pass through the eye toward the retina, they travel through a

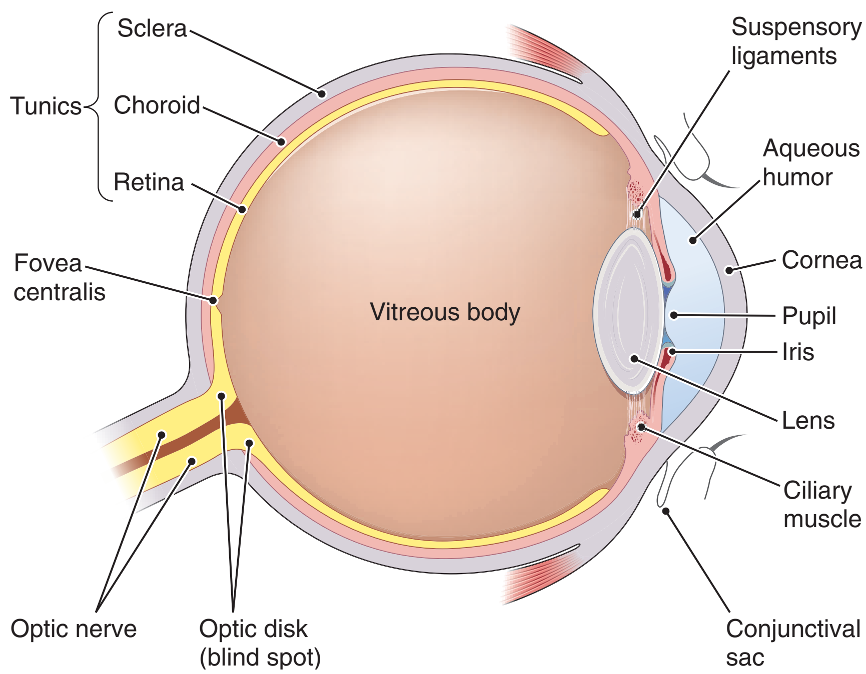

Figure 10-3 The eye. Note the three tunics, the refractive parts of the eye (cornea, aqueous humor, lens, vitreous body), and other structures involved in vision.

series of transparent, colorless parts described below and seen in Figure 10-3. On the way, they undergo a process known as **refraction**, which is the bending of light rays as they pass from one substance to another substance of different density. (For a simple demonstration of refraction, place a spoon into a glass of water and observe how the handle appears to bend at the surface of the water.) Because of refraction, light from a very large area can be focused on a very small area of the retina. The eye's transparent refracting parts are listed here, according to the pathway of light traveling from exterior to interior:

1. The **cornea** (KOR-ne-ah) is an anterior continuation of the sclera, but it is transparent and colorless, whereas the rest of the sclera is opaque and white. The cornea is referred to frequently as the *window* of the eye. It bulges forward slightly and is the main refracting structure of the eye. The cornea has no blood vessels; it is nourished by the fluids that constantly wash over it.
2. The **aqueous** (A-kwe-us) **humor**, a watery fluid that fills much of the eyeball anterior to the lens, helps maintain the cornea's slight forward curve. The aqueous humor is constantly produced and drained from the eye.
3. The **lens**, technically called the *crystalline lens*, is a clear, circular structure made of a firm, elastic material. The lens has two bulging surfaces and is thus described as biconvex. The lens is important in light refraction because it is elastic and its thickness can be adjusted to focus light for near or far vision.
4. The **vitreous** (VIT-re-us) **body** is a soft jellylike substance that fills the entire space posterior to the lens (the adjective *vitreous* means "glasslike"). Like the aqueous humor, it is important in maintaining the shape of the eyeball as well as in aiding in refraction.

CHECKPOINT 10-3 ➤ What are the structures that refract light as it passes through the eye?

Function of the Retina

The retina has a complex structure with multiple layers of cells (Fig. 10-4). The deepest layer is a pigmented layer just anterior to the choroid. Next are the rods and cones, the receptor cells eye's, named for their shape. Details on how these two types of cells differ are presented in Table 10-1. Anterior to the rods and cones are connecting neurons that carry impulses toward the optic nerve.

PASSport to Success: Visit ***thePoint*** or see Student Resource CD in the back of this book for the animation *The Retina* which illustrates the structure and function of this visual receptor.

The rods are highly sensitive to light and thus function in dim light, but they do not provide a sharp image. They are more numerous than the cones and are distributed more toward the periphery (anterior portion) of the retina. (If you visualize the retina as the inside of a bowl, the rods would be located toward the bowl's lip). When you enter into dim light, such as a darkened movie theater, you cannot see for a short period. It is during this time that the rods are beginning to function, a change that is described as **dark adaptation**. When you are able to see again, images are blurred and appear only in shades of gray, because the rods are unable to differentiate colors.

The cones function in bright light, are sensitive to color, and give sharp images. The cones are localized at the retinal center, especially in a tiny depressed area near the optic nerve that is called the **fovea centralis** (FO-ve-ah sen-TRA-lis) (Fig. 10-5; see also Fig. 10-3). (Note that *fovea* is a general term for a pit or depression.) Because this area contains the highest concentration of cones, it is the point of sharpest vision. The fovea is contained

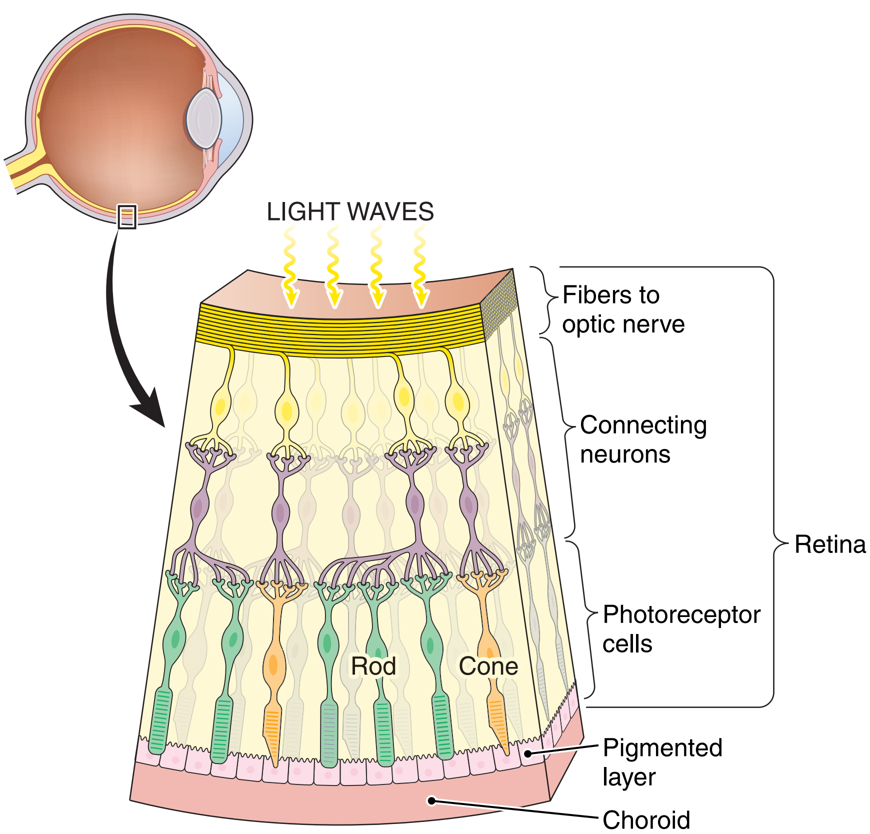

Figure 10-4 Structure of the retina. Rods and cones form a deep layer of the retina, near the choroid. Connecting neurons carry visual impulses toward the optic nerve.

Table 10-1 Comparison of the Rods and Cones of the Retina

Characteristic	Rods	Cones
Shape	Cylindrical	Flask shaped
Number	About 120 million in each retina	About 6 million in each retina
Distribution	Toward the periphery (anterior) of the retina	Concentrated at the center of the retina
Stimulus	Dim light	Bright light
Visual acuity (sharpness)	Low	High
Pigments	Rhodopsin (visual purple)	Pigments sensitive to red, green, or blue
Color perception	None; shades of gray	Respond to color

within a yellowish spot, the **macula lutea** (MAK-u-lah LU-te-ah), an area that may show degenerative changes with age.

There are three types of cones, each sensitive to either red, green, or blue light. Color blindness results from a lack of retinal cones. People who completely lack cones are totally colorblind; those who lack one type of cone are partially color blind. This disorder, because of its pattern of inheritance, occurs almost exclusively in males.

The rods and cones function by means of pigments that are sensitive to light. The rod pigment is **rhodopsin** (ro-DOP-sin), or visual purple. Vitamin A is needed for manufacture of these pigments. If a person is lacking in vitamin A, and thus rhodopsin, he or she may have difficulty seeing in dim light because the light is inadequate to activate the rods; this condition is termed **night blindness**. Nerve impulses from the rods and cones flow into sensory neurons that eventually merge to form the optic nerve (cranial nerve II) at the eye's posterior (see Figs. 10-3 and 10-5). The impulses travel to the visual center in the brain's occipital cortex.

When an **ophthalmologist** (of-thal-MOL-o-jist), a physician who specializes in treatment of the eye, examines the retina with an ophthalmoscope, he or she can see abnormalities in the retina and in the retinal blood vessels. Some of these changes may signal more widespread diseases that affect the eye, such as diabetes and high blood pressure (hypertension). 10

CHECKPOINT 10-4 ➤ What are the receptor cells of the retina?

Muscles of the Eye

Two groups of muscles are associated with the eye. Both groups are important in adjusting the eye so that a clear image can form on the retina.

THE EXTRINSIC MUSCLES The voluntary muscles attached to the eyeball's outer surface are the **extrinsic** (eks-TRIN-sik) **muscles**. The six ribbonlike extrinsic muscles connected with each eye originate on the orbital bones and

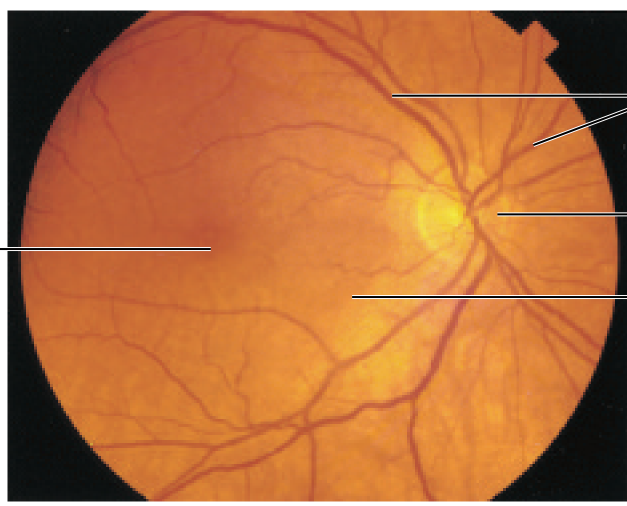

Figure 10-5 The fundus (back) of the eye as seen through an ophthalmoscope. (Reprinted with permission from Moore KL, Dalley AF. *Clinically Oriented Anatomy*, 4th ed. Baltimore: Lippincott Williams & Wilkins, 1999.)

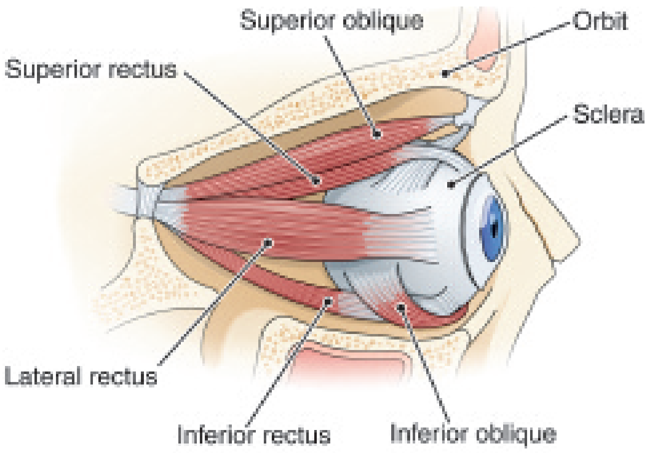

Figure 10-6 Extrinsic muscles of the eye. The medial rectus is not shown. [**ZOOMING IN** ➤ What characteristics are used in naming the extrinsic eye muscles?]

insert on the surface of the sclera (Fig. 10-6). They are named for their location and the direction of the muscle fibers. These muscles pull on the eyeball in a coordinated fashion so that both eyes center on one visual field. This process of **convergence** is necessary to the formation of a clear image on the retina. Having the image come from a slightly different angle from each retina is believed to be important for three-dimensional (stereoscopic) vision, a characteristic of primates.

CHECKPOINT 10-5 ➤ What is the function of the extrinsic muscles of the eye?

THE INTRINSIC MUSCLES The involuntary muscles located within the eyeball are the **intrinsic** (in-TRIN-sik) **muscles**. They form two circular structures within the eye, the iris and the ciliary muscle.

The **iris** (I-ris), the colored or pigmented part of the eye, is composed of two sets of muscle fibers that govern the size of the iris's central opening, the **pupil** (PU-pil) (Fig. 10-7). One set of fibers is arranged in a circular fashion, and the other set extends radially like the spokes of a wheel. The iris regulates the amount of light entering the eye. In bright light, the iris's circular muscle fibers contract, reducing the size of the pupil. This narrowing is termed *constriction*. In contrast, in dim light, the radial muscles contract, pulling the opening outward and enlarging it. This enlargement of the pupil is known as *dilation*.

The **ciliary** (SIL-e-ar-e) **muscle** is shaped somewhat like a flattened ring with a central hole the size of the iris's outer edge. This muscle holds the lens in place by means of filaments, called **suspensory ligaments**, that project from the ciliary muscle to the edge of the lens around its entire circumference (Fig. 10-8). The ciliary muscle controls the lens' shape to allow for vision at near and far distances. This process of **accommodation** occurs as follows.

The light rays from a close object diverge (separate) more than do the light rays from a distant object (Fig. 10-9). Thus, when viewing something close, the lens must become more rounded to bend the light rays more and focus them on the retina. When the ciliary muscle is relaxed, tension on the suspensory ligaments keeps the lens in a more

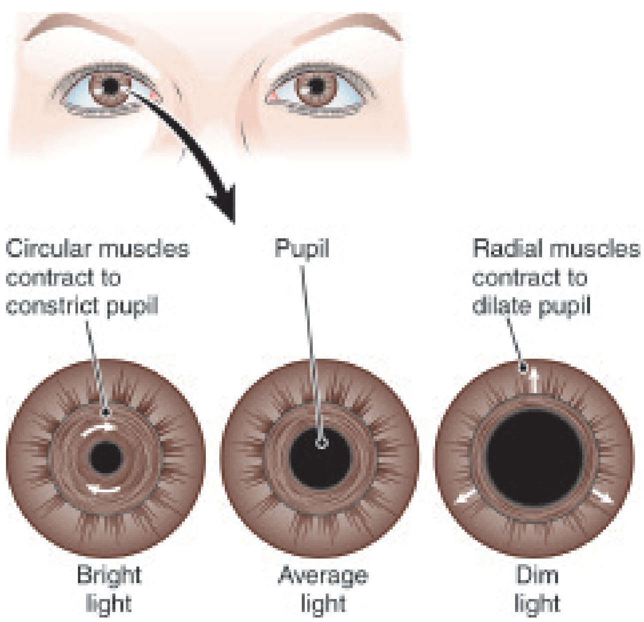

Figure 10-7 Function of the iris. In bright light, circular muscles contract and constrict the pupil, limiting the light that enters the eye. In dim light, the radial muscles contract and dilate the pupil, allowing more light to enter the eye. [**ZOOMING IN** ➤ What muscles of the iris contract to make the pupil smaller? Larger?]

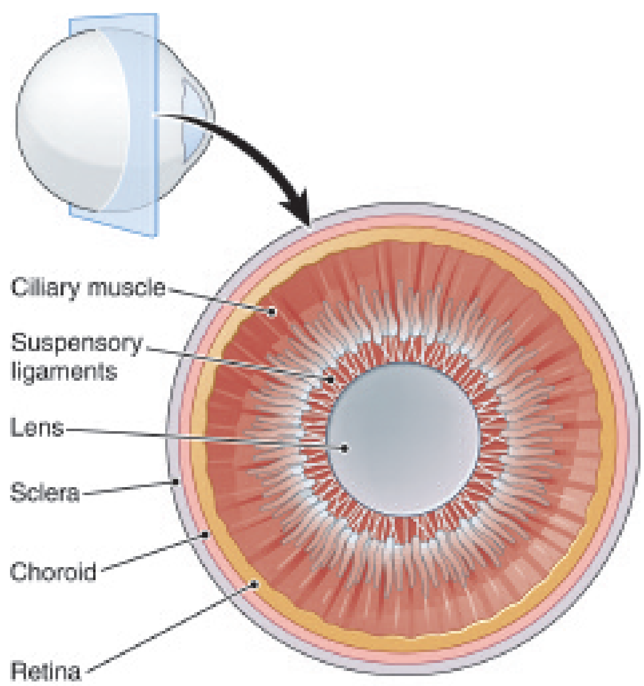

Figure 10-8 The ciliary muscle and lens (posterior view). Contraction of the ciliary muscle relaxes tension on the suspensory ligaments, allowing the lens to become more round for near vision. [**ZOOMING IN** ➤ What structures hold the lens in place?]

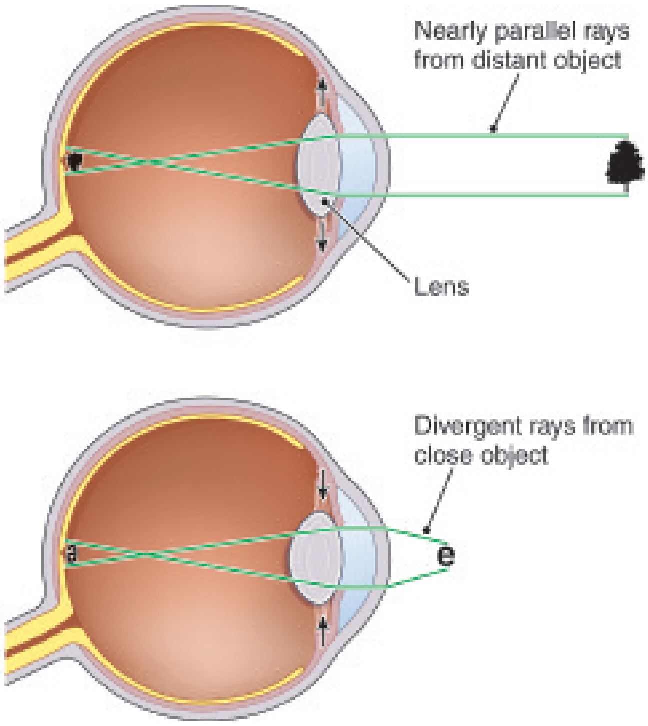

Figure 10-9 **Accommodation for near vision.** When viewing a close object, the lens must become more rounded to focus light rays on the retina.

flattened shape. For close vision, the ciliary muscle contracts, which draws the ciliary ring forward and relaxes tension on the suspensory ligaments. The elastic lens then recoils and becomes thicker, in much the same way that a rubber band thickens when the pull on it is released. When the ciliary muscle relaxes again, the lens flattens. These actions change the lens' refractive power to accommodate for near and far vision.

In young people, the lens is elastic, and therefore its thickness can be readily adjusted according to the need for near or distance vision. With aging, the lens loses elasticity and therefore its ability to accommodate for near vision. It becomes difficult to focus clearly on close objects, a condition called **presbyopia** (pres-be-O-pe-ah), which literally means "old eye." This refractive disorder can be corrected using eye glasses and contacts. Box 10-1, Eye Surgery: A Glimpse of the Cutting Edge, provides information on new methods of treating eye disorders.

CHECKPOINT 10-6 ➤ What is the function of the iris?

CHECKPOINT 10-7 ➤ What is the function of the ciliary muscle?

Nerve Supply to the Eye

Two sensory nerves supply the eye (Fig. 10-10):

- The **optic nerve** (cranial nerve II) carries visual impulses from the retinal rods and cones to the brain.
- The **ophthalmic** (of-THAL-mik) **branch of the trigeminal nerve** (cranial nerve V) carries impulses of pain,

Box 10-1 Hot Topics

Eye Surgery: A Glimpse of the Cutting Edge

Cataracts, glaucoma, and refractive errors are the most common eye disorders affecting Americans. In the past, cataract and glaucoma treatments concentrated on managing the diseases. Refractive errors were corrected using eyeglasses and, more recently, contact lenses. Today, laser and microsurgical techniques can remove cataracts, reduce glaucoma, and allow people with refractive errors to put their eyeglasses and contacts away. These cutting-edge procedures include:

- *Laser in situ keratomileusis (LASIK)* to correct refractive errors. During this procedure, a laser reshapes the cornea to allow light to refract directly on the retina, rather than in front of or behind it. A microkeratome (surgical knife) is used to cut a flap in the cornea's outer layer. A computer-controlled laser sculpts the middle layer of the cornea and then the flap is replaced. The procedure takes only a few minutes and patients recover their vision quickly and usually with little postoperative pain.
- *Laser trabeculoplasty* to treat glaucoma. This procedure uses a laser to help drain fluid from the eye and lower intraocular pressure. The laser is aimed at drainage canals located between the cornea and iris and makes several burns that are believed to open the canals and allow fluid to drain better. The procedure is typically painless and takes only a few minutes.
- *Phacoemulsification* to remove cataracts. During this surgical procedure, a very small incision (approximately 3 mm long) is made through the sclera near the cornea's outer edge. An ultrasonic probe is inserted through this opening and into the center of the lens. The probe uses sound waves to emulsify the lens' central core, which is then suctioned out. Then, an artificial lens is permanently implanted in the lens capsule. The procedure is typically painless, although the patient may feel some discomfort for 1 to 2 days afterward.

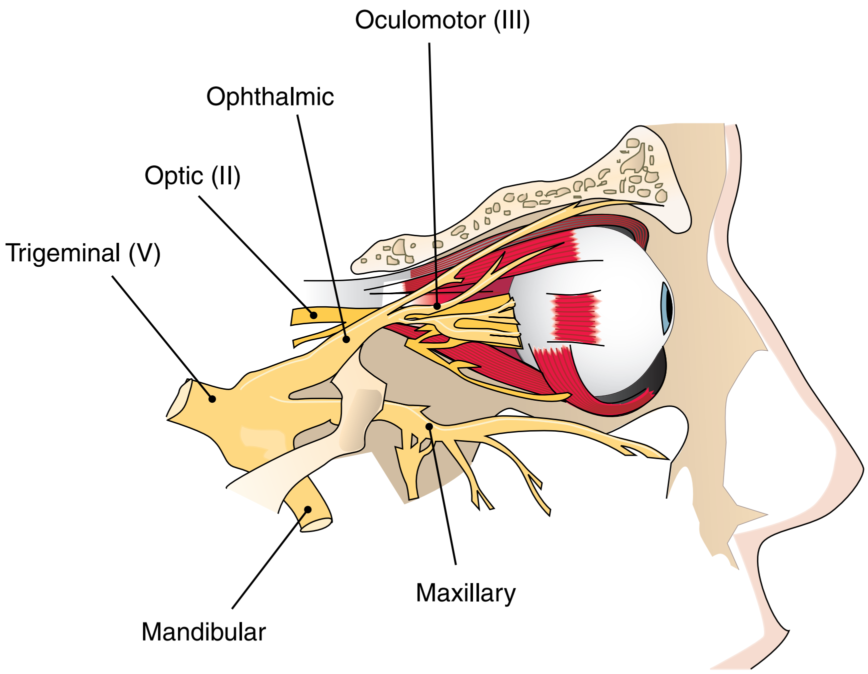

Figure 10-10 Nerves of the eye. [**ZOOMING IN** ➤ Which of the nerves shown moves the eye?]

touch, and temperature from the eye and surrounding parts to the brain.

The optic nerve arises from the retina a little toward the medial or nasal side of the eye. There are no retinal rods and cones in the area of the optic nerve. Consequently, no image can form on the retina at this point, which is known as the blind spot or **optic disk** (see Figs. 10-3 and 10-5).

The optic nerve transmits impulses from the retina to the thalamus (part of the diencephalon), from which they are directed to the occipital cortex. Note that the light rays passing through the eye are actually overrefracted (bent) so that an image falls on the retina upside down and backward (see Fig. 10-9). It is the job of the brain's visual centers to reverse the images.

Three nerves carry motor impulses to the eyeball muscles:

- The oculomotor nerve (cranial nerve III) is the largest; it supplies voluntary and involuntary motor impulses to all but two eye muscles.
- The trochlear nerve (cranial nerve IV) supplies the superior oblique extrinsic eye muscle (see Fig. 10-6).
- The abducens nerve (cranial nerve VI) supplies the lateral rectus extrinsic eye muscle.

To summarize, the steps in vision are:

1. Light refracts.
2. The muscles of the iris adjust the pupil.
3. The ciliary muscle adjusts the lens (accommodation).
4. The extrinsic eye muscles produce convergence.
5. Light stimulates retinal receptor cells (rods and cones).
6. The optic nerve transmits impulses to the brain.
7. The occipital lobe cortex interprets the impulses.

CHECKPOINT 10-8 ➤ What is cranial nerve II and what does it do?

The Ear

The ear is the sense organ for both hearing and equilibrium (Fig. 10-11). It is divided into three main sections:

- The **outer ear** includes an outer projection and a canal ending at a membrane.
- The **middle ear** is an air space containing three small bones.
- The **inner ear** is the most complex and contains the sensory receptors for hearing and equilibrium.

The Outer Ear

The external portion of the ear consists of a visible projecting portion, the **pinna** (PIN-nah), also called the **auricle** (AW-rih-kl), and the **external auditory canal**, or **meatus** (me-A-tus), that leads into the ear's deeper parts. The pinna directs sound waves into the ear, but it is probably of little importance in humans. The external auditory canal extends medially from the pinna for about 2.5 cm or more, depending on which wall of the canal is measured. The skin lining this tube is thin and, in the first part of the canal, contains many wax-producing **ceruminous** (seh-RU-mih-nus) **glands**. The wax, or **cerumen** (seh-RU-men), may become dried and impacted in the canal and must then be removed. The same kinds of disorders that involve the skin elsewhere—atopic dermatitis, boils, and other infections—may also affect the skin of the external auditory canal.

The **tympanic** (tim-PAN-ik) **membrane**, or eardrum, is at the end of the external auditory canal. It is a boundary between this canal and the middle ear cavity, and it vibrates freely as sound waves enter the ear.

The Middle Ear and Ossicles

The middle ear cavity is a small, flattened space that contains three small bones, or **ossicles** (OS-ih-klz) (see Fig. 10-11). The three ossicles are joined in such a way that they amplify the sound waves received by the tympanic

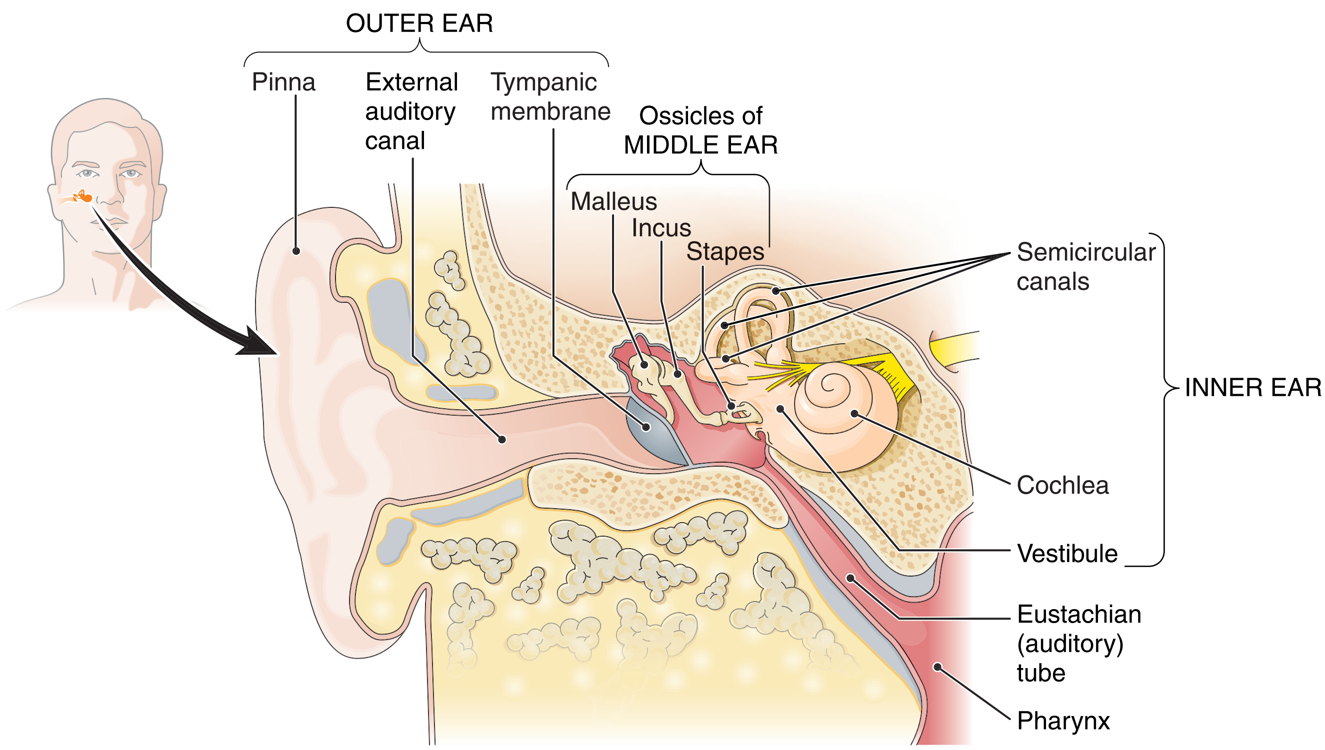

Figure 10-11 The ear. Structures in the outer, middle, and inner divisions are shown.

membrane as they transmit the sounds to the inner ear. The first bone is shaped like a hammer and is called the **malleus** (MAL-e-us) (Fig. 10-12). The handlelike part of the malleus is attached to the tympanic membrane, whereas the headlike part is connected to the second bone, the **incus** (ING-kus). The incus is shaped like an anvil, an iron block used in shaping metal, as is used by a blacksmith. The innermost ossicle is shaped somewhat like the stirrup of a saddle and is called the **stapes** (STA-peze). The base of the stapes is in contact with the inner ear.

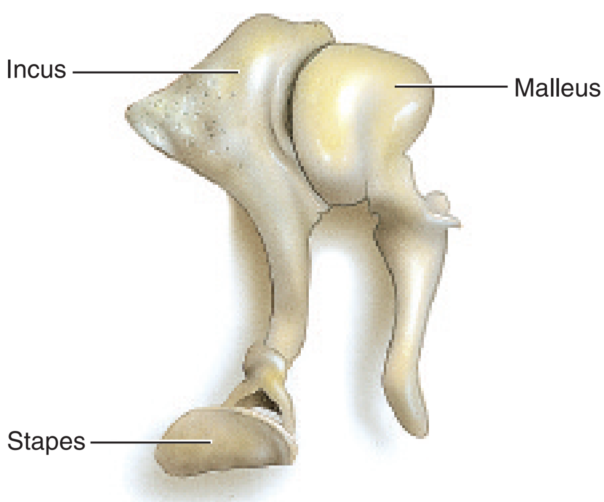

Figure 10-12 The ossicles of the middle ear. The handle of the malleus is in contact with the tympanic membrane, and the headlike part with the incus. The base of the stapes is in contact with the inner ear (×30). (Image provided by Anatomical Chart Co.)

CHECKPOINT 10-9 ➤ What are the ossicles of the ear and what do they do?

THE EUSTACHIAN TUBE The **eustachian** (u-STA-shun) **tube** (auditory tube) connects the middle ear cavity with the throat, or pharynx (FAR-inks) (see Fig. 10-11). This tube opens to allow pressure to equalize on the two sides of the tympanic membrane. A valve that closes the tube can be forced open by swallowing hard, yawning, or blowing with the nose and mouth sealed, as one often does when experiencing pain from pressure changes in an airplane.

The mucous membrane of the pharynx is continuous through the eustachian tube into the middle ear cavity. At the posterior of the middle ear cavity is an opening into the mastoid air cells, which are spaces inside the temporal bone's mastoid process (see Fig. 6-5B).

The Inner Ear

The ear's most complicated and important part is the internal portion, which is described as a *labyrinth* (LAB-ih-rinth) because it has a complex mazelike construction. It consists of three separate areas containing sensory receptors. The skeleton of the inner ear is called the **bony labyrinth** (Fig. 10-13). It has three divisions:

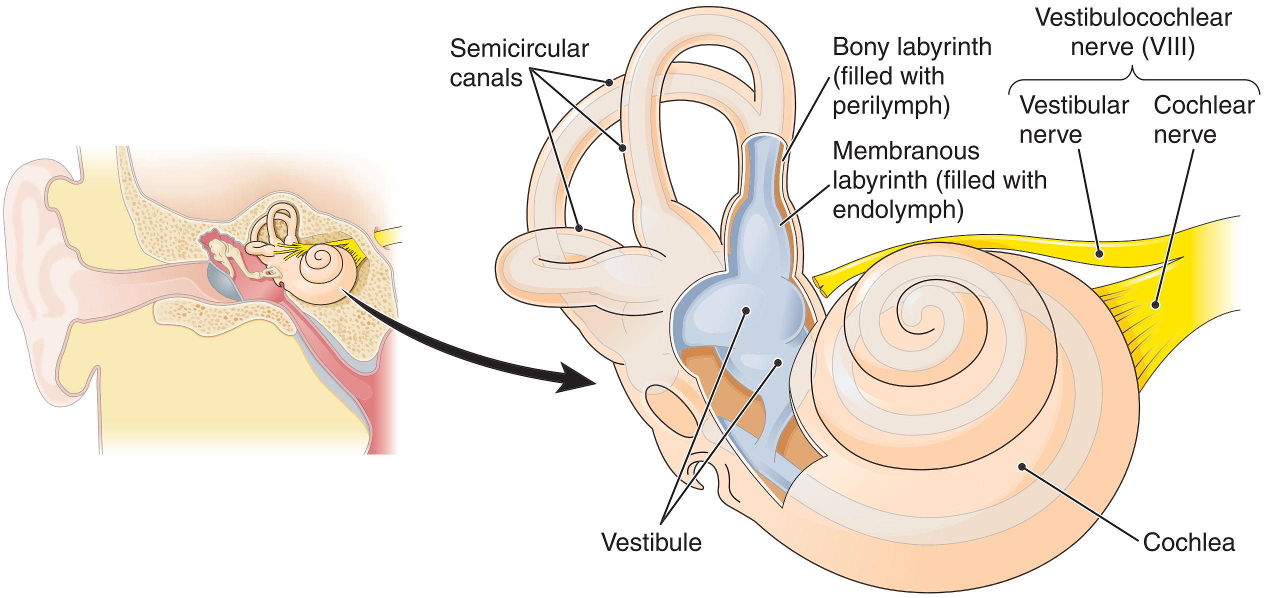

Figure 10-13 The inner ear. The vestibule, semicircular canals, and cochlea are made of a bony shell (labyrinth) with an interior membranous labyrinth. Endolymph fills the membranous labyrinth, and perilymph is around it in the bony labyrinth. The cochlea is the organ of hearing. The semicircular canals and vestibule are concerned with equilibrium.

- The **vestibule** consists of two bony chambers that contain some of the receptors for equilibrium.
- The **semicircular canals** are three projecting bony tubes located toward the posterior. Areas at the bases of the semicircular canals also contain receptors for equilibrium.
- The **cochlea** (KOK-le-ah) is coiled like a snail shell and is located toward the anterior. It contains the receptors for hearing.

All three divisions of the bony labyrinth contain a fluid called **perilymph** (PER-e-limf).

Within the bony labyrinth is an exact replica of this bony shell made of membrane, much like an inner tube within a tire. The tubes and chambers of this **membranous labyrinth** are filled with a fluid called **endolymph** (EN-do-limf) (see Fig. 10-13). The endolymph is within the membranous labyrinth, and the perilymph surrounds it. These fluids are important to the sensory functions of the inner ear.

HEARING The organ of hearing, called the **organ of Corti** (KOR-te), consists of ciliated receptor cells located inside the membranous cochlea, or **cochlear duct** (Fig. 10-14). Sound waves enter the external auditory canal and cause vibrations in the tympanic membrane. The ossicles amplify these vibrations and finally transmit them from the stapes to a membrane covering the **oval window** of the inner ear.

As the sound waves move through the fluids in these chambers, they set up vibrations in the cochlear duct. As a result, the tiny, hairlike cilia on the receptor cells (hair cells) begin to move back and forth against the **tectorial membrane** above them. (The membrane is named from a Latin word that means "roof.") This motion sets up nerve impulses that travel to the brain in the **cochlear nerve**, a branch of the eighth cranial nerve (formerly called the *auditory* or *acoustic nerve*). Sound waves ultimately leave the ear through another membrane-covered space in the bony labyrinth, the **round window**.

Hearing receptors respond to both the pitch (tone) of sound and its intensity (loudness). The various pitches stimulate different regions of the organ of Corti. Receptors detect higher-pitched sounds near the base of the cochlea and lower-pitched sounds near the top. Loud sounds stimulate more cells and produce more vibrations, sending more nerve impulses to the brain. Exposure to loud noises, such as very loud music, jet plane noise, or industrial noises, can damage the receptors for particular pitches of sound and lead to hearing loss for those tones.

The steps in hearing are:

1. Sound waves enter the external auditory canal.
2. The tympanic membrane vibrates.
3. The ossicles transmit vibrations across the middle ear cavity.
4. The stapes transmits the vibrations to the inner ear fluid.
5. Vibrations move cilia on hair cells of the organ of Corti in the cochlear duct.
6. Movement against the tectorial membrane generates nerve impulses.
7. Impulses travel to the brain in cranial nerve VIII.
8. The temporal lobe cortex interprets the impulses.

CHECKPOINT 10-10 ➤ What is the name of the organ of hearing, and where is it located?

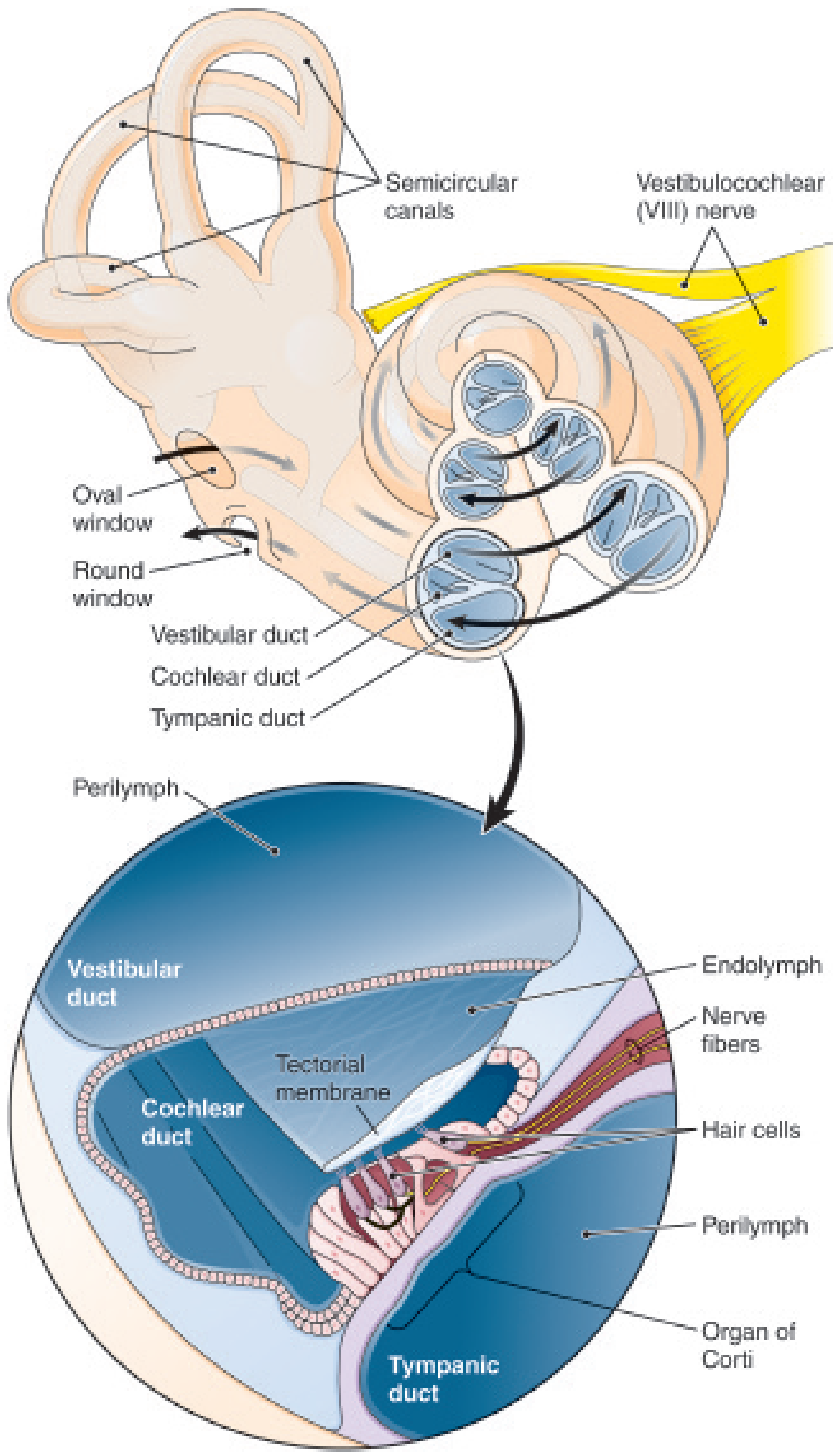

Figure 10-14 **Cochlea and the organ of Corti.** The arrows show the direction of sound waves in the cochlea.

EQUILIBRIUM The other sensory receptors in the inner ear are those related to equilibrium (balance). They are located in the vestibule and the semicircular canals. Receptors for the sense of equilibrium are also ciliated cells or hair cells. As the head moves, a shift in the position of the cilia within the thick fluid around them generates a nerve impulse.

CHECKPOINT 10-11 ➤ Where are the receptors for equilibrium located?

Receptors located in the vestibule's two small chambers sense the position of the head or the position of the body when moving in a straight line, as in a moving vehicle or when tilting the head. This form of equilibrium is termed **static equilibrium.** Each receptor is called a **macula.** (There is also a macula in the eye, but *macula* is a general term that means "spot.") The fluid above the hair cells contains small crystals of calcium carbonate, called **otoliths** (O-to-liths), which add drag to the fluid around the receptor cells and increase the effect of gravity's pull (Fig. 10-15). Similar devices that help in balance are found in lower animals, such as fish and crustaceans.

The receptors for **dynamic equilibrium** function when the body is spinning or moving in different directions. The receptors, called **cristae** (KRIS-te), are located at the bases of the semicircular canals (Fig. 10-16). It's easy to remember what these receptors do, because the semicircular canals go off in different directions.

Nerve fibers from the vestibule and from the semicircular canals form the **vestibular** (ves-TIB-u-lar) **nerve,** which joins the cochlear nerve to form the vestibulocochlear nerve, the eighth cranial nerve.

CHECKPOINT 10-12 ➤ What are the two types of equilibrium?

PASSport to Success

Visit ***thePoint*** or see the Student Resource CD in the back of this book for information on how audiologists.

Other Special Sense Organs

The sense organs of taste and smell are designed to respond to chemical stimuli.

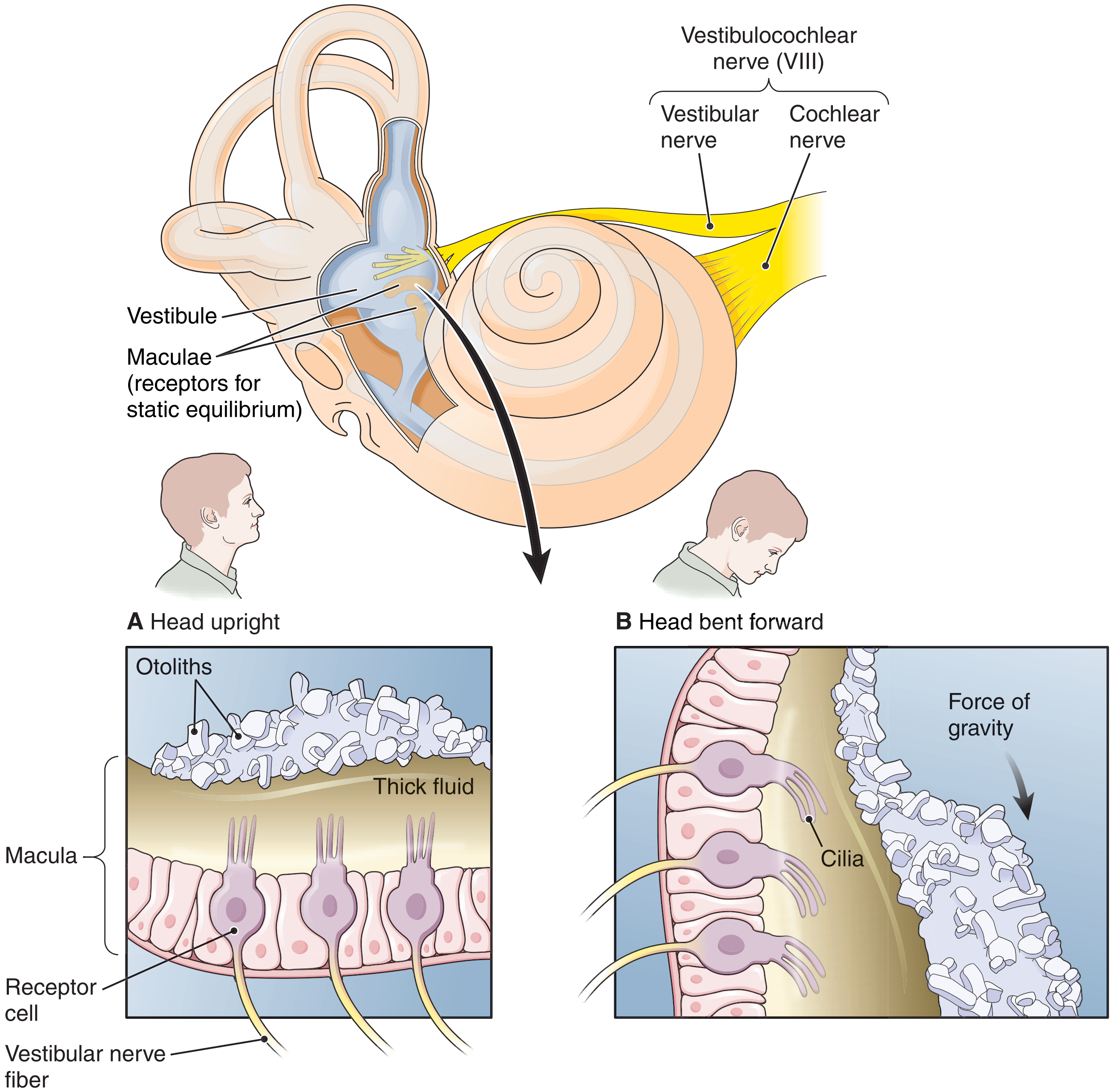

Figure 10-15 **Action of the receptors (maculae) for static equilibrium.** As the head moves, the thick fluid above the receptor cells (hair cells), weighted with otoliths, pulls on the cells' cilia, generating a nerve impulse. [**ZOOMING IN** ➤ What happens to the cilia on the receptor cells when the fluid around them moves?]

Sense of Taste

The sense of taste, or **gustation** (gus-TA-shun), involves receptors in the tongue and two different nerves that carry taste impulses to the brain (Fig. 10-17). The taste receptors, known as **taste buds**, are located along the edges of small, depressed areas called **fissures**. Taste buds are stimulated only if the substance to be tasted is in solution or dissolves in the fluids of the mouth. Receptors for four basic tastes are localized in different regions, forming a "taste map" of the tongue (see Fig. 10-17B):

- **Sweet** tastes are most acutely experienced at the tip of the tongue (hence the popularity of lollipops and ice cream cones).
- **Salty** tastes are most acute at the anterior sides of the tongue.
- **Sour** tastes are most effectively detected by the taste buds located laterally on the tongue.
- **Bitter** tastes are detected at the tongue's posterior part.

Taste maps vary among people, but in each person certain tongue regions are more sensitive to a specific basic taste. Other tastes are a combination of these four with additional smell sensations. More recently, researchers have identified some other tastes besides these basic four: water, alkaline (basic), and metallic. Another is umami (u-MOM-e), a pungent or savory taste based on a

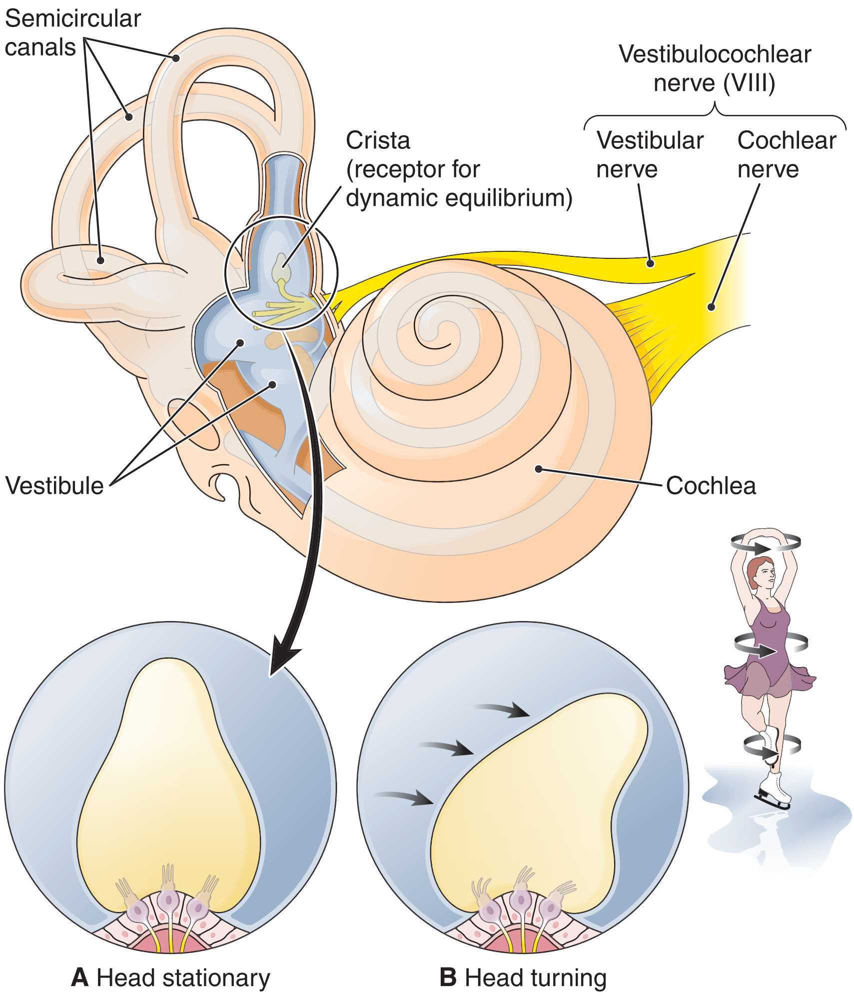

Figure 10-16 **Action of the receptors (cristae) for dynamic equilibrium.** As the body spins or moves in different directions, the cilia bend as the head changes position, generating nerve impulses.

response to the amino acid glutamate. Glutamate is found in MSG (monosodium glutamate), a flavor enhancer used in Asian food. Water taste receptors are mainly in the throat and may help to regulate water balance.

The nerves of taste include the facial and the glossopharyngeal cranial nerves (VII and IX). The interpretation of taste impulses is probably accomplished by the brain's lower frontal cortex, although there may be no sharply separate gustatory center.

Sense of Smell

The importance of the sense of smell, or **olfaction** (ol-FAK-shun), is often underestimated. This sense helps to detect gases and other harmful substances in the environment and helps to warn of spoiled food. Smells can trigger memories and other psychological responses. Smell is also important in sexual behavior.

The receptors for smell are located in the epithelium of the nasal cavity's superior region (see Fig. 10-17). Again, the chemicals detected must be in solution in the fluids that line the nose. Because these receptors are high in the nasal cavity, one must "sniff" to bring odors upward in the nose.

The impulses from the smell receptors are carried by the olfactory nerve (I), which leads directly to the olfactory center in the brain's temporal cortex. The interpretation of smell is closely related to the sense of taste, but a greater variety of dissolved chemicals can be detected by smell than by taste. The smell of foods is just as important in stimulating appetite and the flow of digestive juices as is the sense of taste. When one has a cold, food often seems tasteless and unappetizing because nasal congestion reduces the ability to smell the food.

The olfactory receptors deteriorate with age and food may become less appealing. It is important when presenting food to elderly people that the food look inviting so as to stimulate their appetites.

CHECKPOINT 10-13 ➤ What are the special senses that respond to chemical stimuli?

The General Senses

Unlike the special sensory receptors, which are localized within specific sense organs, limited to a relatively small area, the general sensory receptors are scattered throughout the body. These include receptors for touch, pressure, heat, cold, position, and pain (Fig. 10-18).

Sense of Touch

The touch receptors, **tactile** (TAK-til) **corpuscles**, are found mostly in the dermis of the skin and around hair follicles. Touch sensitivity varies with the number of touch receptors in different areas. They are especially numerous and close together in the tips of the fingers and the toes. The lips and the tip of the tongue also contain many of these receptors and are very sensitive to touch. Other areas, such as the back of the hand and the back of the neck, have fewer receptors and are less sensitive to touch. Also included in this category are receptors in the walls of the large arteries that monitor blood pressure. Known as **baroreceptors** (bar-o-re-SEP-torz), these receptors trigger responses that control blood pressure as the vessels stretch (see Chapter 14). Other areas, such as the back of the hand and the back of the neck, have fewer receptors and are less sensitive to touch.

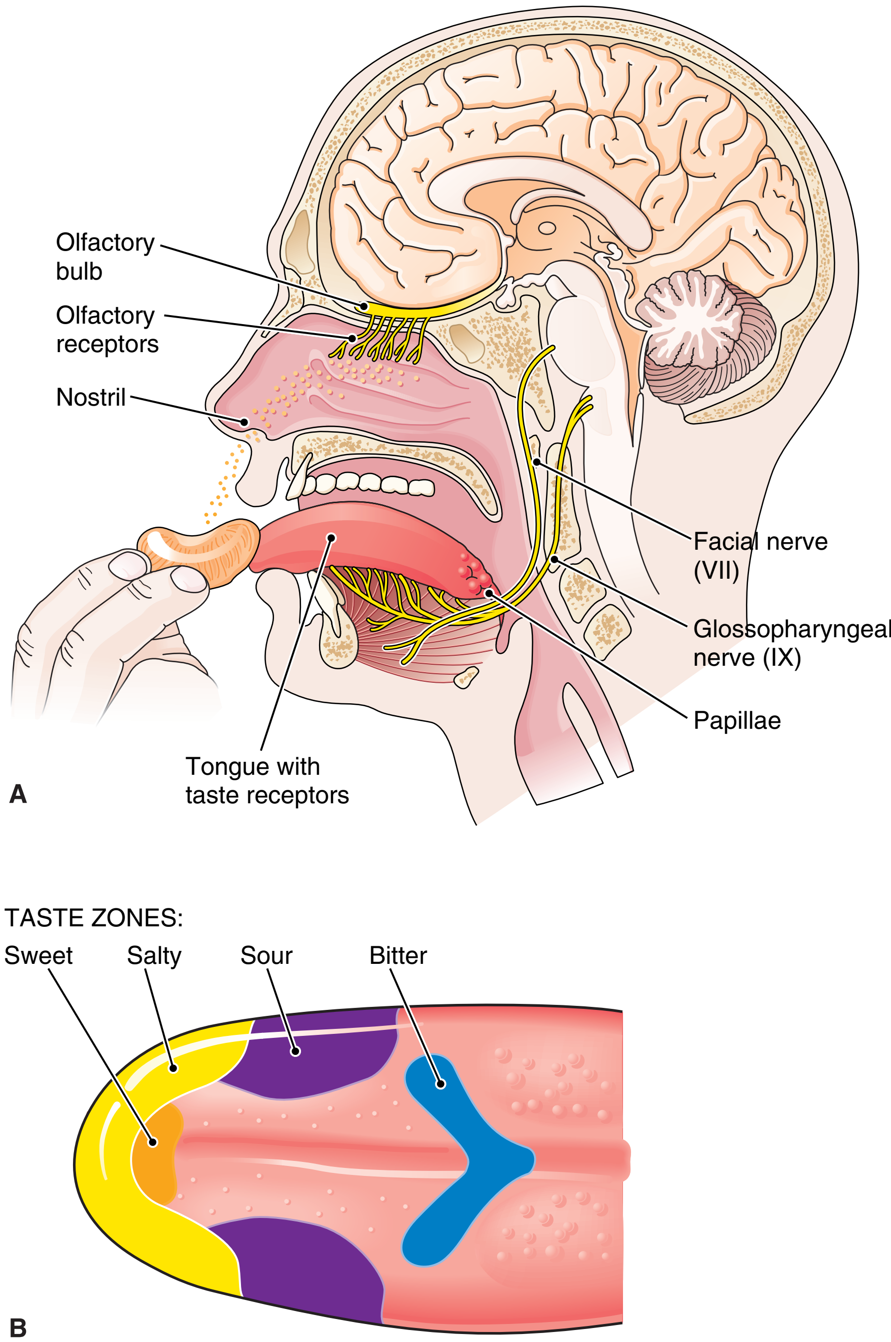

Figure 10-17 Special senses that respond to chemicals. (A) Organs of taste (gustation) and smell (olfaction). **(B)** A taste map of the tongue.

Sense of Pressure

Even when the skin is anesthetized, it can still respond to pressure stimuli. These sensory end-organs for deep pressure are located in the subcutaneous tissues beneath the skin and also near joints, muscles, and other deep tissues. They are sometimes referred to as *receptors for deep touch*.

Sense of Temperature

The temperature receptors are **free nerve endings**, receptors that are not enclosed in capsules but are merely branchings of nerve fibers. Temperature receptors are widely distributed in the skin, and there are separate receptors for heat and cold. A warm object stimulates only the heat receptors, and a cool object affects only the cold receptors. Internally, there are temperature receptors in the brain's hypothalamus, which help to adjust body temperature according to the temperature of the circulating blood.

Sense of Position

Receptors located in muscles, tendons, and joints relay impulses that aid in judging one's position and changes in the locations of body parts in relation to each other. They also inform the brain of the amount of muscle contraction and tendon tension. These rather widespread receptors, known as **proprioceptors** (pro-pre-o-SEP-tors), are aided in this function by the internal ear's equilibrium receptors.

Information received by these receptors is needed for the coordination of muscles and is important in such activities as walking, running, and many more complicated skills, such as playing a musical instrument. They help to provide a sense of body movement, known as **kinesthesia** (kin-es-THE-ze-ah). Proprioceptors play an important part in maintaining muscle tone and good posture. They also help to assess the weight of an object to be lifted so that the right amount of muscle force is used.

The nerve fibers that carry impulses from these receptors enter the spinal cord and ascend to the brain in the posterior part of the cord. The cerebellum is a main coordinating center for these impulses.

CHECKPOINT 10-14 ➤ What are examples of general senses?

CHECKPOINT 10-15 ➤ What are proprioceptors, and where are they located?

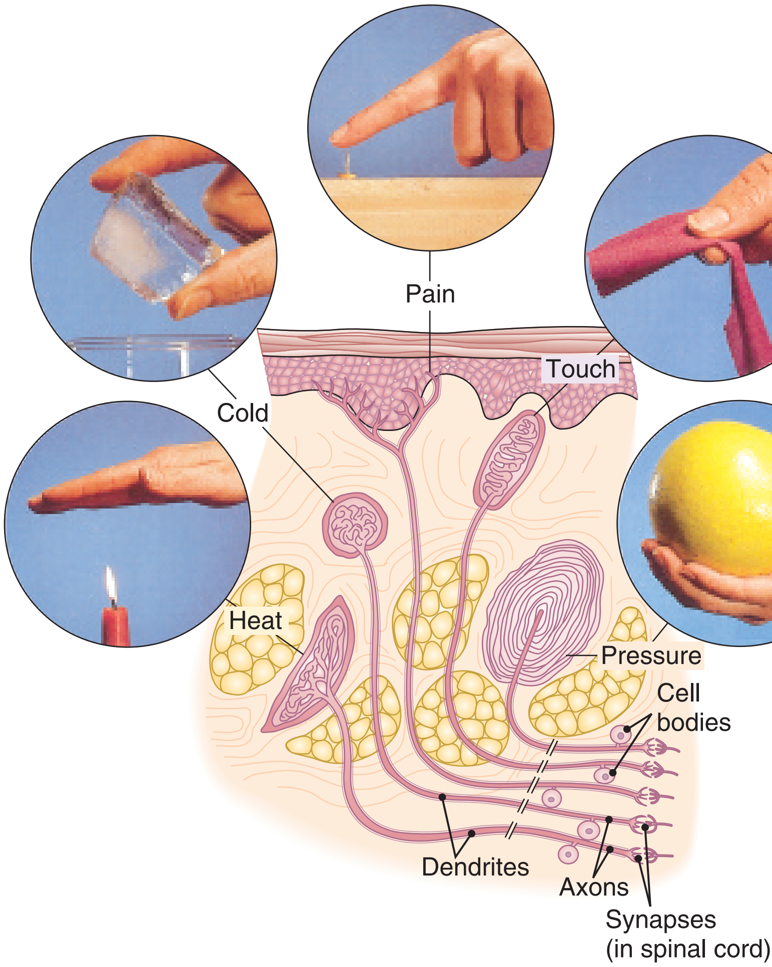

Figure 10-18 **Sensory receptors in the skin.** Synapses are in the spinal cord.

Sense of Pain

Pain is the most important protective sense. The receptors for pain are widely distributed free nerve endings. They are found in the skin, muscles, and joints and to a lesser extent in most internal organs (including the blood vessels and viscera). Two pathways transmit pain to the CNS. One is for acute, sharp pain, and the other is for slow, chronic pain. Thus, a single strong stimulus produces the immediate sharp pain, followed in a second or so by the slow, diffuse, burning pain that increases in severity with time.

Referred pain is pain that is felt in an outer part of the body, particularly the skin, but actually originates in an internal organ located nearby. Liver and gallbladder disease often cause referred pain in the skin over the right shoulder. Spasm of the coronary arteries that supply the heart may cause pain in the left shoulder and arm. Infection of the appendix is felt as pain of the skin covering the lower right abdominal quadrant.

Apparently, some neurons in the spinal cord have the twofold duty of conducting impulses from visceral pain receptors in the chest and abdomen and from somatic pain receptors in neighboring areas of the skin, resulting in referred pain. The brain cannot differentiate between these two possible sources, but because most pain sensations originate in the skin, the brain automatically assigns the pain to this more likely place of origin. Knowing where visceral pain is referred to in the body is of great value in diagnosing chest and abdominal disorders.

Sometimes, the cause of pain cannot be remedied quickly, and occasionally it cannot be remedied at all. In the latter case, it is desirable to lessen the pain as much as possible. Some pain relief methods that have been found to be effective include:

- **Analgesic drugs**. An analgesic (an-al-JE-zik) is a drug that relieves pain. There are two main categories of such agents:
  - **Nonnarcotic analgesics** act locally to reduce inflammation and are effective for mild to moderate pain. Most of these drugs are commonly known as nonsteroidal anti-inflammatory drugs (NSAIDs). Examples are ibuprofen (i-bu-PRO-fen) and naproxen (na-PROK-sen).
  - **Narcotics** act on the CNS to alter the perception and response to pain. Effective for severe pain, narcotics are administered by varied methods, including orally and by intramuscular injection. They are also effectively administered into the space surrounding the spinal cord. An example of a narcotic drug is morphine.
- **Anesthetics**. Although most commonly used to prevent pain during surgery, anesthetic injections are also used to relieve certain types of chronic pain.
- **Endorphins** (en-DOR-fins) are released naturally from certain brain regions and are associated with pain control. Massage, acupressure, and electric stimulation are among the techniques that are thought to activate this system of natural pain relief.
- **Applications of heat or cold** can be a simple but effective means of pain relief, either alone or in combination with medications. Care must be taken to avoid injury caused by excessive heat or cold.
- **Relaxation or distraction techniques** include several methods that reduce pain perception in the CNS. Relaxation techniques counteract the fight-or-flight response to pain and complement other pain-control methods.

10

Sensory Adaptation

When sensory receptors are exposed to a continuous stimulus, receptors often adjust themselves so that the sensation becomes less acute. The term for this phenomenon is **sensory adaptation.** For example, if you immerse your hand in very warm water, it may be uncomfortable; however, if you leave your hand there, soon the water will feel less hot (even if it has not cooled appreciably).

Receptors adapt at different rates. Those for warmth, cold, and light pressure adapt rapidly. In contrast, those for pain do not adapt. In fact, the sensations from the slow pain fibers tend to increase over time. This variation in receptors allows us to save energy by not responding to unimportant stimuli while always heeding the warnings of pain.

A&P in Action revisited

Early Signs of Cataract

Dr. Gilbert's assistant called Paul back to the consultation room after his eye examination. "You seem to be doing fine, Paul," the ophthalmologist reported. "No signs of glaucoma. I am a little concerned about some early signs of cataract, though. These opacities of the lens develop with age in most people, and they're not hereditary, but there's firm evidence that they are influenced by sun exposure."

"Yikes!" Paul exploded. "Another run-in with the sun! I've already heard about the sun's unfriendly rays with my skin cancer, and I thought that's where it would end."

"Cataracts can be dealt with pretty effectively," said Dr. Gilbert, "but there's more. Sunlight is also a factor in a more serious condition, macular degeneration, which affects central vision and can lead to blindness. That's not as easily treatable at present. I don't see any signs of that right now, but you need to wear good quality sunglasses with a UV filter. Wearing dark glasses without the filter is worse than nothing, because they dilate your pupils and allow more harmful UV rays to enter your eyes."

"Great! One more thing to worry about as I get older," Paul complained.

"Not a worry if you take precautions," Dr. Gilbert responded. "Pick up your glasses prescription at the desk, and Paul, also take a pair of the dark disposable glasses we have there to protect your dilated eyes. They will be extra-sensitive to the sun for a while."

During this case, we learned that structural damage leads to functional changes. We also learned that some changes develop with age. Later chapters will include information on age-related changes that affect other systems.

Word Anatomy

Medical terms are built from standardized word parts (prefixes, roots, and suffixes). Learning the meanings of these parts can help you remember words and interpret unfamiliar terms.

WORD PART	MEANING	EXAMPLE
The Eye and Vision		
ophthalm/o	eye	An *ophthalmologist* is a physician who specializes in treatment of the eye.
-scope	instrument for examination	An *ophthalmoscope* is an instrument used to examine the posterior of the eye.
lute/o	yellow	The macula *lutea* is a yellowish spot in the retina that contains the fovea centralis.
presby-	old	*Presbyopia* is farsightedness that occurs with age.
The Ear		
tympan/o	drum	The *tympanic* membrane is the eardrum.
equi-	equal	*Equilibrium* is balance (*equi-* combined with the Latin word *libra* meaning "balance").
ot/o	ear	*Otology* is the study of the ear.
lith	stone	*Otoliths* are small crystals in the inner ear that aid in static equilibrium.
-cusis	hearing	*Presbycusis* is hearing loss associated with age.
The General Senses		
propri/o-	own	*Proprioception* is perception of one's own body position.
kine	movement	*Kinesthesia* is a sense of body movement.
-esthesia	sensation	*Anesthesia* is loss of sensation, as of pain.
-alges/i	pain	An *analgesic* is a drug that relieves pain.
narc/o	stupor	A *narcotic* is a drug that alters the perception of pain.

Summary

I. THE SENSES

- A. Protect by detecting changes (stimuli) in the environment
- B. Sensory receptors—detect stimuli
  - 1. Structural types
    - a. Free dendrite
    - b. End-organ—modified dendrite
    - c. Specialized cell—in special sense organs
  - 2. Types based on stimulus
    - a. Chemoreceptors—respond to chemicals
    - b. Thermoreceptors—respond to temperature
    - c. Photoreceptors—respond to light
    - d. Mechanoreceptors—respond to movement
- C. Special and general senses
  - 1. Special senses—vision, hearing, equilibrium, taste, smell
  - 2. General senses—touch, pressure, temperature, position, pain

II. THE EYE AND VISION

- A. Protection of the eyeball—bony orbit, eyelid, eyelashes, conjunctiva, lacrimal glands (produce tears)
- B. Coats of the eyeball
  - 1. Sclera—white of the eye
    - a. Cornea—anterior
  - 2. Choroid—pigmented; contains blood vessels
  - 3. Retina—receptor layer

- C. Pathway of light rays and refraction
  - 1. Refraction—bending of light rays as they pass through substances of different density
  - 2. Refracting parts—cornea, aqueous humor, lens, vitreous body
- D. Function of the retina
  - 1. Cells
    - a. Rods—cannot detect color; function in dim light
    - b. Cones—detect color; function in bright light
  - 2. Pigments—sensitive to light; rod pigment is rhodopsin
- E. Muscles of the eye
  - 1. Extrinsic muscles—six move each eyeball
  - 2. Intrinsic muscles
    - a. Iris—colored ring around pupil; regulates the amount of light entering the eye
    - b. Ciliary muscle—regulates the thickness of the lens to accommodate for near vision
- F. Nerve supply to the eye
  - 1. Sensory nerves
    - a. Optic nerve (II)—carries impulses from retina to brain
    - b. Ophthalmic branch of trigeminal (V)
  - 2. Motor nerves—move eyeball
    - a. Oculomotor (III), trochlear (IV), abducens (VI)

III. THE EAR

- A. Outer ear—pinna, auditory canal (meatus), tympanic membrane (eardrum)
- B. Middle ear and ossicles
  - 1. Ossicles—malleus, incus, stapes
  - 2. Eustachian tube—connects middle ear with pharynx to equalize pressure
- C. Inner ear
  - 1. Bony labyrinth—contains perilymph
  - 2. Membranous labyrinth—contains endolymph
  - 3. Divisions
    - a. Cochlea—contains receptors for hearing (organ of Corti)
    - b. Vestibule—contains receptors for static equilibrium (maculae)
    - c. Semicircular canals—contain receptors for dynamic equilibrium (cristae)
  - 4. Receptor (hair) cells function by movement of cilia
  - 5. Nerve—vestibulocochlear (auditory) nerve (VIII)

IV. OTHER SPECIAL SENSE ORGANS

- A. Sense of taste (gustation)
  - 1. Receptors—taste buds on tongue
  - 2. Basic tastes—sweet, salty, sour, bitter
  - 3. Nerves—facial (VII) and glossopharyngeal (IX)
- B. Sense of smell (olfaction)
  - 1. Receptors—in upper part of nasal cavity
  - 2. Nerve—olfactory nerve (I)

V. GENERAL SENSES

- A. Sense of touch—tactile corpuscles
- B. Sense of pressure—receptors in skin deep tissue, large arteries
- C. Sense of temperature—receptors are free nerve endings
- D. Sense of position (proprioception)—receptors are proprioceptors in muscles, tendons, joints
  - 1. Kinesthesia—sense of movement
- E. Sense of pain—receptors are free nerve endings
  - 1. Referred pain—originates internally but felt at surface
  - 2. Relief of pain—analgesic drugs, anesthetics, endorphins, heat, cold, relaxation and distraction techniques

VI. SENSORY ADAPTATION

- A. Adjustment of receptors so that sensation becomes less acute
- B. Receptors adapt at different rates; pain receptors do not adapt

Questions for Study and Review

BUILDING UNDERSTANDING

Fill in the blanks

1. The part of the nervous system that detects a stimulus is the ______.
2. The bending of light rays as they pass from air to fluid is called ______.
3. Nerve impulses are carried from the ear to the brain by the ______ nerve.
4. Information about the position of the knee joint is provided by ______.
5. A receptor's ability to decrease its sensitivity to a continuous stimulus is called ______.

Matching > Match each numbered item with the most closely related lettered item.

___ **6.** Consists of ciliated receptor cells sensitive to vibration
___ **7.** The actual receptor layer of the eye
___ **8.** The receptor that senses static equilibrium
___ **9.** The receptor that senses touch
___ **10.** The receptor sensitive to temperature and pain

a. retina
b. free nerve endings
c. macula
d. organ of Corti
e. tactile corpuscle

Multiple Choice

___ **11.** All of the following are special senses except
a. smell
b. taste
c. equilibrium
d. pain

___ **12.** From superficial to deep, the order of the eyeball's tunics is
a. retina, choroid, and sclera
b. sclera, retina, and choroid
c. choroid, retina, and sclera
d. sclera, choroid, and retina

___ **13.** The part of the eye most responsible for light refraction is the
a. cornea
b. lens
c. vitreous body
d. retina

___ **14.** Information from the retina is carried to the brain by the
a. ophthalmic nerve
b. optic nerve
c. oculomotor nerve
d. abducens nerve

___ **15.** Receptors in the vestibule sense
a. muscle tension
b. sound
c. light
d. equilibrium

UNDERSTANDING CONCEPTS

16. Differentiate between the terms in each of the following pairs:
a. special sense and general sense
b. aqueous humor and vitreous body
c. rods and cones
d. endolymph and perilymph
e. static and dynamic equilibrium

17. Trace the path of a light ray from the outside of the eye to the retina.

18. Define *convergence* and *accommodation*.

19. List in order the structures that sound waves pass through in traveling through the ear to the receptors for hearing.

20. Name the four basic tastes. Where are the taste receptors? Name the nerves of taste.

21. Trace the pathway of a nerve impulse from the olfactory receptors to the olfactory center in the brain.

22. Name several types of pain-relieving drugs. Describe several methods for relieving pain that do not involve drugs.

CONCEPTUAL THINKING

23. Why do you taste eyedrops after applying them to your eyeball?

24. You and a friend have just finished riding the roller coaster at the amusement park. As you walk away from the ride, your friend stumbles and comments that the ride has affected her balance. How do you explain this?

25. In the case story, Paul discovered he might be developing an age-related eye disorder. What is a cataract? What are some other age-related disorders of the sensory system?