The sensory function of the nervous system was explained in Chap. 6. Information about the eyes and ears was not included there because these sense organs are more specialized and complicated than other sense receptors.

**THE EYES**

The eyes assist in the monitoring function of the nervous system by receiving information about conditions on the surface of the body and the region surrounding it. This information is used to make proper responses that promote healthy survival and maintain the quality of life.

Unlike most sense receptors, the eyes can also provide information about conditions far from the body and thus enable a person to respond to harmful factors long before they affect the body. Examples include avoiding an oncoming car and seeking shelter from an approaching storm. A person can also efficiently and effectively seek out, move toward, and utilize helpful factors at some distance from the body. For example, the eyes are of inestimable value in obtaining and preparing food and in any project that involves obtaining and assembling parts.

In addition, information provided by the eyes contributes greatly to learning, and much communication occurs through the eyes. Finally, much of the beauty of the world can be appreciated and enjoyed because of the eyes.

**Image Formation and Vision**

To perform these functions successfully, each eye must produce accurate images of objects by focusing some of the light that reflects from or is given off by those objects. Focusing light involves bending it so that by the time it reaches the retina in the rear of the eye, the light has the exact organization it had before leaving the object. For example, a group of people in a room can recognize each other because light from a lamp strikes them and reflects in all directions from each one. Some of the reflected light from each person enters the eyes of each of the other people, where it is focused into accurate, recognizable images (Fig. 7.1).

If enough light enters the eye, it stimulates certain neurons to initiate impulses. The impulses are then processed by other neurons in the eye and by neurons in the brain. The *vision center*, the part of the cerebral cortex at the back of each
cerebral hemisphere, plays a major role in processing these impulses. The final result is the conscious perception of the images, a phenomenon called vision.

Deterrents to Clear Vision

Clear vision is not always possible for three reasons. First, the eye may not be able to focus light well enough for an accurate image to be formed. This can occur if the light is too disorganized before it enters the eye. For example, the water droplets in fog and the irregular surfaces of the glass used in rest room windows cause this effect. Inadequate focusing of light can also occur if parts of the eye are improperly shaped or malfunction because of nearsightedness or farsightedness.

The second reason involves having improper amounts of light strike the receptors in the eye. With insufficient light, not enough impulses are produced for accurate perception to occur, and so errors in vision are made. For example, objects in a very dimly lit area may be misidentified, may seem to move, or may go completely unnoticed. By contrast, when excess light hits the receptors, they may be overly stimulated or damaged.

The third reason is that neurons in the eye and brain may be unable to properly process the impulses sent to them. For example, a person with normal eyes may be blinded because of a stroke.

FORMING IMAGES

Conjunctiva

Each eye is nearly spherical in shape. The front surface consists of a smooth thin layer, the conjunctiva, which covers the part of the eye exposed to air (Fig. 7.2). The conjunctiva also extends away from the edge of this region to form a lining on the inner surfaces of the upper and lower eyelids. It is transparent, and so it does not absorb or block any of the light that strikes the eye.

The conjunctiva secretes a fluid that helps prevent eye damage from drying and lubricates the eye so that the eyelids slide over it easily. Small
blood vessels in the conjunctiva that are visible over the white part of the eye help nourish the cornea.

**Age Changes** Aging results in a small decrease in the smoothness of the conjunctiva, causing light entering the eye to be slightly disorganized and scattered. These changes make focusing the light into a clear image more difficult. The conjunctiva also diminishes slightly in transparency, causing it to absorb and block the passage of some light.

A more important age change is a gradual decline in the amount of fluid the conjunctiva secretes. In some individuals fluid production is so low that the eyelids can no longer glide smoothly over the eye. The irritation and inflammation of the conjunctiva that result can be quite uncomfortable. Artificial tear solutions can relieve this discomfort in most individuals.

**Cornea**

Immediately behind the central region of the conjunctiva is another transparent structure, the *cornea* (Fig. 7.2). Because the cornea is fairly thick and curved, it bends (refracts) the light that passes through it.

**Age Changes** Aging results in a gradual decrease in the transparency of the cornea. This change is usually great enough to block a significant amount of light. Light at the blue end of the spectrum is blocked more than is light toward the red end; therefore, seeing blue objects or objects lit with blue light is reduced preferentially. The blue end of the spectrum has light of shorter wavelengths than does the red end.

Aging of the cornea also increases the degree of scattering of light that passes through the cornea.
Much of the scattered light still reaches the retina, but since it strikes the retina in the wrong places and in a disorganized way, it causes the viewer to see bright areas in wrong places in the field of view. This phenomenon is called **glare**. A similar effect is noted when one looks at outdoor objects on a bright, hazy day. An extreme example can be created by viewing bright lights at night through a window covered with drops of water.

With aging, the cornea becomes flatter, reducing the amount of refraction it can cause and making it difficult to see close objects clearly. The curvature of the cornea also becomes irregular so that light from certain parts of the field of view is not focused properly. This condition, called **astigmatism**, decreases the clarity of images from some parts of the field of view. Eyeglasses or contact lenses can often compensate for astigmatism. Finally, the sensitivity of the cornea to pain from pressure on the eye diminishes, which in turn decreases a person's ability to ward off eye injury from external pressure.

**Iris and Pupil**

A short distance behind the cornea is the **iris** (Fig. 7.2), which is shaped like a phonograph record or compact disk. Pigments in the iris give the eye its color.

The hole in the center of the iris is called the **pupil**. The pupil allows light to pass from the front of the eye into the rear region. Muscle cells in the iris regulate the size of the pupil. These cells are controlled reflexively by autonomic motor neurons.

In the presence of bright light, some muscle cells in the iris constrict the pupil to reduce light entering the eye; this helps protect the eye from being damaged by excess light. The pupil is also constricted when a person looks at an object close to the eye. This helps form a clear image by blocking out stray light.

When light is dim, other muscle cells in the iris dilate the pupil. This allows enough light into the eye to adequately stimulate the receptor neurons.

**Age Changes** With aging, the number and strength of the muscle cells that cause dilation of the pupil diminish and the thickness and stiffness of the collagen fibers increase. As these processes continue, the size of the pupil for any light intensity decreases with each passing year, starting at age 20. The result is a continuous decline in light available to form images.

Age changes in the cells and fibers in the iris may also slow the rate at which the pupil dilates when changing from bright to dim light. This effect, combined with age-related slowing of pupillary constriction, retards pupillary adaptation to changing light intensities.

**Ciliary Body**

The outer edge of the iris is attached to a thickened ring of cells called the **ciliary body** (Fig. 7.2), which contains muscle cells that regulate the curvature of the lens. As in the iris, these muscle cells are controlled by reflexes. The ciliary body also secretes a fluid called **aqueous humor**, which is discussed below.

**Age Changes** An important age change in the ciliary body is the slowing of its secretion of aqueous humor. The significance of this change is discussed below.

**Lens and Suspensory Ligaments**

A short distance behind the iris and the pupil is the **lens** (Fig. 7.2), which is nearly round (Fig. 7.2). However, because the lens is elastic, its shape can be changed. The lens increases in thickness throughout life.

A ring of thin fibers called **suspendory ligaments** radiates outward from the lens much as spokes radiate from the center of a bicycle wheel. These ligaments reach and attach to the ciliary body much as spokes connect to the rim of a wheel.

Since the lens is a thick curved structure, it refracts the light passing through it. Unlike the cornea, however, the curvature of the lens can change so that the lens can refract light to a greater or lesser degree (Fig. 7.3). Alterations in refraction are important because light coming to the eye from close objects must be refracted more than is light from farther objects. Therefore, to focus light from close objects, the lens becomes more rounded so that it bends the light more. The lens becomes flatter and bends light less to help the eye form a clear image of a distant object.

**Age Changes** As the lens ages, it is altered in four ways. One alteration is a decline in transparency
to all colors of light, especially blue light. The markedly declining transparency of the lens blocks more light than does the reduction in the transparency of any other part of the eye. This change begins during the third decade of life and increases exponentially with age.

The second alteration is the development of opaque spots, which begins during the fifth decade. Usually these opacities are toward the periphery of the lens. Lens opacities block the passage of light and cause a great increase in light being scattered. They account for more scattering of light and more glare than do age changes in any other eye component.

If many opacities form close to the center of the lens, vision is greatly impaired and the condition is called cataracts. While cataracts are categorized as a disease, their development is part of aging of the lens. Everyone who lives long enough will eventually develop cataracts.

The third alteration of the lens is a reduction in its ability to refract light. This change results from accumulation of damaged proteins plus age-related formation of abnormal proteins. These two changes offset the age-related increase in lens thickness and curvature. With diminishing refractive power, it becomes increasingly difficult to see close objects clearly. Individuals who are near-sighted during youth may benefit from this age change since their ability to see distant objects improves.

Many individuals have lenses so flat that they cannot focus light even from far objects. This condition may eventually begin to improve because thickening of the lens increases its ability to refract light.

The fourth age change is a decrease in elasticity, which may result partly from an increase in the cross-linkages among collagen fibers. As the lens loses elasticity, its shape changes more slowly when it adjusts to near or distant objects. Declining elasticity actually begins some time before age 10 and continues at a steady rate until about age 50. The decline in elasticity decreases the amount of curvature the lens can achieve, and objects must be farther away from the face to be seen clearly. Thus, the smallest distance from the eye at which an object can be seen clearly—the near point of accommodation—increases.

This increase is usually not noticed until about age 40 because most objects used in daily living are located beyond the near point. After age 40, the reserve capacity of the lens for elasticity has dwindled sufficiently and the near point becomes large enough to interfere with ordinary activities such as reading and writing. This condition, called

**FIGURE 7.3** Focusing light from (a) close objects and (b) distant objects.
presbyopia, involves farsightedness caused by stiffening of the lens. Difficulties and limitations caused by presbyopia can be reduced by wearing eyeglasses or contact lenses.

The increase in the near point is rapid from about ages 40 to 50, but the rate of change slows during the sixth decade of life. By age 60 there is usually no further increase in the near point because the lens has lost all ability to change its curvature.

Because adjusting the curvature of the lens requires the use of the aqueous humor and vitreous humor, a more complete explanation of how the curvature of the lens is adjusted and how this process is affected by aging follows the description of those two humors.

Aqueous Humor

As mentioned above, the ciliary body produces a liquid called aqueous humor (Fig. 7.2). The aqueous humor flows forward from the ciliary body, passes through the pupil, and is removed from the eye by a special tube located around the edge of the cornea.

Since aqueous humor is produced and removed continuously, its steady flow delivers nutrients and removes wastes. These services are important for the cornea and lens, which have no blood vessels.

The aqueous humor fills the cavity between the cornea and the lens. The fluid provides a slight outward pressure that helps keep the cornea curved outward so that it refracts light properly. By causing the entire eye to bulge outwardly, this pressure also helps provide tension on the suspensory ligaments. The tension helps to hold the lens in place and pull it into a slightly flattened shape.

Age Changes

As a person ages, the rate at which aqueous humor is produced declines. This change reduces the rate at which the cornea and lens are serviced. There is also a decrease in the amount of aqueous humor present, and this may contribute to the flattening and irregular curvature of the cornea that develop with aging.

Vitreous Humor

Another eye humor, the vitreous humor, fills the cavity in the eye behind the lens (Fig. 7.2). The transparent vitreous humor is composed of a soft gel that has the consistency of partially solidified gelatin. The center of the gel becomes liquefied early in childhood. Thereafter, the liquefaction slowly and continuously spreads outward.

The vitreous humor is held in place by a ring of attachment on the front edge of the retina and an attachment point at the back of the eye where the optic nerve begins.

The vitreous humor produces an outward pressure so that, like the aqueous humor, it puts tension on the suspensory ligaments. The soft consistency of the vitreous humor allows it to protect eye structures by absorbing shock. It also holds the retina and choroid layers in place by pushing against them.

Age Changes

With aging, alterations in the chemistry of the vitreous humor make it lose transparency and cause more scattering of light. Blocking and scattering of light are increased by small areas of vitreous humor that become opaque and often grow large enough to be visible in the field of view. These areas, which appear as objects of varying sizes, shapes, and textures, are called floaters because they are seen to move, especially when the eye moves. Though floaters are not dangerous, they decrease the quality of the images that are formed, are often distracting, and can obscure parts of the field of view. Some floaters are pieces of vitreous humor that have broken off from the main mass and float between the vitreous humor and the retina.

Chemical changes caused by aging of the vitreous humor also make it decrease in size and shrink away from the retina. These alterations reduce the amount of support provided for the retina. At the same time, more of the central region is becoming liquefied, making the vitreous humor move about when the eye moves. As the vitreous humor shifts, it pulls on the retina, especially during rapid eye or head movements, and causes the person to perceive flashes of light called flashers.

The presence of a few flashers may be distracting but is of little importance. However, as the vitreous humor ages, the tension it places on the retina increases. If the tension becomes great enough, the person may perceive many flashes and part of the field of view may become darkened. These symptoms constitute a warning that the vitreous humor may have detached the retina from the back of the eye. If not treated and corrected immediately, detachment of the retina usually causes some degree of blindness.
ACCOMMODATION

Having described the aqueous and vitreous humors, we now move to a more complete description of the process of adjusting the curvature of the lens. This process is called **accommodation**.

Since the lens is normally in a slightly flattened condition because of pressure from the aqueous and vitreous humors, it is normally set for focusing light from distant objects (Fig. 7.4). For the lens to become more rounded so that it can focus light from near objects, the tension on the suspensory ligaments must be decreased; this is accomplished by having the ring of muscle cells in the ciliary body contract and pull the edges of the ciliary body inward. When this happens, the normal elasticity of the lens causes the lens to spring back to its round shape.

To flatten the lens again to focus on distant objects, the muscle cells in the ciliary body relax, allowing the lens to be pulled back to its slightly flattened shape. When the amount of contraction of the ciliary body is regulated, the curvature of the lens can be adjusted. Then light from the object a person is viewing is in focus. Other objects at different distances appear to be less clear.

**FIGURE 7.4** Accommodation to (a) distant objects and (b) near objects.
**Age Changes**

Age changes in the ciliary body and the lens gradually reduce and finally eliminate the ability to adjust the shape of the lens. Therefore, the range of distances over which the eye can focus diminishes considerably.

A person can partially compensate for diminishing accommodation by using eyeglasses with different refractive powers for viewing objects at different distances. Of course, it is inconvenient to change glasses when the distances being viewed change frequently, as occurs when a person checks prices while shopping or takes notes during a lecture. The expense of two or more sets of eyeglasses is also a significant factor.

These problems can be largely overcome by using eyeglasses with bifocal or trifocal lenses, which have regions with two or three different refractive powers, respectively. Thus, one set of glasses can be used over a wide range of distances simply by looking through the appropriate region of the multipowered lenses. Unfortunately, each region of the lens has a limited field of view, and such lenses are sometimes considered to have undesirable cosmetic effects. They are also expensive.

**RETINA**

We have seen that light from an object being viewed passes through the optic media (conjunctiva, cornea, aqueous humor, lens, and vitreous humor) and the pupil so that it is focused and its intensity is adjusted. In this way, clear and accurate images are formed on the retina. The retina is a thin layer that lines the rear portion of the inner cavity of the eye. It extends back from the edge of the ciliary body and thus partially surrounds the vitreous humor (Fig. 7.2).

**Layers and Regions**

The retina consists of two main layers of cells. The inner layer is called the sensory retina (Fig. 7.5). It is in contact with the vitreous humor and contains several layers of neurons. The neurons in the deeper region are called photoreceptors because they respond to light by starting impulses in the form of action potentials. The neurons in the surface region, closest to the vitreous humor, use their synapses to process these impulses. The impulses are then passed to the optic nerve, which begins near the back of the retina at a spot called the optic disk. This nerve carries the impulses to the brain.

Blood vessels in the retina nourish the neurons that process impulses; these vessels pass through the optic disk. The photoreceptors are nourished by vessels behind the retina in the choroid layer, as is the outer layer of the retina, the pigmented epithelium.

The photoreceptors in the sensory retina are of two main kinds. The cones are clustered together in a small circular region at the very back of the eye. This region is in line with the center of the cornea and the lens and is called the macula lutea or simply the macula. In the center of the macula is a slightly depressed area that contains a very high concentration of cones. This central area is called the fovea centralis or simply the fovea.

The outer layer of the retina is called the pigmented epithelium because it is a darkly colored thin layer of cells. A noncellular membrane (Bruch's membrane) lies behind the pigmented epithelium (Fig. 7.5). The pigmented epithelium and apparently Bruch's membrane regulate the exchange of materials between the choroid and the photoreceptors of the sensory retina.

**Cones**

There seem to be three types of cones, and each type is most sensitive to light of a different color, either blue, green, or red. If only one type of cone is stimulated, the person sees the corresponding color, while stimulation of various combinations of cone types allows a person to see many other colors and shades of color. This principle explains how people can see many colors on a television screen that employs patterns of red, blue, and green dots to form images.

Cones initiate impulses because of specific chemical reactions that occur when light strikes pigmented molecules within them. Cones are not particularly sensitive to light; therefore, relatively high intensities of light must strike them before they initiate impulses.

When a person views a scene, the image of what is in the center of the field of view is focused on the fovea. Since the fovea has a very high concentration of cones, it allows the person to see the
FIGURE 7.5 Structure of the retina and associated eye components.

Object in the center of the scene in color and with maximum visual acuity (the amount of detail that can be seen).

Objects immediately surrounding the center of the field of view are focused on the outer regions of the macula. Since the cones are less concentrated there, these objects are seen with less visual acuity but still are seen in color.

**Rods**

While the regions of the retina immediately surrounding the macula contain some cones, most of the photoreceptors are of the second type, called rods (Fig. 7.5). The concentration of rods diminishes steadily at greater distances from the edge of the macula, and the front edge of the retina has few rods. Therefore, images from very peripheral objects are focused on retinal areas with low concentrations of photoreceptors and are seen with little visual acuity.

Rods are of only one type. Images focused on rods are seen as black and white images. Though rods do not permit us to perceive color, they allow us to see in dim light because they are more sensitive to light than are cones. As in the cones,
the rods produce impulses when light causes specific chemical reactions within them.

**Age Changes**

**Cones** Beginning at age 40, cones decrease in length and many are lost. This decrease in number is greatest in the fovea. The cones that remain in the retina widen to fill the spaces left by degenerated cones.

Since the level of visual acuity and color vision are directly related to the concentration of cones in the retina, the declining number of cones with aging contributes to a gradual drop in visual acuity and a diminishing ability to distinguish colors.

**Rods** Aging causes little if any change in the number of rods. However, the rods lengthen, causing them to be bent into irregular shapes to fit within the confines of the sensory retina. These age changes further diminish an aging person’s ability to see in dim light.

**Processing Neurons** The sensory retina loses not only photoreceptors but also neurons in its inner layer that process impulses from the photoreceptors. The loss is greatest in the neurons that serve the macula. The declining number of neurons processing impulses probably decreases the quality of perceived images and the ability to interpret those images.

**Pigmented Epithelium and Bruch’s Membrane** Cell numbers and cell functioning also diminish in the pigmented epithelium of the retina. Furthermore, the exchange of materials between the sensory retina and the pigmented epithelium decreases, resulting in diminished servicing of the photoreceptors by the pigmented epithelium.

Age changes in Bruch’s membrane seem to further inhibit the exchange of materials required by the cones and rods. Changes in this membrane also cause a reduction in capillaries in the choroid. These capillaries normally provide nutrients for the cones and rods and carry away wastes.

**Free radicals in the eye** A unifying factor contributing to several age-related changes in the eye is damage from free radicals (*FRs) and reactive oxygen species (ROS), especially \( \text{H}_2\text{O}_2 \). Free radicals in the eye are produced by radiation (e.g., UV light); atmospheric oxygen; air pollutants; normal metabolism (e.g., mitochondria); and impulse generation.

The *FR damage may be from a combination of age-related increases in *FRs and ROS in the eye; age-related decreases in *FR and ROS defenses in the eye; and accumulation of damage from *FRs and ROS due to slow turnover of some eye components. Slow turnover seems especially relevant in the lens and the retina. The damage from *FRs and ROS may lead to cataracts, glaucoma, decreasing sensitivity of the retina to light and to color, and age-related maculopathy.

**OTHER EYE COMPONENTS**

**Choroid**

The choroid lies in contact with Bruch’s membrane on the outer surface of the retina (Fig. 7.2). As has been mentioned, it contains many blood vessels that nourish and remove wastes from the photoreceptor layer in the sensory retina.

The choroid also contains a large amount of black pigment that absorbs light that has passed through the retina. Therefore, reflection of the light back through the retina is prevented. If the light were reflected, it would pass through the vitreous humor and strike other parts of the retina, causing foggy or blurry images.

**Age Changes** With advancing age, the blood vessels in the choroid become irregular, decreasing their ability to service the retina. Other age changes in the choroid include thickening, weakening, declining elasticity, and the formation of irregularities. These changes cause irregularities in the retina and therefore interfere with the focusing of light on the retina. These changes also allow the choroid to be more easily torn as a result of trauma.

**Sclera**

The outermost layer of the eye is the sclera, which is the white part (Fig. 7.2). It extends from the edge of the cornea at the front of the eye around to the optic nerve at the back.

The sclera consists of a tightly woven mat of collagen fibers. Its strength allows it to support eye structures and protect them from trauma. The sclera also serves as a firm attachment point for...
the external muscles of the eye, which allow a person to turn the eye in its socket.

**Age Changes** The structure and functioning of the sclera are virtually unaffected by aging, though it becomes somewhat yellow and develops translucent areas that appear as darkened spots. These color changes may have some cosmetic impact.

**External Muscles**

Six external muscles attach to each eye (Fig. 7.6). The arrangement of these muscles allows a person to turn the eye in any direction. Turning the eyes serves several purposes. First, it permits the eye to be pointed directly at a stationary object. Second, it allows the eye to keep a moving object centered in the field of view. Maximum visual acuity is achieved when the eye follows the object smoothly. Third, it permits the scanning of a wide field of view.

Rotating the eyes in their sockets also allows both eyes to be aimed at the same object simultaneously so that a person does not have double vision. This goal cannot be achieved by any other means. For example, since the eyes are positioned for distant viewing when at rest, they must be rotated inward toward the nose (converged) when a person wishes to view a close object. By contrast, they must be rotated outward (diverged) when the person wants to view a distant object again.

To observe divergence and convergence, have a volunteer hold a pencil away from his or her face at arm’s length. Then watch the volunteer’s eyes as he or she looks first at the pencil, then at a distant wall, and then back at the pencil.

Eye movements produced by the external eye muscles are controlled voluntarily at some times and occur under reflex control at others. For example, a person may voluntarily contract the muscles to move the eye to the right and left. By contrast, convergence and divergence, which are caused by contraction of the same muscles, usually occur reflexively.

**Age Changes** The ability of the external eye muscles to turn the eye smoothly declines with age. This may be due to age changes in the muscles or to alterations in the nerve pathways that control the muscles.

The decline in the smoothness of eye movements greatly decreases visual acuity both when

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**FIGURE 7.6** The eye in its orbit, with external eye muscles and fat tissue.
one is viewing moving objects and when one is viewing stationary objects while moving. Decline in vision becomes greater as the speed of movement increases. The reduction in visual acuity caused by this age change results in difficulties in activities such as participating in sports, driving a vehicle, and watching motion pictures.

Adipose Tissue

The space between the eye and the surrounding skull contains much fat tissue (adipose tissue). This tissue cushions the eye from trauma, supports the eye in position, and helps maintain its round shape. The skull bones forming the eye socket also protect and support the eye.

Age Changes The amount of adipose tissue around the eye decreases with aging. This allows the eye to sink deeper into its socket, causing a cosmetic change in the face and a decrease in the size of the field of view. The decrease in fat tissue also reduces the support the eye receives; therefore, the eye may become misshapen. Depending on the nature of the change in eye shape, the position and functioning of several structures, including the cornea, vitreous humor, retina, and choroid may be affected. Any alteration in these structures will adversely affect vision.

Eyelids

The upper and lower eyelids each consist of a fold of skin (Fig. 7.7). Part of the conjunctiva covers the inner surface of each eyelid. A row of hairs is present along the edge of each eyelid.

The front of the eye must be kept moist because it consists of living cells. If the cells on the surface of the eye were to die, as do those on the surface of the skin, light could not be properly focused. The eyelids keep the eye moist by secreting fluid from the conjunctiva, spreading the conjunctival and lacrimal fluids over the eye surface, and closing to prevent evaporation of moisture. The eyelids also protect the eye from traumatic injury and prevent exposure to dust, noxious chemicals, microbes, and excess light.

The functioning of the eyelids depends on their positioning and movement, both of which are determined mostly by the contraction of muscles. Closing the eyelids is accomplished by contracting a ring of facial muscle that surrounds the eye.

Opening the eyelids occurs through contraction of a muscle attached to the upper eyelid. Contraction of other facial muscles can also influence the position of and movement of the eyelids.

Contraction of muscles affecting the eyelids occurs under voluntary control at some times and under reflex control at others. For example, a person may blink any time he or she chooses, but blinking also occurs reflexively. Closing the eyes when falling asleep or sneezing is another example of reflex control of the eyelids.

Age Changes Age changes in the skin of the eyelids are the same as those that occur in other parts of the facial skin. The discomfort and possible injury resulting from the decrease in secretion by an aging conjunctiva were described earlier in this chapter. Finally, age changes in the muscles of the eyelids are the same as those that occur in other voluntary muscles.

Lacrimal Gland

The upper outer portion of the eye socket contains a lacrimal gland, which secretes lacrimal fluid. The eyelids spread this fluid over the front of the eye and the fluid moves gradually toward the corner of the eye near the nose. There it drains through an opening into lacrimal ducts and is eventually carried by ducts to the nasal cavity.

FIGURE 7.7 Eyelids and the lacrimal apparatus.
Besides moistening the eye, lacrimal fluid washes away irritating objects, chemicals, and microbes. It also prevents infections by killing certain bacteria through the action of a chemical called lysozyme.

Age Changes The production of lacrimal fluid decreases with aging. Many people produce enough regardless of age, but production becomes so low in some individuals that they develop dry and irritated eyes. The use of artificial tear solutions significantly reduces these problems, just as it does when secretion by the conjunctiva is inadequate.

TWO EYES

Though each eye can perform all the functions carried out by the other, there are two advantages to having two eyes. The first is that a person’s field of view is wider when viewing with both eyes at the same time. This feature provides more information about the environment and improves a person’s ability to respond to the surrounding conditions.

Depth Perception (Binocular Vision)

The second advantage of viewing with two eyes is that a person can perceive the distance between himself or herself and the objects being viewed. This is known as depth perception or binocular vision. It is very important in activities where a person needs to make contact or avoid making contact with objects in the environment, as occurs when people reach out to grasp something or drive a vehicle.

Depth perception is possible because the eyes are a few inches apart. Because of this separation, the images of objects at different distances from the eyes are seen in slightly different positions relative to each other. This difference can be demonstrated by holding one hand out at arm’s length and looking at a distant scene first with one eye and then with the other. It will be noted that the hand blocks out different parts of the scene when the scene is viewed with each eye. During impulse processing, when viewing occurs with both eyes open, the brain interprets the differences in the impulses from the eyes as depth or distance.

Age Changes Aging causes a decrease in depth perception. Some of this decline occurs because aging does not affect both eyes equally. As the quality of images formed in one eye becomes substantially different from the quality of those formed in the other, the brain has increasing difficulty comparing the impulses from the two sets of images. Any alteration in the ability to aim both eyes at the same object has the same effect. The brain may even completely block its interpretation of impulses from one eye and provide vision that is equivalent to seeing with only the other eye. Another reason for decreased depth perception is aging of the retinal and brain neurons that process the impulses originating in the cones and rods.

AGE CHANGES IN VISION

Light Intensity

As people age, brighter lighting must be present if they are to see as much as they did when they were younger. The main reason for this is that the eye allows less of the light striking the conjunctiva to reach the retina. Less light can pass through the eye partly because of the declining transparency of the conjunctiva, cornea, lens, and vitreous humor. The decreasing size of the pupil also blocks the passage of a substantial amount of light. With less light reaching the retina, fewer cones and rods are stimulated enough to send impulses in response, and the photoreceptors that do respond send fewer impulses.

Brighter lighting is also needed to compensate for age changes in the cones and rods. These changes reduce the sensitivity of the retina to light, causing an additional decrease in the number of impulses being produced for a given amount of light. Aging of the processing neurons of the retina may further reduce the number of impulses that leave the eye. Since fewer impulses go to the brain, it is less able to perceive clearly and accurately what is being viewed. Aging of neurons in the visual pathways and processing areas of the brain seems to add to the problem.

The deficit in retinal impulses is probably greatest in the macula region because that region contains cones. Recall that cones need bright light to be stimulated and that they and the processing neurons for the macula are more affected by aging than are the rods and their processing neurons. Therefore, aging causes a decline in the ability to distinguish colors. Since age-related decreases in transparency preferentially affect short wavelengths, the perception of violet, blue, and
green decrease the most. The need for brighter lighting causes vision problems in aging individuals whenever the field of view is lit dimly. This is especially apparent when they move from a brightly lit environment to a dimly lit one or when the lighting consists mostly of light with shorter wavelengths, such as violet and blue light.

Aging individuals also see less well when light intensity changes rapidly, because the pupil adjusts to such changes more slowly. Rapidly interspersed periods of dim light may produce alternating periods of inadequate lighting and excess lighting. Such conditions may be encountered during the day when one is driving through patchy shade (e.g., wooded areas) and at night when one is driving past bright lights (e.g., oncoming traffic, electric lights in roadside signs).

**Quality of Light**

Vision in old age is also affected by the quality of light. This phenomenon occurs because more of the light entering the eye is scattered. Age changes in the cornea, the vitreous humor, and especially the lens contribute significantly to light scattering. Since much of the scattered light strikes the retina in the wrong places, the retina produces scattered impulses, which cause glare. Depending on the degree of aging of the eye and the conditions present, the amount of glare may range from being barely a nuisance to obscuring objects completely.

As age increases, external conditions that intensify problems from glare include having brightly lit objects or bright lights against a dark background (e.g., driving at night); having bright light strike the eye at an angle (e.g., multiple bright lights); and viewing light with shorter wavelengths, such as blue light. Sunlight causes glare because it contains much short-wavelength light. Yellow light produces less glare. Aging also slows recovery of good vision after being exposed to glare.

**Visual Acuity**

Even when light is bright and glare is minimized, there is a decrease in visual acuity with aging. Almost all the decrease for close objects is due to stiffening of the lens, which causes a great reduction in the refractive power of the eye. Other age changes that contribute to declining refractive power include flattening of the cornea and lens and the diminishing ability of the ciliary body to move. Close visual acuity is decreased to a lesser degree by reductions in the sensitivity to contrast caused by changes in the neuron pathways. Since most of the decline in close visual acuity is caused by a decrease in refractive power, the use of eyeglasses that increase refractive power can restore much of the lost acuity.

Recall that the decline in near visual acuity caused by aging is usually not noticed until about age 40. Most of the deterioration of close visual acuity is completed by age 60 because by then the lens has become completely stiff. However, since the neuronal changes and flattening of the cornea and lens continue for many years, close visual acuity may continue to decline gradually after age 60. By contrast, in some individuals the continued thickening of the lens and the resulting increase in its refractive power may restore some close visual acuity that has been lost.

Visual acuity for distant vision also declines with aging. However, distant visual acuity does not begin to decline until about age 45, after which the decline is usually steady but slow. The deterioration of distant visual acuity is so slow that more than 50 percent of those who reach age 80 have fairly good distant vision as indicated by scores of 20/40 or better on a Snellen eye chart.

Most of the decline in distant visual acuity is caused by age changes that reduce the amount of light that passes through the eye. Since only a small proportion of the decline is caused by focusing problems, eyeglasses and contact lenses can compensate for only a limited amount of the loss. Thus, unlike near visual acuity, distant visual acuity declines steadily even if corrective lenses are used.

Declining close and distant visual acuity is noticed whether a person is observing stationary or moving objects. However, the decline for moving objects is much greater than that for stationary ones because viewing moving objects involves additional processes that also undergo age changes.

One of these processes is smooth movement of the eyes to keep the object being viewed centered in the field of vision. Recall that with aging, the movement of the eyes becomes less smooth, causing the image of a moving object to move irregularly on the retina. The brain has difficulty
interpreting the increasing complexity of the resulting retinal impulses.

Another relevant process is the rapid recovery of each neuron every time it is stimulated. This is needed because moving objects produce rapid changes in the light striking the photoreceptors. Since aging causes slowing of the neurons involved in vision, neuron recovery lags behind changes in the moving images. The result is a lengthening of afterimages.

An afterimage is a lingering perception that an image is present even though the image in the eye has changed or disappeared. For example, a light that is flickering rapidly may be perceived as emitting a steady light because the individual images blend into one continuous image. Another effect of long afterimages is the apparent blurring of an object as it moves faster. This effect is easily observed by watching a fan as it begins to spin.

As aging lengthens afterimages, blurring of moving objects increases and therefore visual acuity for moving objects decreases. Detecting small movements in nearly stationary objects also becomes more difficult. These results adversely affect a person's performance in walking and driving, recreational and occupational activities, and even spectator activities.

**Depth Perception (Binocular Vision)**

A person's eyes usually do not undergo age changes at the same rate. As the eyes become more different from each other, they send increasingly different impulses to the brain. These differences, together with the declining ability of the brain to interpret them, result in a decrease in binocular vision, as was discussed previously.

**Field of View**

The width of the field of view (i.e., peripheral vision) decreases gradually from 170 degrees to 140 degrees. Also, there is an age-related decline in the ability to notice a specific object in a field of view. This latter change is more evident in the periphery of the field of view and with increasing complexity of the items in the field of view.

**Optimizing Vision**

Though age changes that affect vision cannot be prevented, the limitations and disabilities they cause can be minimized by (1) providing adequate lighting, (2) reducing sources of glare, (3) enlarging items, (4) increasing contrast, (5) positioning objects at greater distances from the eyes, (6) slowing the motion of moving objects, and (7) using eyeglasses or contact lenses. These steps can help prevent accidents and injuries while preserving much of an aging person's activity, independence, and quality of life.

**DISEASES OF THE EYES**

In many people, one or more diseases compound the adverse effects of aging of the eyes. The incidence of such diseases increases with age, so that the risk for those over age 75 is 2.5 times greater than the risk for those between ages 50 and 65. Some of these diseases are little more than a nuisance, while others drastically reduce the quality of vision and in severe cases cause blindness.

**Minor Diseases**

**Lacrimal Fluid** The production of lacrimal fluid may decline so far that the eyes become dry, causing irritation. The application of wetting solutions can largely relieve this problem. Other individuals experience what seems to be an excessive production of lacrimal fluid because the fluid pours out of the eye, forming tears.

In most cases the cause of the tearing is not excess production of fluid but some factor that prevents the fluid from draining properly into the nasal cavity. One common cause of such tearing is excessive weakening of the circle of muscle surrounding the eyelids. When it is weak, the muscle allows lacrimal fluid to accumulate behind the eyelid until it overflows onto the face. Tearing may also be caused by infection or other factors that block the lacrimal ducts that lead from the eye to the nasal cavity.

**Eye Muscles** Weakening of the eye muscles may cause problems other than tearing. For example, inadequate contraction of the circular muscle surrounding the eyelids may cause drying of the eye if the eyelids are not closed completely during sleep. Also, weakening of the muscle that raises the upper eyelid causes drooping of the lid. Besides producing the appearance of drowsiness, a drooping lid may obstruct part of the field of view.

The circular eye muscle sometimes contracts
excessively, causing the lower eyelids to turn inward. The edge of the lid and its eyelashes then scrape on the eye, producing irritation. If this condition is severe and is not corrected, the scar tissue that forms can drastically reduce vision by blocking and scattering light.

Cataracts

Cataract formation is the most common serious eye disease among the older population. However, its impact in the United States has been lowered considerably by the high rate of success in treating this disease surgically. Cataract surgery is the most common surgical procedure in the U.S. There are one million surgeries per year, accounting for 12% of annual Medicare expenses.

Cataracts are the most common age-related eye disease and the main cause of blindness in “third world” locations.

Recall that aging causes the formation of opacities in the lenses. Free radicals and glycation are main contributing factors. At first opacities usually develop toward the periphery of the lens, where they scatter light and cause glare, but eventually they form toward the center of the lens. Central opacities cause glare and decrease visual acuity because they scatter and block light. An affected individual is said to have cataracts when central opacities reduce visual acuity substantially.

Main risk factors for cataract formation in descending order of importance are increasing age; exposure to UV-B light; and topical or internal corticosteroids. Other risk factors include being female; having diabetes mellitus; smoking; family history; low socioeconomic status; malnutrition or low levels of AOXs (e.g., vit A, vit C, vit E, carotenoids); dehydration; and eye trauma or internal eye inflammation. Diabetes mellitus is a disease involving hormone imbalances and abnormally high levels of a sugar called glucose in the blood. Opacities in the lenses of diabetics seem to be caused by the conversion of glucose to another sugar, sorbitol, which accumulates in the lenses. Estrogen supplements in postmenopausal women seem to reduce their risk of developing cataracts.

When cataracts are treated by surgical removal of the affected lens, the ability of the eye to refract light is restored by implanting an artificial lens or by wearing eyeglasses or contact lenses. However, not all individuals with cataracts can or should undergo eye surgery.

Age-Related Macular Degeneration

The second most common serious eye disease among the elderly is age-related macular degeneration (AMD), also called senile macular degeneration. It accounts for about 25 percent of visual loss among those under age 80 and about 40 percent among those over age 80. As the name indicates, this disease causes deterioration of the retina. Though the cause of AMD is not known, factors that increase the likelihood of its occurrence include being of advanced age, having high blood pressure, having family members with the disease, and having atherosclerosis.

The mechanism by which AMD causes retinal damage is not clear, but it seems to involve *FR damage and formation of lipid peroxides (LPs). It seems that age changes in the pigmented epithelium and Bruch’s membrane begin to occur in excess near the edge of the macula. These changes substantially reduce the passage of nutrients from the choroid to the sensory retina, leading to degeneration of the cones. There is no treatment for the disease at this stage.

If the disease progresses no further, there will be decreased visual acuity in the center of the field of view. However, in about 10 percent of cases blood leaks from choroid vessels and passes between the pigmented epithelium and the macular region of the sensory retina. Phagocytic cells from the choroid also invade the retina. These changes cause more severe degeneration, and about 90 percent of these advanced cases result in macular blindness.

The onset of AMD is indicated by gradual deterioration of vision in the central region of the field of view. Sudden rapid distortion of vision in this area is a warning sign that bleeding and rapid macular degeneration are occurring. Professional help should be sought at once. Treatment with lasers can slow or stop further vessel damage and bleeding in about 50 percent of advanced cases. If treatment is not obtained or is unsuccessful, macular blindness is likely.

Since AMD affects only the macula, peripheral vision is not appreciably altered. When central vision is affected, activities such as driving and reading become difficult or impossible.
**Glaucoma**

Glaucoma is the third leading serious eye disease among older people. It causes diminished vision because the high pressure that develops from accumulation of aqueous humor inside the eye damages the retina and optic nerve. The pressure inside the eye is called *intraocular pressure* (IOP). About 9 percent of people over age 65 have one of the three types of glaucoma.

**Open-Angle Glaucoma** About 80 percent of all patients with glaucoma have *open-angle glaucoma*. Its risk factors include being of increasing age, having relatives with glaucoma, being black, and being male.

The cause of and the mechanism producing high IOP are unknown. Pressure in both eyes is affected. When the pressure remains somewhat high for extended periods, it slowly damages the retina and optic nerve. The damage may be noticed by the affected individuals as a gradual shrinkage in the width of the field of view. Unfortunately, this narrowing may go undetected until permanent injury has occurred. If left unchecked, open-angle glaucoma leads to total blindness.

Fairly simple procedures that are normally part of a complete eye examination can detect the presence of open-angle glaucoma long before significant eye damage has occurred. These procedures include measurement of IOP and visual examination of the optic nerve using an ophthalmoscope. The combination of the two tests identifies about 80 percent of all affected people.

Though there is no cure for open-angle glaucoma, the IOP can be controlled and the effects of the disease can be prevented with appropriate medications.

**Angle-Closure Glaucoma** *Angle-closure glaucoma* or *narrow-angle glaucoma* gets its name from the accompanying abnormally narrow space between the lens and the cornea. It accounts for about 10 percent of all cases of glaucoma.

With angle-closure glaucoma, the IOP may rise quite high within a matter of minutes or hours. Affected individuals often experience eye pain, headache, nausea and vomiting, halos around lights, and blurred vision. If this is not treated within 2 to 3 days, permanent eye damage and blindness can result. Treatment usually involves surgery that reestablishes normal drainage of the aqueous humor.

**Secondary Glaucoma** The remaining 10 percent of glaucoma cases involve *secondary glaucoma*. This condition is characterized by elevated IOP resulting from another disorder such as diabetes, tumor, or disease of the vessels in the eye. Each type of secondary glaucoma is treated according to its specific cause.

**Diabetic Retinopathy**

*Diabetic retinopathy* (DR) means “disease of the retina associated with diabetes.” The form of diabetes involved is diabetes mellitus. While DR is not nearly as common as cataracts, AMD, or glaucoma, it is the third leading cause of blindness in the United States and the most prevalent cause of blindness among those with diabetes mellitus. The incidence of DR among diabetics increases with the length of time since the onset of diabetes. For example, only 7 percent of those who have had diabetes for less than 10 years have developed DR, while more than 62 percent of those who have had it for more than 15 years have developed DR.

Diabetic retinopathy seems to develop because some of the extra glucose in the blood is converted to sorbitol, which weakens retinal capillaries so much that they are overly dilated by normal blood pressure. Some weak spots in the capillaries bulge outward as aneurysms that leak and bleed. Injured vessels and hemorrhaged blood can be seen when the inside of the eye is examined with an ophthalmoscope. Fluids and blood from the leaking dilated capillaries injure the retina.

As more blood flows through the dilated capillaries, unaffected capillaries receive less blood flow and eventually shrink and close. The areas of the retina that were served by these shrunken capillaries are injured because they receive inadequate blood flow. Such ischemic areas can be seen with an ophthalmoscope. As the number of abnormally dilated and shrunken retinal vessels increases, more of the retina is adversely affected and vision deteriorates.

In more advanced cases of DR, retinal vessels near the optic nerve grow into the vitreous humor. Since these proliferating vessels are weak, they rupture easily, especially when the vitreous humor moves. Hemorrhaging near or into the vitreous humor often leads to blindness from secondary glaucoma or from detachment of the retina from the choroid.
Chapter 7 - Eyes and Ears

The best treatment for diabetic retinopathy is to maintain blood sugar levels within the normal range. Once vessels become dilated, the progressive destruction of the retina can be slowed by destroying the dilated vessels with laser surgery.

THE EARS

Much of what was stated about the eyes at the beginning of this chapter is also true of the ears. The ears help monitor conditions and provide information not only about the body, but also about conditions far from the body. Their functioning helps preserve homeostasis, contributes to learning, aids in communication, and provides enjoyment.

The ears accomplish all this by detecting four different types of stimuli. One type consists of vibrations within a certain range of frequencies, which are called sound vibrations. Hearing is the conscious perception of sound vibrations. The second type is the pull of gravity. A person's awareness of gravity is perceived as a sense of the position of the head and results in the person's knowing whether the head is right side up, upside down, or tilted. The third type of stimulus is change in the speed of motion of the head. For example, a person feels the speed of the head change when a vehicle in which he or she is riding speeds up or slows down. The fourth type of stimulus is rotation of the head. For example, a person in a vehicle senses when the vehicle makes a turn even if the speed remains the same.

Aging adversely affects the ability of the ears to detect all four types of stimuli. The perception of these stimuli is further hampered by age changes in the CNS that interfere with the processing of impulses sent by the ears. Beginning with the sense of hearing, we will examine how aging alters the monitoring of each type of stimulus and see the impact these alterations have on people.

HEARING

External Ear

Most sound vibrations that are heard travel in air or, occasionally, water before reaching the ear. The visible part of the ear, the pinna or auricle, collects the vibrations and directs them into the ear canal, which is about 2.5 cm (1 inch) long. These two components make up the external ear (Fig. 7.8).

Air in the ear canal carries vibrations to a thin flexible membrane covering the inner end of the ear canal. This membrane is called the eardrum or tympanic membrane because it resembles the membrane on a drum. The eardrum marks the beginning of the middle ear. Air vibrations cause the eardrum to vibrate.

The lining of the outer two-thirds of the ear canal contains modified apocrine sweat glands called ceruminous glands. These glands secrete a semisolid waxy material called earwax or cerumen. Hairs are also located in the outer part of the ear canal.

The sticky cerumen and the hairs trap small particulate matter and insects, preventing such items from reaching the eardrum and injuring it or interfering with its vibrations. Cerumen inhibits infections and also keeps the eardrum pliable so that it can vibrate easily. Cerumen slowly moves to the outer opening of the ear canal, where it is easily removed by wiping or washing.

Age Changes Aging of the external ear has some cosmetic impact. The pinna becomes thicker, longer, broader, and stiffer. Hairs on the pinna and within the ear canal become more visible because they thicken and lengthen. Aging of the skin on the pinna is similar to aging of other parts of the facial skin.

Each ceruminous gland produces cerumen at the same rate regardless of age. However, the overall rate of production decreases because the number of ceruminous glands slowly decreases. The cerumen may also become thicker in consistency. Therefore, it takes longer to move to the end of the ear canal and becomes even firmer. Age-related reductions in skin elasticity and adipose tissue cause the ear canal to sag. Therefore, cerumen tends to accumulate within the ear canal. The problem is increased when attempts to remove the cerumen with cotton swabs or other objects push it deeper into the canal.

A buildup of cerumen in the ear canal inhibits the passage of vibrations to the eardrum and thus diminishes a person's ability to hear. Removal of accumulated cerumen, which should be done by properly trained individuals, restores normal functioning of the ear canal. Except for increasing the likelihood of cerumen retention, aging of the external ear has no effect on hearing.
Middle Ear

Sound vibrations causing the eardrum to vibrate are passed to a small bone attached to the inner surface of the eardrum, the *hammer* (*malleus*). The vibrations then pass in turn through two other bones, the *anvil* (*incus*) and the *stirrup* (*stapes*). The stirrup passes the vibrations to another thin flexible membrane, the *oval window*, which marks the end of the middle ear and the beginning of the *inner ear*.

The bones of the middle ear provide a system of levers that amplify the sound vibrations passing through them. Amplification is adjusted by altering contraction of the small muscles attached to the eardrum and stirrup. These muscles are controlled reflexively.

The space surrounding the three bones of the middle ear is filled with air so that the bones can vibrate easily. To prevent bulging of the eardrum, the air pressure within the middle ear must be adjusted so that it always equals the air pressure in the ear canal. This is done by allowing air to pass between the middle ear and the nasal cavity through the *eustachian tube*.

Age Changes  As age increases, the eardrum becomes slightly stiffer and the joints between the hammer and anvil and the anvil and stirrup become calcified and deteriorated. However, these
age changes do not have a significant effect on hearing. Age changes in the muscles and the eustachian tube are also of no consequence in hearing.

**Inner Ear**

The vibrations of the oval window are passed to a liquid called *perilymph* in the inner ear (Fig. 7.9). The vibrations travel through the perilymph in the part of the inner ear that detects sound vibrations. This section is called the *cochlea* because it has a spiral shape like that of a cockle or snail shell. Vibrations in the perilymph pass through a flexible membrane (vestibular membrane) within the cochlea and enter another liquid called *endolymph*. The vibrating endolymph causes the vibration of another flexible membrane within the cochlea, the *basilar membrane*. This membrane protrudes inward from the wall of the spiraling cochlea much as a spiral staircase protrudes from the inner wall of a building.

Sound vibrations with the highest frequency or pitch cause vibration of the beginning region of the basilar membrane. This region is comparable to the bottom steps of a spiral staircase. Sound vibrations of lower frequency or pitch cause more distant regions of the basilar membrane to vibrate. The lower the frequency of the vibrations, the farther along (higher on the spiral staircase) the membrane vibrates.

The basilar membrane bristles with rows of neurons, called *hair cells*, which are sensitive to vibrations. The rows of neurons make up the *organ of Corti*. Vibration of the basilar membrane agitates the hair cells of this organ, causing them to initiate impulses.

All the components of the inner ear may also be set into motion by vibrations reaching them through the skull bones. Scratching one’s head, chewing on crunchy food, and clicking one’s teeth together are a few ways to produce skull bone vibrations. These vibrations also initiate impulses.

The impulses from the hair cells are passed to other neurons in the ear that carry them to the brain. Auditory centers in the brain process and interpret the impulses, and the result is hearing.

**Age Changes** Several changes are known to occur in the inner ear as people get older, but a variety of other factors are also involved in producing these changes. These factors include the amount of fat and cholesterol in the diet, genetic factors, noise, and atherosclerosis. Identifying which factors besides aging cause each of the following observed changes is not yet possible, but these changes will be referred to as age changes here because they seem to occur to some extent in all people.

As age increases, there is shrinkage of the mass of small blood vessels servicing the cochlea and producing endolymph. The resulting decline in nourishment may be partly responsible for changes in the organ of Corti. The reduction in endolymph production diminishes the passing of vibrations through the cochlea, resulting in a decreasing ability to hear all frequencies of sound.

There are decreases in the numbers of several types of cells, including the hair cells in the organ of Corti, the cells that support that organ, and the neurons that carry impulses to the brain. The organ of Corti becomes flattened and distorted, most often at the beginning of the basilar membrane. The net result is an exponential decline in the ability to hear; since most age changes occur at the beginning of the basilar membrane, hearing loss of high-frequency sounds is usually greatest.

**Localizing Sound**

While each ear can provide the same information about sound, the use of both ears at the same time allows a person to detect an additional feature: the direction of the source of the sound.

Since the ears are on opposite sides of the head, sounds originating closer to one side of a person reach the ear on that side with greater intensity and the brain receives more impulses from that ear. By comparing and interpreting the differences in impulses, the brain gives the person a sense of the direction from which the sound originated. This process is called *localization of sound*.

When the source of a sound is in line with the center of the body, each ear receives the sound with equal intensity. The brain often has difficulty localizing such sounds because the impulses from both ears are similar.

**Age Changes** Aging does not affect a person’s ears equally, and the ability to hear with one ear may decline much more than does the hearing ability of the other ear. The brain will receive fewer impulses from the cochlea of the more affected ear regardless of the source of the sound. Since the localization of sound depends on comparing the
FIGURE 7.9 Pathway of sound vibrations and structure of the cochlea.
differences in impulses from the ears, greater hearing loss from one ear causes errors that can lead to disorientation.

Central Nervous System

Age changes in the central nervous system cause further hearing impairment because the ability of the brain to process and interpret impulses from the cochlea is adversely affected. These effects are noticed as increased difficulty understanding sounds that contain echoes or background noise, sounds that change quickly, and speech that is broken up or has syllables or words missing.

DISORDERS IN HEARING

Presbycusis

Aging causes different degrees of hearing loss. Individuals who have lost a great deal of hearing because of aging are said to have presbycusis, which is the third leading chronic condition among those over age 65. Only arthritis and high blood pressure occur more frequently among the elderly.

The incidence of presbycusis increases exponentially with age. About 12 percent of those between ages 45 and 65 are affected. This increases to more than 24 percent for those age 65 to 74 and may reach 39 percent for those over age 75. The incidence among those in institutions is considerably higher, reaching 70 percent.

Both the percentage of cases and the seriousness of presbycusis are greater for men than for women. It is thought that greater hearing loss among men may be caused by noise associated with occupations traditionally held primarily by men. Presbycusis becomes progressively worse as the age of an affected person increases. This condition tends to run in families.

Presbycusis seems to result when the previously mentioned age changes in the cochlea and in neurons and brain areas involved in hearing occur to an unusually severe degree. Though some of these changes cause hearing loss of all sound frequencies, most cause hearing loss predominantly of higher-frequency sounds.

Effects Presbycusis reduces the ability of the ears to alert a person to desirable factors and harmful factors in his or her surroundings, hinders learning and communication, and reduces the enjoyment sound provides. Since presbycusis affects high-frequency sounds most, it substantially reduces the ability to hear the quality of music called brilliance. Presbycusis makes understanding speech difficult primarily because many consonant sounds in words are high-frequency sounds. High-pitched voices become especially difficult to understand.

The increasing difficulty in understanding speech has diverse effects on people with presbycusis. For example, these people may fail to respond or respond incorrectly when others speak to them. Other people may begin to believe that the person is becoming demented. Both the people with this condition and others may feel that they are being ignored. Individuals with presbycusis sometimes believe that others are trying to deceive them or talk about them in demeaning ways and often tend to withdraw from social contacts. Depression and paranoia are not uncommon outcomes.

Presbycusis may also alter speaking ability because affected individuals can no longer hear their own voices well. People with presbycusis may become annoying because they sometimes talk very loudly.

Prevention and Compensatory Techniques

While presbycusis is at least partially due to aging, it seems that chronic exposure to loud sounds increases both the likelihood of developing it and the severity of the problems it causes. Therefore, avoiding exposure to loud sounds, such as loud music and noise from tools and machinery, may help prevent presbycusis. When loud sounds are unavoidable, earplugs or other protective devices should be used.

Though there is no cure for presbycusis, people can be helped to compensate for it. Hearing can be increased by raising the volume of sound, such as by talking louder, or by using amplifying hearing aids.

The probability that a particular person with hearing loss will benefit from the use of a hearing aid depends on several factors. These include the type of presbycusis or other condition (e.g., eardrum injury, middle ear infection) that produced the hearing loss, the nature and severity of the hearing loss, and the ability of the person to use a hearing aid. The evaluation for hearing aid use is best done by a qualified audiologist.
Reducing background noise, echoes, and the speed of speaking can also improve the understanding of what is heard. Individuals with presbycusis can be trained to do lipreading and use other visual cues to increase their ability to understand those who are speaking. Speakers can help by getting the listener's attention; facing the listener; using more gestures and facial expressions; speaking slowly and clearly; repeating; keeping their mouths visible; and asking for feedback to confirm the listener's understanding.

**Tinnitus**

*Tinnitus* is the perception of sound when there is no sound external to the person. Sometimes the perceived sound originates from within the body; in other cases there is no sound whatever. Until 1990, tinnitus was among the ten most common chronic conditions among the elderly. It has now been displaced to a lower rank because of the higher reported frequencies of visual impairment and varicose veins.

Tinnitus can result from many causes including obstruction of the ear canal; abnormality of any of the parts of the middle ear, inner ear, or eustachian tube; infection in the ear or CNS; tumor in the ear or CNS; high blood pressure; atherosclerosis; diabetes mellitus; hormone imbalances; malnutrition; migraine headaches; medications; and toxic chemicals.

In many cases of tinnitus the sound being perceived is little more than a nuisance, although sometimes it becomes quite distracting. Tinnitus may alter or prevent normal sleep.

Eliminating tinnitus requires elimination of the cause. Individuals who cannot be cured can sometimes be helped by using low levels of other sounds as a distraction or cover for the tinnitus. Other treatments include dietary modifications (e.g., vitamin supplements, reduce caffeine), and surgery.

**DETECTING OTHER STIMULI**

**Gravity and Changes in Speed**

Recall that the second and third types of stimuli detected by the ear are gravity and changes in speed. Two chambers in the inner ear are specialized to detect these stimuli. The *saccule* is connected to the beginning of the cochlea (Fig. 7.10). The *utricle* is connected to the saccule. Both chambers are filled with endolymph.

One region of each chamber contains a patch of nerve cells protruding into the endolymph. Each patch is called a *macula*, the same name used for a patch of cones in the retina. Attached to the ends of the nerve cells is a gel containing heavy crystals called *otoliths*.

When gravity pulls on the otoliths, it causes them and the gel to shift. This causes a bending of the nerve cells to which the otoliths and gel are attached. Speeding up or slowing down of the head also causes a shifting of the otoliths and gel, resulting in bending of the neurons. Changes in speed produce this effect because the otoliths tend to keep moving at the same speed because of inertia.

The effects produced by gravity and inertia on the otoliths and nerve cells can be observed if a weight is attached to the end of a flexible rod such as a fishing pole. When the rod is pointed straight up, it will be fairly straight. If the rod is tilted or moved from side to side, gravity or inertia will cause it to bend.

Bending the nerve cells in the macula causes them to initiate impulses. Since the macula in the saccule is at a different angle from the macula in...
the utricle, some neurons will always be bent. Depending on the angle of the head or its direction of acceleration or deceleration, the shifting and bending occur in different directions, causing different impulses to be sent.

The impulses are passed to neurons that carry them to the brain, where they are processed and interpreted. The result is the perception of head position relative to gravity or the sensation of speeding up or slowing down. The person can then adjust his or her position or motion voluntarily to suit the situation.

Some ear impulses are sent to the cerebellum, causing reflexive contraction of muscles automatically to maintain posture and balance. Maintaining posture and balance allows a person to interact with the environment effectively and helps prevent falling.

**Rotation**

Head rotation is monitored by three curved tubes—the semicircular canals—which are connected to the utricle. These canals are filled with endolymph. One end of each canal is enlarged, forming an ampulla (Fig. 7.11). Each ampulla contains a patch of inwardly protruding neurons called the crista ampullaris (Fig. 7.11).

Each of the semicircular canals is positioned at right angles to the others. Therefore, rotation of the head in any direction in three-dimensional space will cause one or more of the semicircular canals to shift relative to the endolymph, causing an apparent swirling of the endolymph. The shifting and apparent swirling bend the neurons in the crista ampullaris. This effect on the neurons is like the bending of aquatic plants in a current or of tall trees or grass in a breeze.

Bending the neurons causes them to initiate impulses. These impulses are passed to other ear neurons that send them to the brain, where they are processed and interpreted. The result is the perception of turning or rotation. The person can then adjust his or her movements voluntarily. Some impulses are sent to the cerebellum to initiate reflexive muscle contractions that maintain balance.

**Age Changes (Gravity, Changes in Speed, and Rotation)**

With aging, there is a decrease in the number of sensory cells in the saccule, the utricle, and the three ampullae. The number of neurons that carry impulses from the ear to the brain also decreases. The cells supporting the sensory neurons show degeneration. Aging also results in a steady decrease in the size and number of otoliths.

The combined effects of all these changes cause a decreased sensitivity of the ear to gravity, changes in speed, and rotation of the head because fewer impulses are sent to the brain. Also, age changes reduce the ability of the brain to process and interpret the impulses and initiate voluntary and reflexive responses.

Properly responding to gravity and changes in speed is hampered further because the saccule loses more otoliths than does the utricle. The brain may be confused when the saccule sends an unusually low number of impulses relative to the utricle.
**Dizziness and Vertigo**

A severely diminished ability to detect and respond to gravity, changes in speed, and rotation of the head produces two types of sensations. One is *dizziness*, which is the sensation of instability. Affected individuals feel that they are unable to maintain their posture, body position, or balance. The other is *vertigo*, the feeling that either the body or the surrounding environment is spinning when no spinning is actually occurring.

Vertigo is usually experienced under one of four conditions: holding the head stationary, rotating the head, changing head position relative to gravity (e.g., sitting up from a recumbent position), and walking. Some relief can be obtained by avoiding conditions that initiate or amplify vertigo and by moving more slowly.

Both dizziness and vertigo caused by age changes in the ears are unpleasant. They can also be dangerous because they increase the risk of losing one’s balance and falling.

Several other factors increase the incidence and seriousness of injuries from falling as age increases. Aging reduces the information provided by the eyes, the skin receptors, and the proprioceptors in muscles and joints. This information normally helps the ears in maintaining posture and balance. Voluntary and reflexive movements used to stop or slow a fall are reduced because of age changes in the nervous system, the muscles, and the skeletal system. Many disorders and a variety of medications further hamper the functioning of all these organs and systems. Because so many factors are involved in promoting loss of balance and falling, diagnosis of the causes of individual cases of falling is complicated and requires a broad perspective on the body.

Another factor that makes falls more serious for the elderly is thinning of the subcutaneous fat, leading to less cushioning of the body. Furthermore, age-related weakening of the skin, bones, blood vessels, and other structures make them more susceptible to injury from a fall. Aging also lengthens the time needed for recovery from an injury.

The risks from loss of balance and falls can be reduced by providing handrails, better lighting, stable floor surfaces, and uncluttered walking areas.