23B—The Sensory Organs

It is commonly thought that humans have five senses: sight, smell, taste, touch, and hearing. If those were all, a person would have great difficulty. For example, a person not only sees his hand as he moves it in front of his face, but he also "senses" its movement. By extremely complicated mechanisms, one sees thousands of shades of color clearly. Skin not only relays the information to the brain that something has been touched, but it also senses the texture and temperature of the object.

The "sense of balance" seems to be two separate senses functioning together. A person is able to sense not only when *he* moves his body but also when some external force moves it. Further, he can sense the relative positions of parts of his body even when they are not moving. Scientists surmise that humans are somehow able to sense humidity, atmospheric pressure, and even the presence of static electricity.

All known sensory organs contain **sensory receptors**, specialized dendrites of sensory neurons. Receptors are stimulated by various external and internal conditions and inform the body of changes. Usually a receptor is sensitive to only one type of stimulus. The neurons of the eye, for example, are sensitive to light but not to sounds or odors.

The sensory organs also contain structures and tissues that support and assist the receptors. For example, the back of the eyeball contains light receptors. Other structures of the eyeball direct and focus the light entering the eye while they support and protect the receptors.

23.3 Minor Senses

23.3

Objectives
- Identify and describe the minor senses
- List the cutaneous receptors
- Explain how taste and smell are detected

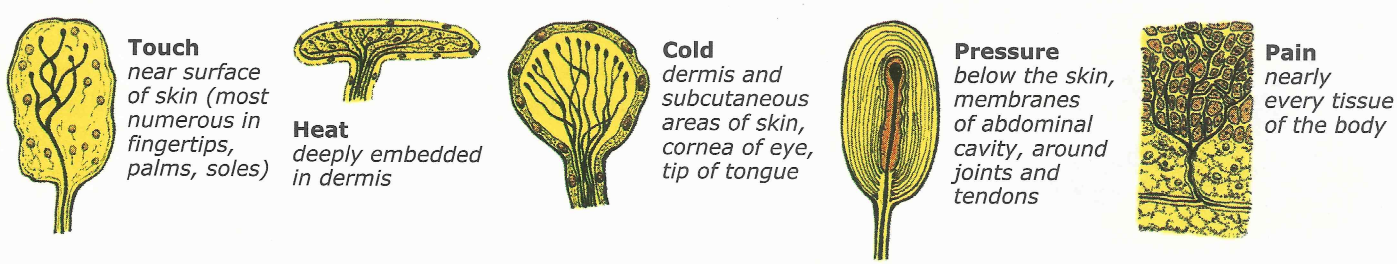
Key Terms
sensory receptor
accommodation

Those senses that most people do not greatly depend on are the *minor senses*. They include the senses of the skin (such as temperature, touch, and pain) and the senses of smell and taste.

Often people who do not have use of one of their major senses (sight or hearing) are said to develop special abilities in their other senses. A person deprived of one sense may become more aware of the changes noted by his other senses, but there is little evidence to suggest that a person who is blind, for example, can smell or hear significantly better than other people.

Senses of the Skin

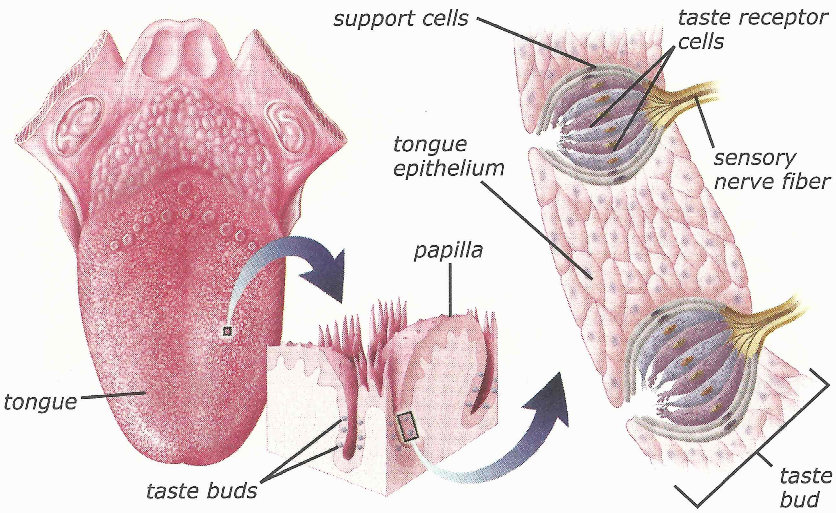
Cutaneous receptors sense cold, heat, pain, pressure, and touch in the skin. (Other regions of the body also have pain receptors.) Each sensation has different receptors, and certain receptors are more numerous in certain areas. For example, touch receptors are densely arranged in the tip of the tongue but are relatively few in number on the back of the neck. Other neurons transport impulses from the receptors to the brain. A stimulated heat receptor in a person's



23-9
The five types of cutaneous receptors and their locations

Referred Pain

The term *referred pain* is used when pain seems to be in one area of the body but actually originates in a different part of the body. A diseased liver or gallbladder often causes pain in the right shoulder region. A decreased blood supply to the heart may cause pain along the left shoulder and arm. One cause of referred pain is that the neurons that supply the damaged organ originate from the same area of the spinal cord as the neurons supplying the skin area that seems to be in pain. The brain does not distinguish the pain originating from the internal organ from pain impulses coming from the skin area. Automatically it assigns the pain to the skin, which usually senses pain, rather than to the organ, which may have never before sent pain sensations to the brain up those nerves.



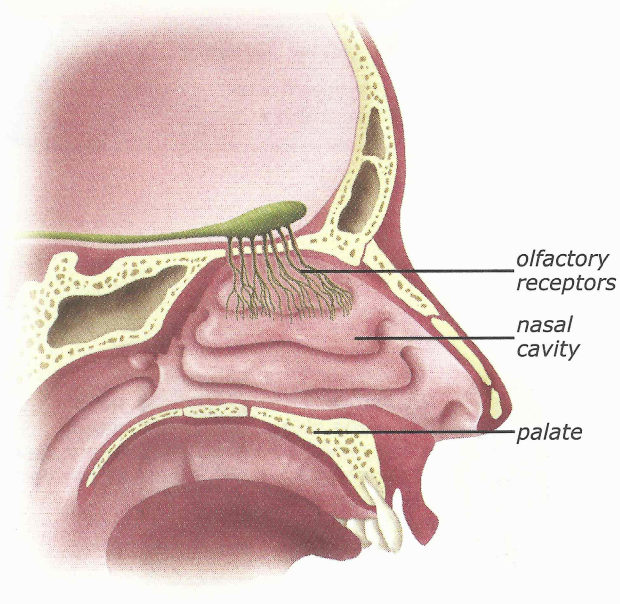
23-10
Location of taste buds

finger sends impulses up a set of neurons and stimulates a particular area of the brain. The brain then determines that what is felt in the finger is heat.

Taste and Smell

There are about 10 000 *taste buds*—the receptors for taste—on the average adult's tongue. Children, however, have considerably more. Most taste buds are on the *papillae* of the tongue, but some may be found on the inner surface of the cheek, roof of the mouth, tonsils, and epiglottis. All portions of the tongue respond to the five basic taste sensations—sweet, sour, bitter, salty, and umami. However, different areas of the tongue respond more to certain tastes.

The cells that form the taste buds are not neurons, but they are attached to nerve endings. The taste cells have chemoreceptors that stimulate a nerve impulse when they bind to a particular molecule. These cells live only about five to ten days and are replaced continually. The rate of replacement slows with age; therefore, many older people cannot taste substances as well as children. This fact may explain a child's objection to certain foods that he may enjoy as an adult. Exceptionally hot or spicy foods can damage taste buds. Consequently, some older people require more seasonings in order to enjoy foods.



23-11
Location of olfactory receptors

The *olfactory sense* (sense of smell) is one of the least understood senses. The *olfactory receptors* consist of numerous cells in the mucous membranes that line the upper region of the nasal cavities. Olfactory receptors are neurons; therefore, if they are injured (as during infection or trauma), they do not regenerate. Even under normal conditions, these neurons decrease in number with age. As with taste, the older a person becomes, the less sensitive his sense of smell becomes.

Humans apparently can distinguish several thousand different odors. However, these odors can be detected only if the molecules stimulate the olfactory receptors. Since the olfactory receptor areas are poorly ventilated, the ability to detect odors is greatly increased by sniffing. The sense of smell is less acute when someone has a cold because the olfactory receptors are blocked by mucus, preventing odors from reaching them. A person's sense of taste is also affected because much of taste is actually smell.

Receptors for smell reach a point of **accommodation** quite rapidly. Accommodation means that after a short period of stimulation, the receptors become insensitive to that specific stimulus, and a person does not "smell" it any more. Accommodation also occurs with most other nerve sensations (except pain), although usually not as quickly as with smell. For example, it is common to become accustomed to the feel of what you are wearing or the background noise you are hearing (such as a fan or air conditioner) so that you no longer notice them.

Review Questions 23.3

1. List the five cutaneous receptors.
2. Why is the sense of taste more acute in children than in adults?
3. What is accommodation to a sensation?
4. Occasionally when a body part is amputated, the person can still feel sensations that seem to come from the missing limb. This is called phantom limb pain. What could explain these sensations?

23.4 The Ear: Hearing and Balance

When discussing hearing, many people think first about the skin-covered flap of cartilage on either side of the head. However, this plays a rather small role in the sense of hearing. Embedded within the temporal bone is a small chamber, and beyond that is a tiny bony structure shaped like a snail's shell. These areas inside the bones of the skull are a small fraction of the size of the outer flaps, but they are actually responsible for the sense of hearing and most of the sense of balance.

Within the inner structures of a person's ear are thousands of nerve endings that are indirectly stimulated by sound waves (vibrations). These nerve endings transform an almost limitless variety of sound waves into nerve impulses, which travel along neurons to the brain where they are "heard."

The Ear

The *outer ear* consists of the *auricle*, an outer flap of tissue designed to collect sound waves, and the **external auditory canal**, a tube which goes into the head and ends at the **tympanic membrane** (eardrum). The skin lining the canal contains *ceruminous glands* (wax glands). The skin continually sheds dead surface cells, which combine with earwax and gradually move out of the ear. It is unnecessary and even dangerous to the delicate tissues of the ear to use any object other than a washcloth to clean the outer ear. (A physician should be consulted if the ear becomes clogged with wax.)

23.4

Objectives

- Identify the structures of the ear and describe their functions
- Trace the path of a sound wave from the external ear to the formation of a nerve impulse
- Identify the structures involved in the sense of balance and explain their functions

Key Terms

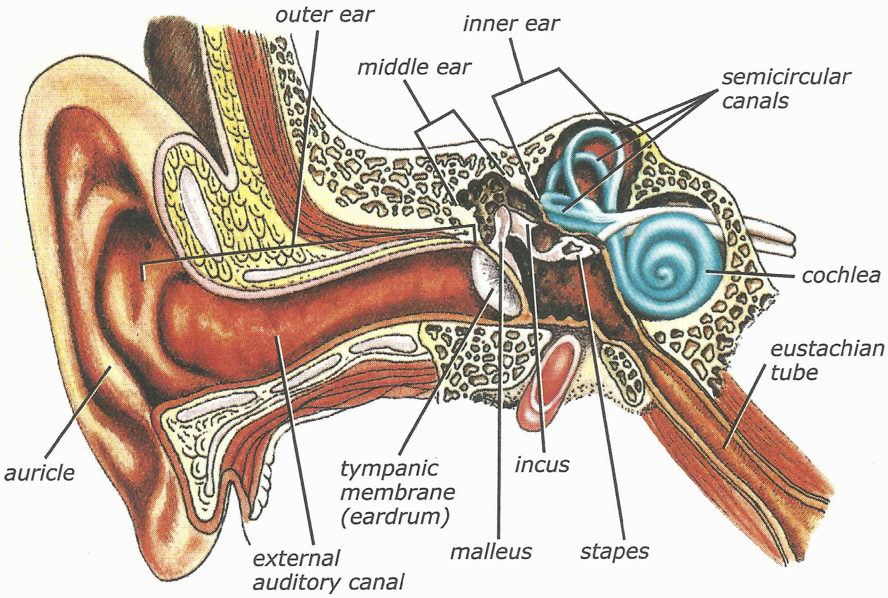
external auditory canal
tympanic membrane
ossicle
oval window
cochlea
static equilibrium
dynamic equilibrium
semicircular canal

Popping Your Ears

Have you ever felt your ears "popping" when driving up a mountain? What causes this sensation? The middle ear connects with the pharynx by the *eustachian tube.* This tube makes it possible for the air pressure within the middle-ear chamber to remain the same as the atmospheric pressure.

When driving high in the mountains, a person experiences a decrease in atmospheric pressure, but the pressure in the middle-ear chamber remains the same. The higher pressure in the ear causes the eardrum to bulge outward. When a person blows, yawns, or swallows, the eustachian tube opens and allows the air pressure in the middle-ear chamber to equalize with the atmospheric pressure. As the eardrum snaps back to a flat position, a "popping" sensation may be felt and/or heard in the ears.

auricle: (L. *auricula*—little ear)
auditory: (L. *audire*—to hear)



23-12
Human ear anatomy

The *middle ear* is a moist, air-filled chamber containing three tiny bones, or **ossicles** (AHS ih kulz): the *malleus* (MAL ee us, hammer), *incus* (ING kus, anvil), and *stapes* (STAY peez, stirrup). The joints between the bones are movable and form a lever system that picks up vibrations of sound waves that strike the tympanic membrane. The vibrations are transferred to the **oval window**, a membrane-covered opening of the inner ear.

Two small muscles attach to the ossicles and modify their movements. When exposed to sudden loud noises, they respond by limiting the vibrations, protecting the delicate membranes of the inner ear. In contrast, they also respond to soft sounds by amplifying the movement of the ossicles, enabling better hearing.

The *inner ear* consists of a *bony labyrinth* enclosing a *membranous labyrinth*. The bony labyrinth consists of channels and cavities within the temporal bone. The inner membranous labyrinth closely duplicates the shape of the bony channels. It is a tube-within-a-tube arrangement. The spaces between the bony and membranous labyrinths are filled with two slightly different fluids necessary for the sensations of hearing and equilibrium.

ossicle: (L. *ossiculum*—small bone)
cochlea: (L. *cochlea*—snail shell)
static: (standing)
dynamic: (power)

Hearing

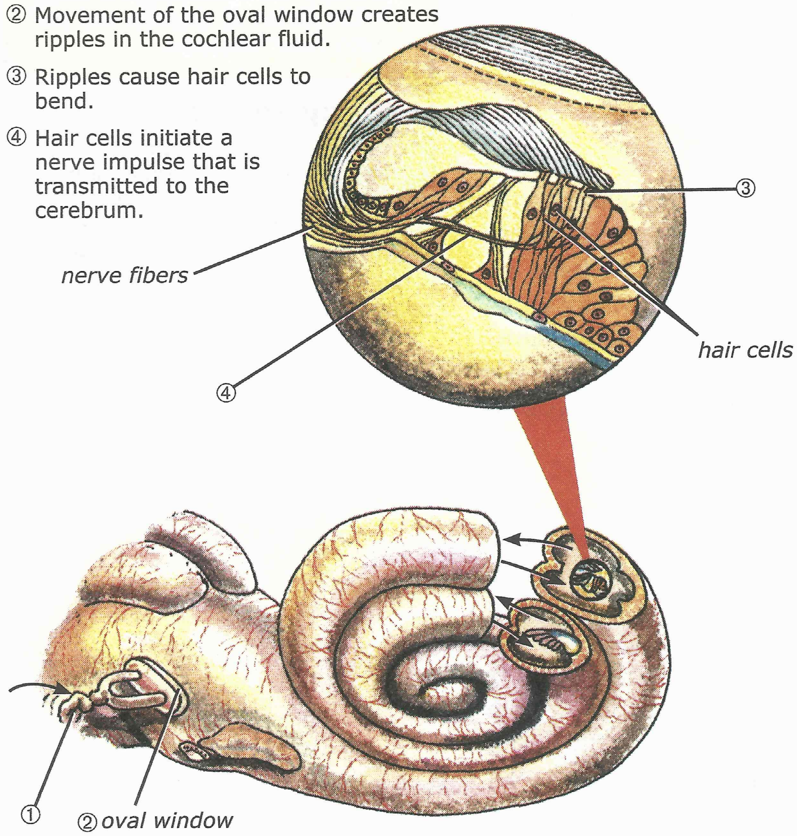
The **cochlea** (KOH klee uh), a snail-shaped division of the inner-ear labyrinths, receives sound waves. Along the full length of the cochlea's inner surface runs the actual sound receptor, the *organ of Corti* (KOHR tee), which contains thousands of receptor cells called hair cells.

The sound waves in the atmosphere hit the eardrum, moving the ossicles in the middle ear. The vibrations of the stapes move the oval window in and out. This motion sets up "ripples" in the cochlear fluids, which cause some of the cilia-like projections of the hair cells to bend. The bending of the hair cells produces a nerve impulse that is transferred to the nerve cells. These impulses are carried to the temporal lobe of the cerebrum, where they are perceived as different sounds.

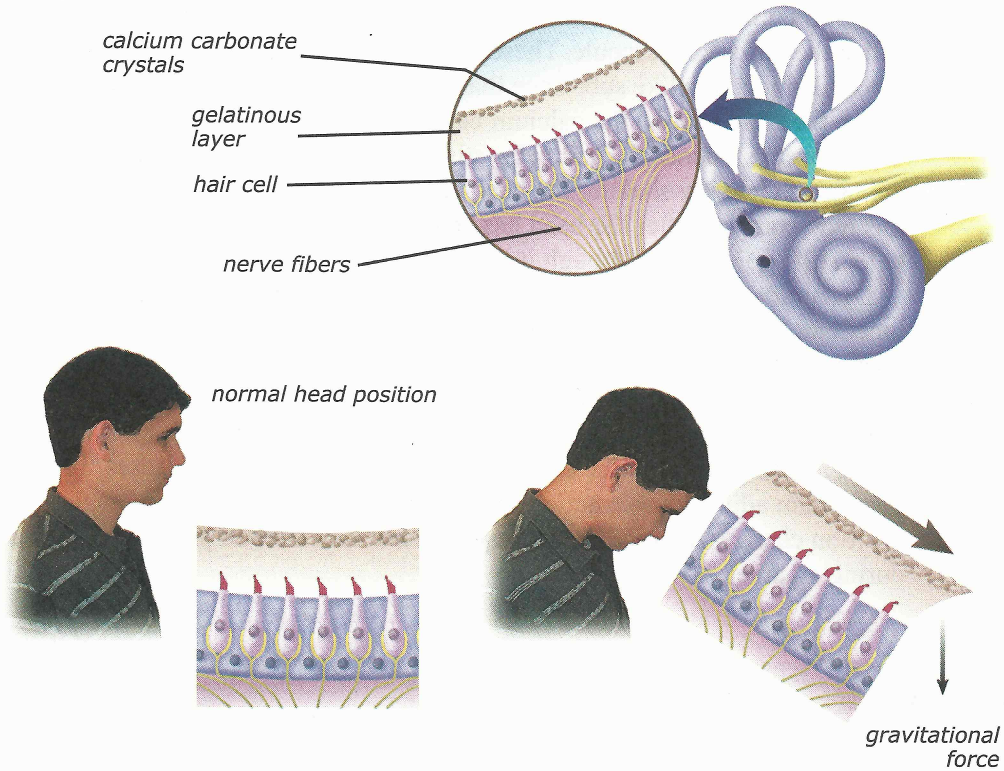
The Sense of Balance

The body maintains balance by two different senses: the sense of static equilibrium and the sense of dynamic equilibrium. **Static equilibrium** refers to the sense of body position when a person is not moving. **Dynamic equilibrium** is the ability of the body to respond automatically to positional changes when it is moving.

① Stapes responds to sound waves.
② Movement of the oval window creates ripples in the cochlear fluid.
③ Ripples cause hair cells to bend.
④ Hair cells initiate a nerve impulse that is transmitted to the cerebrum.



23-13
The cochlea and the organ of Corti (inset)



23-14
When the head is depressed, gravity causes the calcium carbonate crystals to shift, stimulating the hair cells. Nerve impulses are sent to the brain, which interprets the new head position.

Two Kinds of Deafness

Most people define deafness as the inability to hear or the loss of the sense of hearing. Deafness can be a partial or complete hearing loss. Other symptoms include the inability to understand speech when there is background noise or difficulty hearing soft speech such as whispers. Loss of balance, dizziness, and ringing in the ears are other symptoms of hearing loss. There are two major types of deafness, distinguished by the anatomical structures that are affected.

- *Conductive deafness.* Anything that blocks the transmission of sound vibrations to the inner ear is called *conductive deafness.* This is the most common type of deafness (95%). Common causes include blockage of the auditory canal, stiffness or fusion of joints between ossicles, stiffness or tearing of the tympanic membrane, and middle-ear infections. Otosclerosis is the deposition of excess bone around the base of the stapes that decreases or totally prevents the transmission of sound vibrations. Some types of conductive deafness can be treated by surgery or by a hearing aid. A hearing aid is a small microphone that amplifies the sound. Some hearing aids have filters that reduce the amount of background noise.
- *Nerve deafness.* The other type of hearing loss is *nerve deafness*, or *sensorineural* hearing loss. This type of loss occurs when the cochlea, the auditory nerve, or the brain does not function properly. Although one in one thousand children is born with nerve deafness, this kind of deafness can also be caused by prolonged exposure to loud noise, such as construction noise, loud music, and gunfire at close range. Some drugs, such as the antibiotic vancomycin, can cause nerve deafness.

Cochlear implant

Nerve deafness cannot be treated with the same type of surgery done for conductive loss or by the use of traditional hearing aids. However, in some people a special type of hearing aid called a cochlear implant can help. A cochlear implant is a surgically implanted device that converts sound waves into electrical signals that stimulate the neurons. It will not restore hearing but will enable the person to detect medium to loud sounds and speech rhythms. Therefore, cochlear implants are most successful in people who had normal hearing at one time. Nevertheless, some children who were born deaf have been able to learn to detect and to recognize certain sounds and have progressed quite well using these devices.

Static equilibrium is controlled by two small chambers in the inner ear called the utricle and saccule. These chambers are lined with sensory hair cells embedded in a jellylike substance that contains crystals of calcium carbonate. When the head moves, the calcium carbonate crystals slide, pulling the jelly. This movement bends the hair cells, stimulating nerve impulses that are sent to the brain. Violently shaking the head can set the jelly and crystals in motion; this may continue after the head has stopped moving, and the head may seem to be still "going" even though it is not moving.

Dynamic equilibrium is controlled by the three **semicircular canals** in the inner ear, which are also lined with hair cells embedded in a gelatinous layer. During walking, running, and other dynamic activities, the fluid in the semicircular canals flows over the gelatinous material, bending the hair cells. The movement of the hairs stimulates nerve impulses that travel along a branch of the auditory nerve to the temporal lobe and cerebellum. Impulses from the cerebellum adjust muscle actions, producing coordinated movements for each position change. Imagine all the impulses that a basketball player experiences during a game!

Review Questions 23.4

1. What are the three main divisions of the ear? What structures are in each division? What structures separate each division from the next?
2. What is the primary function of the eustachian tube?
3. Describe the process of hearing in the inner ear.
4. List and describe the two main types of equilibrium. What are the primary organs for sensing each type?

23.5

Objectives

- Identify the anatomical structures of the eye
- Summarize the functions of the structures involved in vision
- Explain the difference between rods and cones

Key Terms

sclera
cornea
choroid
iris
pupil
retina
lens
rod
cone

23.5 The Eye and Sight

The eyes are a pair of spheres a bit smaller than table tennis balls. They supply a continuous series of nerve impulses for about sixteen hours per day and then operate repair and maintenance systems while the body is sleeping. Normal eyes can focus on a hair as near as a few inches and on large objects as distant as several miles.

The brain controls muscles that move and focus the eyes so that they work harmoniously to provide a stereoscopic image that permits depth perception. While only silhouettes can be seen in near darkness, a person can distinguish minute variations in color in bright light. Scientists have not been able to explain completely how the eyes operate. The beauty and wonder of the eye is that it is perfectly designed by God to permit sight.

The Eye

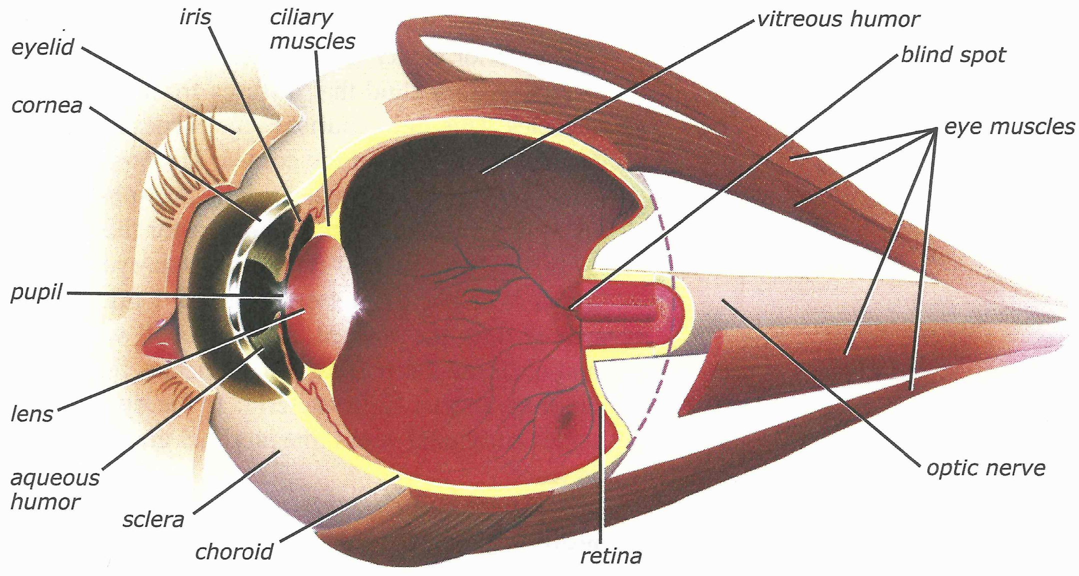
The eyeball has three tissue layers. The outer layer, known as the **sclera**, is the "white of the eye." This white fibrous tissue maintains the shape of the eyeball. The transparent, anterior portion of the sclera, the **cornea** (KOHR nee uh), allows light to enter the eyeball. The cornea lacks blood vessels but receives nourishment from the fluid underneath it in the eyeball.

The middle layer, the **choroid** (KOHR OYD), is fragile and thin with many blood vessels for nourishing the innermost part of the eye. The anterior portion of the choroid, the **iris** (EYE ris), contains muscles and is the colored part of the eye. The circular opening in the iris is the **pupil**, which lets light into the

sclera: (hard)
iris: (Gk. *iris*—rainbow)

eyeball. Muscles in the iris change the diameter of the pupil, regulating the amount of light entering the eye. In bright light the pupil is almost closed, protecting the eye from too much light. In dim light, however, it dilates (opens), permitting all the available light to enter.

The third and innermost layer of the eyeball is the **retina**, composed of thousands of specialized neurons and their fibers. The neurons of the innermost layer are *photoreceptors* that can be stimulated by light. The impulses from the photoreceptors are transmitted to the occipital lobe of the brain by way of the *optic nerve*.



23-15
Human eye anatomy

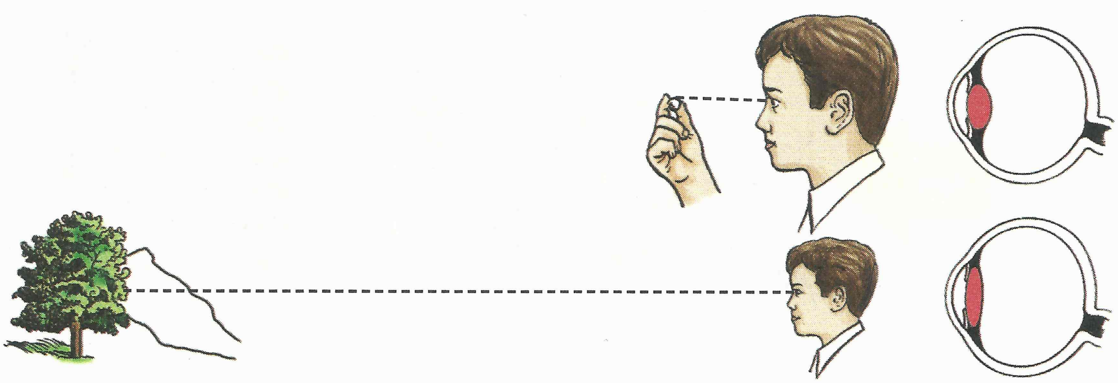
There are no photoreceptors where the optic nerve fibers leave the eye to form the optic nerve. This area is the *blind spot*. In people with normal eyes, the blind spot of each eye affects a different area of vision; therefore, the total field of vision is unbroken.

The **lens** of the eye is a biconvex, semisolid substance supported by the *ciliary* (SIL ee EHR ee) *muscles* and *suspensory ligaments*. The ciliary muscles and suspensory ligaments can change the shape of the lens. When looking at a close object, the muscles contract, making the lens thicker (more convex) and focusing the image on the retina. When looking at a distant object, the muscles relax and the lens flattens to focus the image.

The ability to focus on objects at different distances from the eye is *visual accommodation*. The lens is elastic in children but becomes more rigid with age. Therefore, about age forty some people begin having difficulty focusing on things closer to them; they hold reading material farther from their eyes. Lenses in glasses can compensate for the hardened natural lenses.

photoreceptor: photo- (light) + -receptor (L. *receptare*—to receive)

ciliary: cili- (eyelid) + -ary (related to)



23-16
The thickness of the lens changes, permitting the eye to focus on objects at different distances.

There are two cavities in the eyeball: one in front of the lens and one behind. The anterior cavity is filled with the *aqueous* (AY kwee us) *humor*, a transparent, watery fluid that diffuses from blood vessels located near the ciliary muscles. This fluid nourishes the cornea and diffuses into the blood by way of canals on the edge of the cornea. The larger, posterior chamber of the eyeball contains a clear, permanent, jellylike substance called the *vitreous* (VIT ree us) *humor*, which provides support for the eye.

In the upper lateral region of each eyelid is the *lacrimal* (LAK ruh mul) *gland* (tear gland). It secretes about 1 mL of fluid each day, which is spread evenly over the surface of the eyeball with each blink. The fluid moistens and cleanses the cornea and lubricates the eyelid. It also contains *lysozyme*, an enzyme that kills bacteria. If the eyeball is irritated or if the person is under emotional stress, the lacrimal gland secretes more fluid, often resulting in tears.

Several sets of muscles control the movement of the eyeballs so that both eyeballs are directed toward the same object. In some individuals, muscles that are not equal in length or strength or that are paralyzed cause the eyes to cross.

23-1 Photoreceptors

Rods	Cones
night vision	color vision
produce general outlines of objects	produce sharp images
scattered over retina	concentrated at fovea
about 125 million per eye	about 7 million per eye

aqueous humor: aqueous (L. *aqua*—water) + humor (fluid)

vitreous: (L. *vitrum*—glass)

lacrimal: (L. *lacrima*—tear)

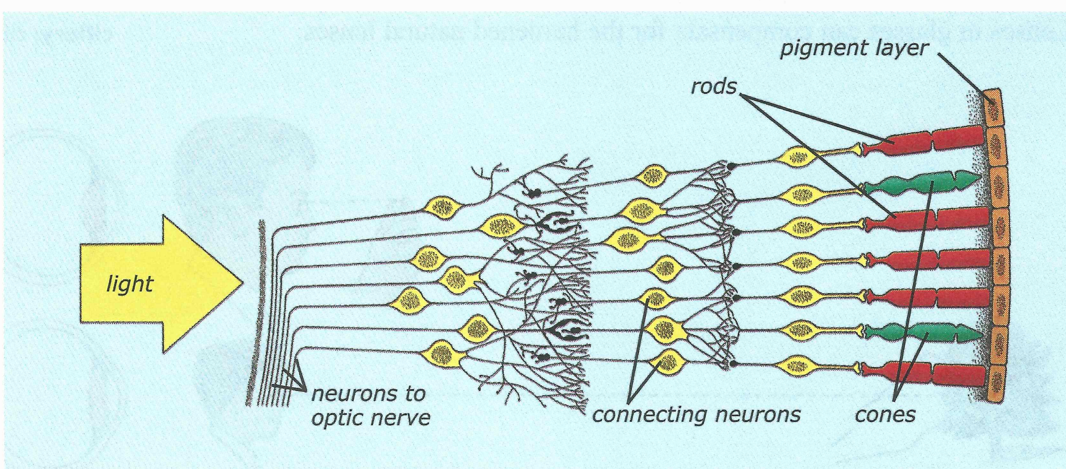
fovea: (L. *fovea*—pit)

Vision

There are more than 130 million photoreceptors in each eye, most of which are shaped like rods. **Rods**—responsible for night vision—are scattered over the retina. They are sensitive to low intensity light and produce a shadowed or silhouette image. Rods cannot determine color but can rapidly discern movements.

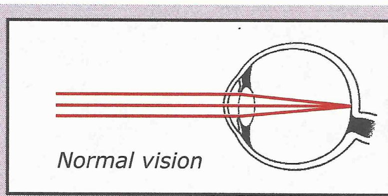
Cone-shaped photoreceptors detect colors. The **cones** are especially concentrated at the *fovea* (FOH vee uh), a small depression in the central region of the retina. Therefore, a person sees the sharpest color image of an object when he is looking directly at it in a well-lit environment; in dim light the image would not be clear because there are no rods at the fovea.

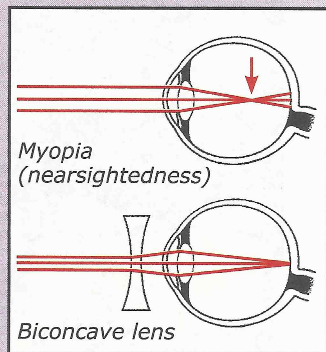
Both rods and cones contain light-sensitive pigments, and when the rods and cones are stimulated by light, the pigments decompose. These substances initiate a complex biochemical pathway that changes light energy into a nerve impulse that is carried to the brain by the optic nerve. The brain then interprets the sensory input as images and colors.

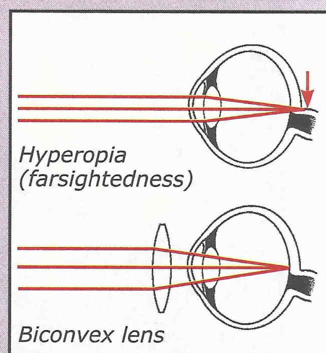


23-17
Cross section of the retina

Eye Disorders







- ✦ *Myopia* (mye OH pee uh), or *nearsightedness*: a condition in which light rays from close objects can be focused on the retina, but those from distant objects are focused in front of the retina and therefore are not seen clearly. The problem is usually caused by an abnormally long eyeball, which is an inherited trait. Eyeglasses with biconcave lenses may compensate for myopia.
- ✦ *Hyperopia* (HYE puh ROH pee uh), or *farsightedness*: a condition in which light rays from far objects can be focused on the retina but those from near objects focus behind the retina. Hyperopia may be caused by an inherited short eyeball or by hardening lenses. Eyeglasses with biconvex lenses may help a farsighted person to see close objects. Occasionally bifocal glasses, which have lenses for farsightedness in the lower portion and other lenses in the upper portion, are necessary.
- ✦ *Astigmatism* (uh STIG muh TIZ um): condition in which either the cornea or lens or both are uneven or unequally curved and the light rays from an object are not focused properly on the retina. This results in an area of the person's vision being out of focus. Sometimes the other eye will compensate for mild astigmatisms.
- ✦ *Cataracts*: clouded lenses that may be caused by old age, overexposure to bright sunlight, or diseases such as diabetes. Treatment may involve surgically removing the lens and implanting an artificial one. Sometimes special eyeglasses are used to compensate for the loss of the lens. Clouded corneas can also be removed and replaced with transplants.
- ✦ *Glaucoma*: the buildup of aqueous humor resulting in abnormal pressure within the eye. This causes a decrease of circulation to the retina and may damage the retina and cause blindness.
- ✦ *Night blindness*: lack of a certain pigment in the rods of the eye. Using cones, the person can see clearly in bright light, but in dim light he cannot see well. Vitamin A is needed to form this pigment; therefore, a diet with insufficient vitamin A can cause this condition.

astigmatism: a- (without) + -stigmat- (Gk. *stigma*—spot) + -ism (E. *-ism*—indicating a condition)

Review Questions 23.5

1. List and describe the functions of the three main layers of the eye.
2. How is the amount of light that enters the eye regulated?
3. How does the eye focus?
4. Where are the lacrimal glands? What do they produce, and what are the functions of this substance?
5. Name and describe the two types of photoreceptors in the eye.
6. Describe myopia and hyperopia.
7. Differentiate between cataracts and astigmatisms.