# The Special Senses

R ollercoasters and tilt-a-whirls are notorious for inducing nausea, but some people get similar problems from the little swerves and dips of a journey by car, boat, or plane. These folks break into a cold sweat and get a headache. They get nauseous and feel listless or uneasy.

The syndrome goes by many names: carsickness, seasickness, airsickness, or, more generically, motion sickness. Many people suffer from it it, at least under some conditions, even 70 percent of first-time astronauts.

The problem seems to arise from a war between the senses. In the back seat of a car, most of what you see is stationary in relation to you, so your eyes tell your brain that you are not moving. But other senses say you are. The seat presses against your skin on each bump, your joints flex, and your inner ear registers changes in direction. As your brain struggles with what to believe, the conflicting messages cause inner turmoil, the release of stress hormones, and misery.

The commonsense prescription for motion sickness is to try to reduce this sensory war. Move to the front seat of a car or the deck of a boat, and stare at the horizon. Show your brain that you are indeed moving. Generally, it's easier to prevent symptoms than to control them.

The special senses evolved to protect organisms from danger so they can reach reproductive age, and anything that affects reproduction can have species-wide effects. As motion sickness shows, the special senses can be fooled into having us believe we are in danger, and can even render us totally incapacitated until we remove ourselves from the situation, Obviously, these senses can affect us whether we want them to or not.

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## CHAPTER OUTLINE

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Vision is our most acute special sense p. 000



 The special senses are our connection to the outside world p. 000



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# The Special Senses Tell us About Our **Environment**

## LEARNING OBJECTIVES

Describe the special senses.

Discuss the physiology of balance and hearing.

Relate the structure of the eye to its function. **Explain** the physiology of the chemical senses of taste and smell.

he intricate functioning of the central nervous system is best appreciated when discussing our special senses. These extremely sensitive receptors supply us with detailed information about the world around us, including the sights, sounds, smells and tastes present in our surroundings. The wealth of information they

provide occupies most of our brain and forms the basis for our logical and rational decisions. We rely on our senses to get through even the

simplest task. To eat an apple, we first locate it visually, and we may scan it for rotten spots or an appealing color. Picking it up, we gain more information from the firmness of the skin and the fruit's density. We may even raise the apple to our nose and smell it before taking the first bite. Consciously or not, we assess that first bite to make sure it tastes right. Each of these small, practically automatic actions supplies information to the brain through the special senses.

Our special senses include **photoreceptors** for vision, mechanoreceptors for hearing and balance, and chemoreceptors for smell and taste. (There is an indepth discussion of mechanoreceptors in the skin in Chapter 9.) We are extremely visual creatures, using our eyes to provide most clues about the environment. Hearing is our second most acute sense, providing enough information to allow us to move through the environment even when we cannot see. Our sense of balance, or equilibrium, is closely allied with hearing in that both reside in the ear. However, balance is often overruled by our strong visual perceptions. The thrill of amusement park rides and the awful feeling of seasickness both come from our brain trying to reconcile visual information with conflicting balance information from the inner ear. The senses of smell and taste are interwoven to provide us with a subtle palate for food and a wide range for detecting aromas.

## **SMELLING AND TASTING ARE CHEMICAL SENSES**

Both olfaction and gustation are chemical senses, because these sensory receptors respond to chemicals dissolved in the mucus lying over them.

Olfaction occurs in the upper chambers of the

nasal passages, on the roof of the nasal cavity. We take deep breaths when we smell something to flood the upper portion of the nasal cavity with inhaled odor. Olfactory cells extend from the olfactory bulb (at the end of cranial nerve I) through the cribriform plate of the ethmoid, and into the mucus lining of the nasal cavity. The sensory receptors themselves are a small yellow patch of olfactory epithelium in the lining of the nasal cavity. Each cell is a modified neuron that ends in five olfactory cilia, which bear one of many thousands of specific olfactory receptors. When the receptor binds its specific odor molecule, a sensory impulse is sent to the olfactory bulb and on to the brain. Neural connections between the olfactory bulb and the limbic system explain why smells trigger memories and emotions. The perfume industry depends on this anatomical connection between odor and emotion.

The sense of taste is closely allied with olfaction. Have you noticed how food loses its appeal when you

Olfaction The sense of smell. Gustation The sense of taste.

suffer nasal congestion? In the mouth, food is broken down by the grinding of the teeth and chemically degraded by enzymes in saliva. Taste buds in the lining of the mouth and on the surface of the tongue (FIGURE **B.1**) permit us to distinguish only four categories of taste: sweet, sour, salty, or bitter. Like the olfactory epithelium, individual taste buds respond to only one class of chemical compound, although as a group taste buds respond to only four classes of compounds rather than the thousands that olfactory neurons recognize.



When stimulated, taste buds send information on to the brain. At the brain, the stimuli are analyzed to determine the overall taste of the food we are eating.

Rarely do we classify a food as tasting simply sweet or bitter. We describe coffee as "rich" or "full bodied." Starbucks<sup>©</sup> describes its flavors for November as "elegant sweet fruit" and "intense floral notes." The subtle differences in food tastes are actually due to the involvement of olfaction. Food in the mouth is dissolved in the mucus as we chew. At the back of the oral



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## What is the role of odor in emotional communication?

**A**nimals use chemicals for all sorts of communication, and not surprisingly it turns out that humans do likewise. Communication can occur both with chemicals that we recognize (odors) and with chemicals that we can't name, or even consciously detect. The many examples of chemical communication start with newborns, who use olfaction to find mother's breast. Scientists have recently learned that newborns cry less when they can smell their mother's amniotic fluid

Many people have observed that the memories that odors evoke are curiously powerful, and the connection between odor and emotion is well established. Scientists have learned that neural messages about scents go directly to the limbic system, the emotional center of the brain. For example, after exposing subjects to an unpleasant odor, scientists have recorded increased blood flow in the amygdala, a portion of the brain's limbic system that is central to emotion

Some of the most interesting studies have placed sweat samples in front of subjects' noses. One such study used samples taken from people who were either exercising or under the stress of preparing for an academic exam. When the female subjects were asked to respond emotionally to photos of faces, their response differed depending on which scent they had smelled. The sweat from a stressed individual caused the females to respond more negatively to the facial images.

Odors can also give insights into the emotions of strangers. In a fascinating study, scientists asked women and men to watch a frightening movie and a happy one, and after each one, collected smelly underarm pads. Women subjects could distinguish the odors collected from "happy" men and women. Male subjects could also do that—but only with samples taken from women.

Human chemical communication reflects animal use of chemicals to identify individuals, mark social rank and territories, and signal reproductive status. In animals, many of these behavior-affecting chemicals are called pheromones. Moths, for example, release vanishingly small concentrations of pheromones to attract mates. Honey bees use

pheromones when sharing information such as the route to food sources with the rest of the hive. Many vertebrates use pheromones to signal readiness for mating.

Do humans also respond to pheromones? Some perfume makers are eager to market the idea that pheromones can facilitate Homo sapien's dating and mating, but the claim is still debatable. For years, scientists denied that humans could respond to pheromones because we do not have a vomeronasal organ, the anatomical structure in the nasal passages which other vertebrates use to detect pheromones. Now, it appears that we do have such an organ, although it may deteriorate after birth. The exact role of pheromones and the vomeronasal organ is uncertain in humans. But amid a cascade of incredible discoveries about how people communicate with chemicals, more olfactory surprises would not be too astonishing.



Not all communication in the animal kingdom is auditory or even visual. Bees have a strong communication system that allows them to share information on the location and type of pollen to be found. Humans also communicate using emotional cues along with, or sometimes rather than, the spoken word.

## Uvula

The tab of soft tissue that hangs down in the back of the throat, visible as a pointed tab.

the hole is open, food in the mouth can be smelled by the olfactory epithelium. The combination of the food's texture (determined by the tongue), taste (sweet, sour, salty, or bitter), and odor (determined by the olfactory epithelium) are all related to our description of the taste of a food. The food industry has become quite skilled at "engineering" new foods with specific tastes and "mouth feels." (See "I Wonder . . . What is the role of odor in emotional communication?")

> Opening of auditory (eustachian) tube NASOPHARYNX Soft palate UVULA ·

OROPHARYNX

Epiglottis

(hypopharynx)

Esophagus

cavity, posterior to the **uvula**, lies a hole connecting to the nasal cavity (FIGURE 8.2). During swallowing, the uvula closes this hole, preventing swallowed items from being propelled out the nose. When

## **HEARING AND BALANCE** ARE DETECTED BY **MECHANORECEPTORS**

Our sense of hearing gives us the amazing ability to detect the slightest noises. The recent movie Ray documented the life story of rhythm-and-blues legend Ray Charles. Born with normal vision, Ray lost his sight in grade school. Few of us use our ears as well as Ray Charles did, even though we were born with the same capability. In a touching scene, 10-year-old Ray learned he could "see" by listening carefully. By following the sound of a cricket's feet on the wood floor, he located and caught the cricket. He turned to his mother and told her he knew she was present, even though she was quiet, and asked why she was crying as she watched him discover his world through sound instead of sight.





The ear FIGURE 8.3

The ear (FIGURE 8.3), as we all know, houses our sense of hearing. It has three functional parts: the outer, middle, and inner ear (FIGURE 8.4). The outer ear is composed of the **pinna** and **auditory canal**, both of which capture sound waves and funnel them to the middle ear.

The ear drum, or **tympanic membrane**, marks the beginning of the middle ear. Compression waves in the air (sound) cause the membrane to vibrate, converting sound into mechanical vibration. Attached to the inside of the tympanic membrane is the malleus, one of the three smallest bones in the human body. The vibrating tympanic membrane moves the malleus, which in turn moves the incus through a synovial joint. One more small bone, the **stapes**, is joined to this chain through another tiny synovial joint. The stapes is the final small bone, or ossicle, of the middle ear.

These three bones can dampen or amplify the movement of the tympanic membrane. Extremely loud noises that cause tremendous vibration of the tympanic membrane are dampened in the middle ear when tiny skeletal muscles tighten at these synovial joints. We can hear soft noises more clearly as these muscles relax, allowing the bones to move freely.

Beyond the stapes is the inner ear (see FIGURE **8.4**). The stapes connects to the oval window, a membrane that functions like the tympanic membrane. The oval window bounces in response to movement of the stapes, creating fluid waves in the inner ear.

The entire middle and inner ear are actually within a hollow portion of the temporal bone. The middle ear is filled with air and communicates with the external environment through the Eustachian, or auditory, tube. Air pressure must be almost equal on both sides of the tympanic membrane for it to freely vibrate in response to sound waves. When we pop our ears, we are actually opening the auditory tube, allowing air to equilibrate on both sides of the eardrum.

The cochlea is a coiled tube, built like a snail shell (FIGURE 8.5). If we unwound it, the cochlea would be a straight tube, extending from the oval window at the beginning of the inner ear to the round window. The cochlear tube has three compartments. The uppermost compartment, continuous with the oval window, is called the **vestibular canal**. At the tip of the snail shell, this compartment rounds the end of the tube and forms the tympanic canal at the bottom of the cochlea. The tympanic canal ends at the round window. These two chambers form a U-shaped fluid-filled passage for the pressure waves generated at the oval window.

Within the center of the cochlea is a third chamber. This chamber houses the actual organ of hearing, the Organ of Corti. The flattened tectorial membrane lies on top of the Organ of Corti. The membrane rests on the top of hair cells, with the hairs, or stereocilia, just touching the membrane. The hair cells of the Organ of Corti are directly linked to the vestibulocochlear nerve, cranial nerve VIII.

## THE MECHANICS OF HEARING **INVOLVES WAVES, HAIRS,** AND NEURONS

When the tectorial membrane is deformed and the underlying hairs are bent, as happens in response to sound, a nerve impulse is created in the neuron of





External ear Middle ear Internal ear

The parts of the ear include the outer ear, the middle ear, and the inner ear. The inner ear is a completely self-contained, fluid-filled chamber within the temporal bone. In this fluid floats a *membranous* labyrinth. There are two parts to these floating membranes:





### The parts of the ear FIGURE 8.4

1 the *cochlea* contains the organ used in hearing; 2 the vestibule and semicircular canals contain the organs of balance.

## Hearing FIGURE 8.6

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that particular hair cell. This impulse is carried to the brain, where it is interpreted as a particular pitch. Each part of the tectorial membrane is sensitive to a different pitch, allowing us to receive discrete information concerning the sounds we hear. Lower frequency noises vibrate the Organ of Corti near the tip of the cochlea, whereas higher frequency noises cause vibrations at the base. The nerves from each portion of the cochlea lead to specific areas of the brain, further enhancing our ability to discriminate sounds (FIGURE 8.6).

## EQUILIBRIUM IS ALSO HOUSED IN THE INNER EAR

Most people are surprised to learn that the sense of balance is also housed in the ear. The vestibule and semicircular canals of the inner ear house structures responsible for the two types of equilibrium-static and dynamic (FIGURE 8.7).

Static equilibrium Static equilibrium is the physical response to gravity that tells us which direction is



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"down." The **utricle** and **saccule** are structures located in the vestibule of the inner ear. Much as in the sense of hearing, these two structures initiate a nerve impulse when hairs within them bend. The utricle and saccule contain two gelatinous blobs situated at right angles to one another in the vestibule, called the maculae. Each of these organs contains tiny pieces of bone that respond to gravity. These organs are held in the vestibule by hair cells. The ends of the hairs are stuck in the gelatin, allowing them to respond to movement of the organ.

The utricle and saccule are arranged at right angles to one another, so that when the head is upright one of them is always vertical and the other horizontal. As gravity pulls on the vertical element, the hairs associated with it bend. As before, this bending causes a nerve impulse to be generated, except that this impulse goes to the area of the brain that interprets static equilibrium. As head position changes with respect to gravity, these impulses change in frequency and direction, continually providing information on the up-and-down placement of your head.

Dynamic Equilibrium Your sense of dynamic equilibrium detects acceleration or deceleration of your

head. This sense is composed of three semicircular canals situated so that each one lies in a separate plane; X (the horizontal plane, or the plane this book lies on when you lay it flat on the table), Y (the vertical plane, or the plane this book lies on when you stand it upright on the table with the spine facing you), and Z (transverse plane, or the plane that this book lies on when you again stand it upright on the table this time with the cover facing you). The fluid in these tubes rocks in response to acceleration in their particular plane. At the base of each semicircular canal is a swelling. This swollen area houses the dynamic equilibrium receptor, a flame-shaped cupula of gel with hairs embedded. As the fluid in the semicircular canal rocks through the swollen base of the canal, it pushes on the cupula and bends its hairs, again sending a nerve impulse to the brain. These structures are responsible for the strange feeling you get in an elevator. The fluid in the canals responds to the acceleration of your head, but your eyes perceive no motion, so you get that familiar flipping feeling in your stomach.





Decribe the anatomy of the eye Follow the pathway of light through the eye



the interpretation of visual images. De-



Ciliary body: Ciliary muscle Ciliary process

CONCEPT CHECK

GIVE examples of sensations you might receive from a chemoreceptor, a mechanoreceptor, and a photoreceptor.

Briefly describe the anatomy of your

olfactory sense.

Why do we consider some foods so tasty. when we can sense only four tastes?

Follow the path of sound through the ear.

Compare the functioning of static and dynamic equilibrium. What do these organs have in common?



Medial rectus muscle

Vitreous chamber (contains vitreous body)

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# Vision is our Most Acute Sense

Explain nearsightedness and farsightedness, listing the proper corrective measures **Discuss** the chemical reactions involved in photoreception

e are visual creatures. We perceive the world primarily through our eyes, devoting a large percentage of our brain to

spite the enormous importance of our eyes, they are simple structures (FIGURE 8.8). The eye works like a pinhole camera. It regulates the amount of light that enters the photoreceptor area and then captures that



Superior view of transverse section of right eyeball

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light as an image. The brain, like film in a camera, interprets that image and makes sense of what is seen.

The eye has three layers, or tunics: the **fibrous tunic** (sclera), the **vascular tunic** (choroid), and the **nervous tunic** (retina). The outermost layer, the fibrous tunic, is composed of dense connective tissue forming the white **sclera** and the clear **cornea**. The fibrous tunic is protected by the eyelids, eyelashes, and eyebrows, which prevent dust and particles from entering the eye.

The fibrous tunic provides a stiff outer covering for attaching the six extrinsic muscles that connect the eyeball to the bony orbit. **Lateral, medial, superior**, and **inferior rectus muscles** roll the eye left and right, up and down, in its socket, whereas the **superior** and **inferior oblique muscles** pull the eye obliquely. For example, when you contract your superior oblique muscle, your eye rolls upward and inward. The oblique muscles also help stabilize the eye as it is pulled by the four rectus muscles.

The anterior sclera and cornea are bathed continuously by **lacrimal gland** secretions, or tears. These glands lie in the superior lateral aspect of the orbit (the upper outer corner of the eye). The tears wash across the eye and are collected in holes, called **lacrimal punctae**, on either side of the nasal cavity. These holes drain into the nasal epithelium, helping to moisten that as well. When we cry, the lacrimal secretions exceed the carrying capacity of the lacrimal punctae, and the tears spill over the lower eyelid onto the face. The tears collected by the lacrimal punctae can also overflow the nasal epithelium, causing a runny nose (FIGURE 8.9).

Immediately beneath the fibrous tunic is a dark pigmented layer, the **choroid**. This layer houses the blood supply for the eye and contains melanin to absorb light. (Imagine how difficult it would be to interpret visual images if light bounced around inside the eye. With the light not absorbed, we would see repeated images, much like the echoes in a canyon.) The choroid ensures that light strikes the **retina** only once.

The choroid is visible as the **iris**, the colored portion in the front of eye. The iris is a muscular diaphragm that regulates light entering the eye. When contracted, concentric muscles constrict the **pupil**, whereas radial muscles dilate it. The color of the iris is a reflection of the amount of melanin produced by the

choroid. Dark eyes have more light-absorbing melanin on both sides of the choroid. Lighter eyes have less melanin on the underside of the

choroid, which is what we see through the cornea.

Immediately behind the iris, the choroid thickens and becomes the ciliary body. This structure holds the lens in place, pulling it to change the shape of the lens to accommodate near and far vision.



Lacrimal system FIGURE 8.9

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**Pupil** The hole in the center of the iris.



Eye structures a

**FIBROUS TUNIC** 

nd their	functions TABLE 8.1
nea	<i>Cornea:</i> Admits and refracts (bends) light. <i>Sclera:</i> Provides shape anbd pro- tects inner parts.
Gilian	<i>Iris:</i> Regulates amount of light that eneters eyeball.
body	<i>Ciliary body:</i> Secretes aqueous humor and alters shape of lens for near or far vision (accom- modation).
	<i>Choroid:</i> Provides blood supply and absorbs scattered light. Receives light and converts it
- Retina	into nerve impulses. Provides output to brain via axons of ganglion cells, which form the optic (II) nerve.
_ens	Refracts light.
Anterior cavity	Contains aqueous humor that helps maintain shape of eyeball and supplies oxygen and nutri- ents to lens and cornea.
Vitreous	Contains vitreous body that helps maintain shape of eyeball and keeps the retina attached to the choroid.
chamber	

The lens and cornea are both bathed in **aqueous humor**, a fluid that is constantly filtered from the blood. The aqueous humor is returned to the blood via the canals of Schlemm, at the junction of the cornea and the sclera. These canals get constricted in glaucoma, causing an increase in pressure that can eventually destroy the light-sensitive cells in the retina. See **TABLE B.1** for a complete listing of the structures of the eye, and their functions.

## THE LENS CHANGES SHAPE TO ACHIEVE OPTIMAL OPTICS

**Visual acuity** requires the eye to focus the light that enters it at the front onto the nervous tunic at the back. The lens, immediately behind the pupil, is held inside a

connective tissue covering that connects to the ciliary body. When the muscles of the ciliary body contract, the entire ring of the ciliary body gets

## Visual acuity The resolving power of the eye.

smaller. This releases pressure on the connective tissue covering the lens, and the lens bulges. When the muscle relaxes, the ring of the ciliary body enlarges, pulling the lens flat and enabling the eye to focus on nearby objects. This changing of lens shape, called **accommodation**, gets more difficult with age. This is because with each passing year, the lens continues to add layers that resemble the layers of an onion. These extra layers make the lens thicker and stiffer, so it resists flattening when the ciliary body relaxes. Starting around age 45 or 50, this flattening becomes so difficult that many people start to need reading glasses. These glasses enlarge the image before it reaches the pupil, giving the lens a larger image to bring into focus.

Nearsightedness and farsightedness are both caused by the lens's inability to accommodate light properly. In nearsightedness, the eye is too long for the lens to focus the light rays on the retina. The focal point winds up in the vitreous humor (the fluid in the back chamber of the eye), and the image is spreading out and fuzzy again when it hits the photoreceptors. A concave lens will spread the light rays farther before they enter the eye, correcting this problem. Farsightedness is the opposite of nearsightedness. The lens

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focuses the image from the pupil behind the retina. A convex lens will begin the process of focusing the light rays before they enter the eye, moving the focal point forward to the retina itself.

Astigmatism is another common abnormality of the eye. In this case, the cornea is not round, resulting in an uneven pattern of light hitting the retina. Some areas of the image are in focus, whereas others are not. A carefully crafted lens that mirrors the uneven flaws of the cornea is used to correct this problem. (See FIG-URES 8.10 and 8.11.) See the Health Wellness and Disease box, What are the most common visual impairments, for more information on visual troubles.

Behind the lens lies a large chamber filled with vitreous humor, a gel-like fluid that holds the third tunic, the retina, in place. Unlike aqueous humor which is continuously formed through our our life, vitreous humor is formed during fetal development and remains in the eye for life. The retina spreads out over the inside rear of the eye somewhat like the cloth of an umbrella, which is spread over the umbrella frame. Un-



### An eye exam FIGURE 8.10

Vision check-ups are an important part of maintaining good health. Visual acuity and astigmatism are routinely monitored during a simple eye exam. Visual acuity is determined by reading successively smaller type until the letters are too blurred to distinguish. Astigmatism can be diagnosed by observing a diagram of a wheel with spokes extending in all directions. If a few of these spokes are not distinct, the eye maybe out of round in those areas.

like the umbrella cloth, however, the retina is not physically attached to the back of the eyeball anywhere other than at its center. The retina is firmly attached to the eye at only one point at the center, at the blind spot. Photoreceptors line the surface of the retina that is exposed to the vitreous humor, directed toward the lens and the pupil. There are no photoreceptors in the blind spot of the retina because it is in this area that



## **Refraction of light rays and accomodation** FIGURE 8.11

Refraction is the bending of light rays. When the eye is focusing on a close object, the lens becomes more convex and refracts the light rays more.

The eye is an astonishing sensory organ, far superior to even a good camera. But things can go wrong with eyes, just as they can with cameras. Many serious vision impairments grow from physiological problems like a shortage of blood in the retina or a necessary visual chemical. But the most common vision problems emerge from simple anatomy, causing eyes that are nearsighted, farsighted, or astigmatic. In nearsighted, or myopic, eyes, images of distant objects focus in front of the retina, while close-up images do focus on the retina. This explains why nearsighted people can "see" close-up objects. Eyes that are farsighted, or hyperopic, have the opposite problem: close-up images are focused behind the retina, while distant images focus properly.



## What are the most common visual impairments?

retinal nerves dive through the retina toward the brain. The vitreous humor maintains slight pressure on the retina, pressing it flat against the back of the eye. Because it is not attached, the retina can be "detached" if

In the eye, the lens and cornea both focus light rays so that they converge on the retina. In myopia and hyperopia, the eyeball may simply be the wrong size for this focusing. Myopia and hyperopia are quite common, each affecting between 10 and 40 percent of various populations. Astigmatism is caused by a nonsymmetrical cornea or lens. Typically, astigmatism causes a blur in vertical or horizontal images, but not both. Astigmatism may be even more common than myopia or hyperopia, and it can coexist with either of them.

Myopia often causes children to squint, hold a book up close, or sit unusually close to a television or computer monitor. Hyperopia is often less troublesome early in life, because young lenses are often flexible enough to focus on close-up objects. Myopia and hyperopia can cause headaches or eyestrain, owing to the extra muscular effort needed to distort the lens to focus images on the retina.

Both myopia and hyperopia seem to have a genetic component, for they tend to run in families. Environment may also be a factor, as eye function is closely related to health of the individual and clarity of the surrounding air. For example, a diet low in vitamin A will cause visual disturbances, as vitamin A is necessary to form rhodopsin. And of course we have all experienced watery, painful eyes when trying to see near a smoky bonfire, or trying to see clearly after swimming in a chlorinated pool. Many studies have associated myopia with doing close work. Some also link myopia with the use of night lights, a previous surgical correction for a retinal problem, or other events. Eye specialists are not in agreement on how to interpret these studies.

Eyeglasses and contact lenses are the traditional technologies used to help the lens and cornea focus in myopia, hyperopia, and astigmatism. Today corrective surgery is becoming a more viable method to reshape the cornea for the necessary correction.

Ophthalmologists are still struggling to treat blinding diseases, such as glaucoma, macular degeneration, and retinitis pigmentosa. Fortunately, however, the most common vision problems are easy to detect and resolve.

the eye is hit hard enough to slosh the vitreous humor—even a momentary movement may allow the retina to fold. If this happens, light cannot reach the photoreceptors inside the fold, so they detect nothing.

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## PHOTORECEPTORS DETECT LIGHT IN THE RETINA

The retina (FIGURE 8.12) is composed entirely of neurons in layers containing rods and cones, bipolar cells, and ganglionic cells. The rods and cones are the neurons that detect light—the photoreceptors. The ganglionic cells and bipolar cells are interneurons carrying the action potential generated by the photoreceptors to the brain. The cones respond to bright light, providing color vision and high resolution, high enough to allow us to distinguish very small individual structures such as human hairs; the rods function in low levels of light, providing only vague images. These two types of cells are unevenly distributed. Cones are concentrated near the center of the retina, where incoming light is strongest. In fact, the area of the retina immediately behind the pupil is slightly yellow owing to the high concentration of cones, and it is called the macula lutea. This area provides our highest resolution, allowing us to discriminate subtle differences in objects needed, for example, to read. Rods are spread across the periphery of the retina. They are not terribly good at resolution, but they do respond in extremely low levels of light.

The layers of neurons in the human eye seem backwards, because the photoreceptors are against the back of the eye, oriented toward the brain rather than the source of light. Light rays must pass through the entire retina before they stimulate the photoreceptors at the back of the retina. This so-called indirect retina is found in most mammals. Interestingly, the squid and octopus have eyes that are anatomically very similar to our own, except that they do NOT have an indirect retina. Their photoreceptors are directly behind the vitreous humor, so light strikes them first. As a

Macula lutea

Macula = spot;

lutea = yellow.

Rhodopsin

Visual pigment that

levels of white light.

responds to low

result, they do not have a blind spot, which is doubtless helpful in the deep, dark depths of the ocean.

Rods and cones operate using different chemical mechanisms. When a photon of light hits a rod, a neural response is initiated via the chemical **rhodopsin**. The energy from the photon of light splits rhodopsin into two compounds (retinal and opsin), releasing energy that starts a se-



ries of events ultimately resulting in a closing of ion gates on the photoreceptor membrane. When the ion gates on the photoreceptor close, ion movement ceases, an action potential is generated and the brain receives a single bit of visual information.

Rhodopsin is easily **bleached**, meaning a slight increase in light can cause it to fall apart and not be able to re-combine. Until the light is reduced, rhodopsin cannot regenerate. This means that the rods cannot detect another photon of light when in bright light. If rhodopsin is not put back together, there can be no further action potentials.

When you star gaze, you are using rods. You may know that to see especially dim stars, it's better to focus to one side of the star. Why? Because rods are not found directly behind the pupil but rather on the periphery of the retina. The dim starlight is not strong enough to stimulate the cones directly behind the pupil, but strong enough to stimulate the rods. You may also be aware that you see far more stars after 15 to 20 minutes of looking at the heavens. After this period, bleached rhodopsin has entirely re-formed in the rods.

> Cones-the fine-detailed source of color vision—operate slightly differently. You have three types of cones, which are sensitive to different wavelengths of light, representing red, green, or blue. Cones also use the visual pigments retinal and opsin but with slight variation. Although the retinal and opsin in rods fall apart and do not regenerate in bright light, they readily regenerate in the cones.

photopigment. This initiates an action potential in the photoreceptor, which starts the journey to the brain.



These physiological responses explain how our eyes respond to sudden changes in light. When the lights first go down in a movie theater, they dim slowly to give our eyes time to adjust to the dark. The rhodopsin in the rods, which had bleached in the bright light, is being given time to regenerate. After the rods resume working, we can see nearby chairs even in near darkness. Cones respond almost immediately to brightening light. If you leave a theater, you can soon see in the lobby. But if you reenter a dark theater, you may experience momentary panic because the sudden dark effectively blinds you. If you exit a dark theater for the sunlit outdoors, the rhodopsin in your rods, which were providing vision in low light, suddenly bleaches, sending information to your brain



that you experience as a "white flash." In the bright light, rhodopsin cannot regenerate, and the rods remain defunct, but cones will quickly start sending impulses to the brain, your pupils will close, and your vision will be restored (FIGURE 8.13).

Regardless of whether the visual nerve impulse came from a rod or a cone, it travels from the eye to the brain in basically the same pathway. The impulse first passes toward the front of the eye, from the photoreceptors to the bipolar neurons. These bipolar neurons transmit the impulse to the ganglionic cells in the anterior of the retina. Ganglionic cells collect impulses from a small cluster of bipolar cells and pass them to the brain via the optic nerve (cranial nerve II) (FIG-URE 8.14).

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The ganglionic cells are in the front of the retina, and the brain is behind it. To reach the brain, axons of the ganglionic cells must penetrate the retina, which they do by literally diving through the retina. This location can have no photoreceptors, which explains why a blind spot is located just off-center in each eye. We generally do not recognize the blind spot owing to our **stereoscopic** vision. Each eye sees a slightly different view of the world because the eyes are placed slightly apart, angled just a little bit away from one another. Our brains meld these two views into one continuous field of vision. Objects that fall on the blind spot

Stereoscopic Depth perception gained through use of the visual field of both eyes.

of the right retina are seen by the left retina, and vice versa. The brain fills in the missing details from each view, providing us an unobstructed perception of our environment, and disguising the blind spot.

Exactly how the brain interprets the flood of information it receives from the eyes is a field of study in and of itself. Vision is so important that it occupies more space in the brain than any other special sense. We know the impulses travel along the optic nerve, through the thalamus to the occipital lobe of the brain. Some impulses cross to the opposite side of the brain at the optic chiasma. The view from the right eye is partially projected on the left side of the visual cortex of the cerebrum, and that from the left is partially projected on the right side. Additionally, the image reaching the occipital lobe is upside down and inverted. The

brain must flip and invert the image before it makes sense to us. All of this occurs continuously and almost instantaneously, without your even knowing it.

**Optic chiasma** The physical crossing of the left and right optic nerves.



# The Special Senses are Our Connection to the Outside World

LEARNING OBJECTIVES Discuss how society views sensory loss.



lthough aging can impair many of the special senses, most people can still lead productive, active lives even with some decline in their ability to perceive the world. Mild eyesight defects are usually easy to correct with eyeglasses. In fact, an entire market has been created for designer eyewear. And several surgical techniques, such as laser eye surgery, can improve the focusing of light rays, permitting many to see well without corrective lenses (FIGURE 8.15).

LASIK surgery refers to the specific use of lasers to alter the shape of the cornea. A small flap of cornea is cut and lifted back, exposing the center of the cornea. This middle corneal tissue is then vaporized in small, precisely controlled sections, causing the cornea to lie in a more conducive shape for clear vision when the flap is replaced. Radial keratotomy is essentially the same process, except that instead of lifting a flap of cornea, the outer layer is removed completely.

## CONCEPT CHECK

Describe the path of light through the eye and into the brain.

OW do rods and cones differ anatomically?

Describe the anatomy of the retina.

Why does the lens change its shape when focusing on near objects?





Understand conduction deafness and nerve deafness.

### Laser eye surgery FIGURE 8.15



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Complete loss of sight is another story, however. The blind are not easily assimilated into mainstream culture. As mentioned earlier, we humans are extremely visual organisms, relying mainly on our sight to get us through the world. Our social and economic systems require us to pick up visual cues, leaving blind people to function in a society designed for the sighted. Despite the use of Braille on elevator buttons and a few restaurant menus, many blind people must obtain aid from a sighted person or a seeing-eye dog to function (FIGURE 8.16). Simply getting around can be challenging for a blind person.

Like vision, hearing can diminish with age. Some hearing loss is due to mechanical malfunctions. In conduction deafness, sound is poorly conducted from the outer ear to the inner ear, as would happen, for example, if the ossicles were prevented from moving easily. Hearing aids can help those suffering from conduction deafness by increasing the amplitude of sound that enters the ear. But deafness is often due to neurological malfunction rather than a conduction problem. If auditory troubles are caused by nerve deafness, a hearing aid does not help because the problem is that the sound is either not detected or the nerve impulse is not transmitted to the brain. Cochlear implants convert sound vibrations into electrical impulses and have shown some promise in treating nerve deafness. Just like blindness, deafness can be life threatening. Sirens, smoke alarms, even the ringing of a phone are all auditory cues that warn us of dangerous situations. Visual cues have been added to most fire and hazard alarms in public buildings to assist those with hearing loss. In addition, many phones are available with a visual ring cue. For an alternative viewpoint on deafness, see the Ethics and Issues box, Being born deaf is not always considered a disability.



Is deafness a disability? Should it be corrected? To most hearing people, these questions have obvious answers: "yes," and "whenever possible." But many deaf people answer differently. To understand their reason, you need to understand something about the culture of deafness. Deaf people live among us, but many live separate lives because they "speak" with their hands, using American Sign Language (ASL). Sign language uses the words, but not the grammar, of English, and it can be just as subtle as English. According to the Web site aslinfo.com, the use of sign language is a central and desirable aspect of deaf culture: "Far from seeing the use of sign as a handicap, deaf people regard ASL as their natural language, which reflects their cultural values and keeps their traditions and heritage alive." A massive student protest in 2006 at Gallaudet University in Washington, D.C., long a center of deaf culture, emphasized the central role of ASL. The protests erupted after it was learned that the university's newly named president had not learned sign language until age 23. The appointee had also gone to regular schools rather than the "residential" schools that are a major avenue of socialization for the

### CONCEPT CHECK



**CHAPTER B** The Special Senses

## Being born deaf is not always considered a disability

deaf. These schools assist in the unique ASL socialization of deaf people because everyone in these schools speaks with sign instead of English. The new president's background aroused fears among the protestors that henceforth speech and lip reading might play a greater role than ASL at Gallaudet, thereby excluding deaf people who communicate best with sign.

Deaf culture is changing, and ASL is a major barometer of this change. For many years, "mainstreaming" was the goal of education for the deaf, and so deaf people were forced to try the difficult task of reading lips. This practice continued at most schools for the deaf, such as Gallaudet, for many years. Not until 1988 was a deaf person, fluent in ASL, appointed president of Gallaudet.

Today the cultural battle involving the deaf has entered a new phase, as a rising number of deaf young people are gaining the ability to hear through the use of cochlear implants. These devices detect sound with a microphone and directly stimulate the auditory nerves, bypassing the defective cochlea, the cause of the patient's deafness. The implants have allowed many deaf young people to enter mainstream culture rather than become immersed in a deaf culture reliant on ASL. That prospect constitutes yet another threat to the deaf community for whom ASL is central. As aslinfo.com has noted, although it sounds contrary to usual parental concerns, many deaf parents hope their children will be deaf, so that they can keep deaf culture alive.

Historically, discrimination and isolation have spawned high culture and distinctive art forms: jazz, klezmer, and gypsy music, for example, all flourished under oppressive conditions. What do you think? Should we try to "cure" deafness, or should we support a flourishing deaf culture based on American Sign Language?





What is the difference between conduction deafness and nerve deafness?

Can any type of nerve deafness be corrected?

Can lack of visual acuity be corrected?

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## **CHAPTER SUMMARY**



### The Special Senses Tell Us 1 about Our Environment

Special senses include smell, taste, hearing, balance, and vision. Smell and taste are chemical senses, requiring compounds to be dissolved in mucus to be sensed. In the ear, sound waves are converted into mechanical motion, and then nerve impulses travel to the brain. Static

equilibrium is monitored by the maculae in the saccule and utricle, and the cristae of the semicircular canals provide our sense of dynamic equilibrium. Taste originates at chemoreceptors on the tongue, and smell (olfaction) originates in chemoreceptors in the nose.

# **KEY TERMS**

- **gustation** p. 000 **macula lutea** p. 000 **olfaction** p. 000
- optic chiasma p. 000
- **pupil** p. 000

- smell? The sense of taste?
- now enjoy?)



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Vision begins with the eye, where light is converted to nervous impulses, and concludes in the occipital lobe of the brain, where these impulses are organized and interpreted. Vision is the best-developed of the special senses in the human body, and it occupies more of the brain than any other

special sense. The pathway of light through the eye begins with the cornea and aqueous humor. Light passes through the pupil, is focused by the lens, and strikes the retina. When there are problems focusing the light rays with the lens, glasses or laser surgery can help.



## **2** The Special Senses Are Our **O** Connection to the Outside World

Loss of visual or auditory acuity causes difficulty functioning in our society. We are visual beings—everything from road signs to menus to walking paths are designed for the sighted. Braille is used to present textual messages to those who cannot see well enough to read, and trained dogs give the blind a degree of independence in a sighted world. Deafness can be caused by conduction problems or neurological malfunction. Hearing aids and cochlear implants can restore hearing to many patients.



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- **rhodopsin** p. 000
- **stereoscopic** p. 000
- **uvula** p. 000
- **visual acuity** p. 000



# **CRITICAL THINKING QUESTIONS**

**1.** Some people are born with a condition in which the cribriform plate of the ethmoid bone is not formed properly. The tiny perforations that allow the olfactory neurons to extend into the upper nasal passageway are not present, and the cribriform plate is instead a solid bone. How would this affect the sense of

**2.** As we age, we lose many of the taste buds of our youth. The function of those remaining does not change, but the sheer number of taste buds declines over time. How do you think this might alter our perception of food? Can you relate this phenomenon to your own life? (Did you always enjoy the foods that you

- **3.** When you ride an elevator, why does your stomach feel like it is "dropping" when you ascend? Which sensory organ(s) account for this feeling, and what perceptual conflict helps create this sickening feeling?
- **4.** A cataract is a clouded lens, usually associated with age. How would a cataract affect vision? Trace the light entering an eye with a cataract, listing possible effects of the clouded lens. From what you know about the pathway of light through the eye, what might correct these visual disturbances?
- 5. Why do hearing aids not help a person suffering from nerve deafness? What is the difference between nerve deafness and conduction deafness? Which is easier to correct, and why?

## **SELF TEST**

- 1. All of the following are special senses EXCEPT:
- a. Vision
- b. Equilibrium
- c. Olfaction
- d. Proprioception
- 2. The following sense involves mechanoreceptors:
- a. Smell
- b. Taste
- c. Touch
- d. Balance
- e. C and d are correct
- **3.** True or False: We are capable of distinguishing only four different odors.

### 4. Identify the structure seen in this figure.

- a. Olfactory neuron
- b. Gustatory neuron
- c. Taste bud
- d. Retina

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- **5.** What is the function of the structure labeled A?
- a. Prevent choking
- b. Block the passageway from mouth to nose
- c. Prevent mucus from entering mouth
- d. Allow foodstuffs to enter nasal cavity



The next five questions all relate to this figure





### 6. What is the function of the structure(s) labeled A?

- a. Collect and transmit sound
- b. Convert sound waves to vibrations
- c. Dampen loud sounds
- d. Equilibrate pressure on either side of the tympanic membrane
- 7. What is the function of the structure labeled G?
- a. Hearing
- b. Static equilibrium
- c. Dynamic equilibrium
- d. Olfaction
- 8. Which area is responsible for transmitting sound waves into vibrations?
- a. A
- b. B
- c. C
- d. H
- 9. The label that indicates the ossicle responsible for transmitting vibrations to the inner ear is
- a. D
- b. E
- c. F
- d. I

### **10.** What is the function of the structure indicated H?

- a. Hearing
- b. Static equilibrium
- c. Dynamic equilibrium
- d. Olfaction



- b. Dynamic equilibrium
- c. Static equilibrium
- d. All of the above
- cornea is the
- a. Vascular tunic
- b. Fibrous tunic
- c. Nervous tunic
- d. Innermost tunic
- a. Produce tears
- b. Collect tears c. Moisten the nasal
- passages
- d. Spill tears onto the cheek bones



## 14. What is the name of the structure indicated as E?

- a. Aqueous humor b. Choroid
- c. Lens

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**11.** The bending of hairlike projections generates nerve impulses

- 12. The layer (tunic) of the eye that includes the whites and the
- **13.** The function of the structure labeled A on this image is to



Questions 14–16 require the use of the following diagram:

- d. Vitrous humor
- e. Retina

- **15.** What is the function of the structure labeled B?
- a. Focus light entering the eye
- b. Regulate the amount of light entering the eye
- c. Direct light rays on the retina
- d. Send visual impulses to the brain
- 16. Which of these structures continues to grow during your lifetime?
  - a. A
  - b. B
  - c. C
  - d. D e F

## **17.** Nearsightedness is caused by the lens focusing images

- a. In front of the retina
- b. Behind the retina
- c. Unevenly on the retina
- d. Directly on the macula lutea of the retina
- **18.** Correction for farsightedness usually requires
- a. A concave lens
- b. A convex lens
- c. Laser surgery to re-shape and smooth the cornea
- d. A carefully crafted lens that matches the contours of the cornea
- **19.** True or False: The cones allow us to see indistinct shapes in low light, but they bleach and are ineffective when light levels increase.
- 20. The correct layers of neurons in the retina, from anterior to posterior in the eye, is
  - a. Bipolar neurons  $\rightarrow$  ganglionic neurons  $\rightarrow$  rods and cones  $\rightarrow$ back of eye
  - b. Rods and cones  $\rightarrow$  bipolar neurons  $\rightarrow$  ganglionic neurons  $\rightarrow$  back of eye
  - c. Ganglionic neurons  $\rightarrow$  rods and cones  $\rightarrow$  bipolar neurons  $\rightarrow$ back of eye
  - d. Ganglionic neurons  $\rightarrow$  bipolar neurons  $\rightarrow$  rods and cones  $\rightarrow$ back of eye
- **21.** Despite being a visual society, people with impaired vision can function by taking advantage of
  - a. Braille menu's and buttons
  - b. Seeing eye animals
  - c. Cochlear implants
  - d. ASL
  - e. Both a and b are correct
  - f. Both c and d are correct

Self Test 253

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