CHAPTER 6: SENSORY SYSTEM

At the end of this chapter, student will be able to:

a) Explain the general purpose of sensations.
b) Name the parts of a sensory pathway, and state the function of each.
c) Describe the characteristics of sensations.
d) Name the cutaneous senses, and explain their purpose.
e) Explain referred pain and its importance.
f) Explain the importance of muscle sense.
g) Describe the pathways for the senses of taste and smell, and explain how these senses are interrelated.
h) Name the parts of the eye and their functions.
i) Describe the physiology of vision.
j) Name the parts of the ear and their functions.
k) Describe the physiology of hearing.
l) Describe the physiology of equilibrium.
m) Explain the importance of the arterial pressoreceptors and chemoreceptors.

6.0. INTRODUCTION

Traditionally, there are five senses: sight, smell, taste, touch, and hearing. Each of the senses consists of specialized cells that have receptors for specific stimuli. These cells have links to the nervous system and thus to the brain. Sensing is done at primitive levels in the cells and integrated into sensations in the nervous system. Sight is probably the most developed sense in humans, followed closely by hearing.

6.1. SENSORY PATHWAY

The impulses involved in sensations follow very precise pathways, which all have the following parts:

1. **Receptors**: detect changes (**stimuli**) and generate impulses. Receptors are usually very specific with respect to the kinds of changes they respond to. Those in the retina detect light rays, those in the nasal cavities detect vapors, and so on. Once a specific stimulus has affected receptors, however, they all respond in the same way by generating electrical nerve impulses.

2. Sensory neurons: transmit impulses from receptors to the central nervous system. These sensory neurons are found in both spinal nerves and cranial nerves, but each carries impulses from only one type of receptor.

3. Sensory tracts: white matter in the spinal cord or brain that transmits the impulses to a specific part of the brain.

4. Sensory areas: most are in the cerebral cortex. These areas feel and interpret the sensations. Learning to interpret sensations begins in infancy, without our awareness of it, and continues throughout life.

6.2 TYPES OF SENSORY RECEPTORS

Several structural and functional characteristics of sensory receptors can be used to group them into different classes.

- ✓ **On a <u>microscopic level</u>**, sensory receptors may be:

(1) free nerve endings,
(2) encapsulated nerve endings, or
(3) separate cells.

Free nerve endings are bare dendrites; they lack any structural specializations that can be seen under a light microscope.
Receptors **for pain, thermal, tickle, itch,** and some touch sensations are free nerve endings. Receptors for other somatic and visceral sensations, such as pressure, vibration, and some touch sensations are **encapsulated nerve endings.**

Their dendrites are enclosed in a connective tissue capsule that has a distinctive microscopic structure, for example, pacinian corpuscles.

The different types of capsules enhance the sensitivity or specificity of the receptor. Sensory receptors for some special senses are specialized, **separate cells** that synapse with sensory neurons. These include *hair cells* for hearing and equilibrium in the inner ear, *gustatory receptor cells* in taste buds, and *photoreceptors* in the retina of the eye for vision.

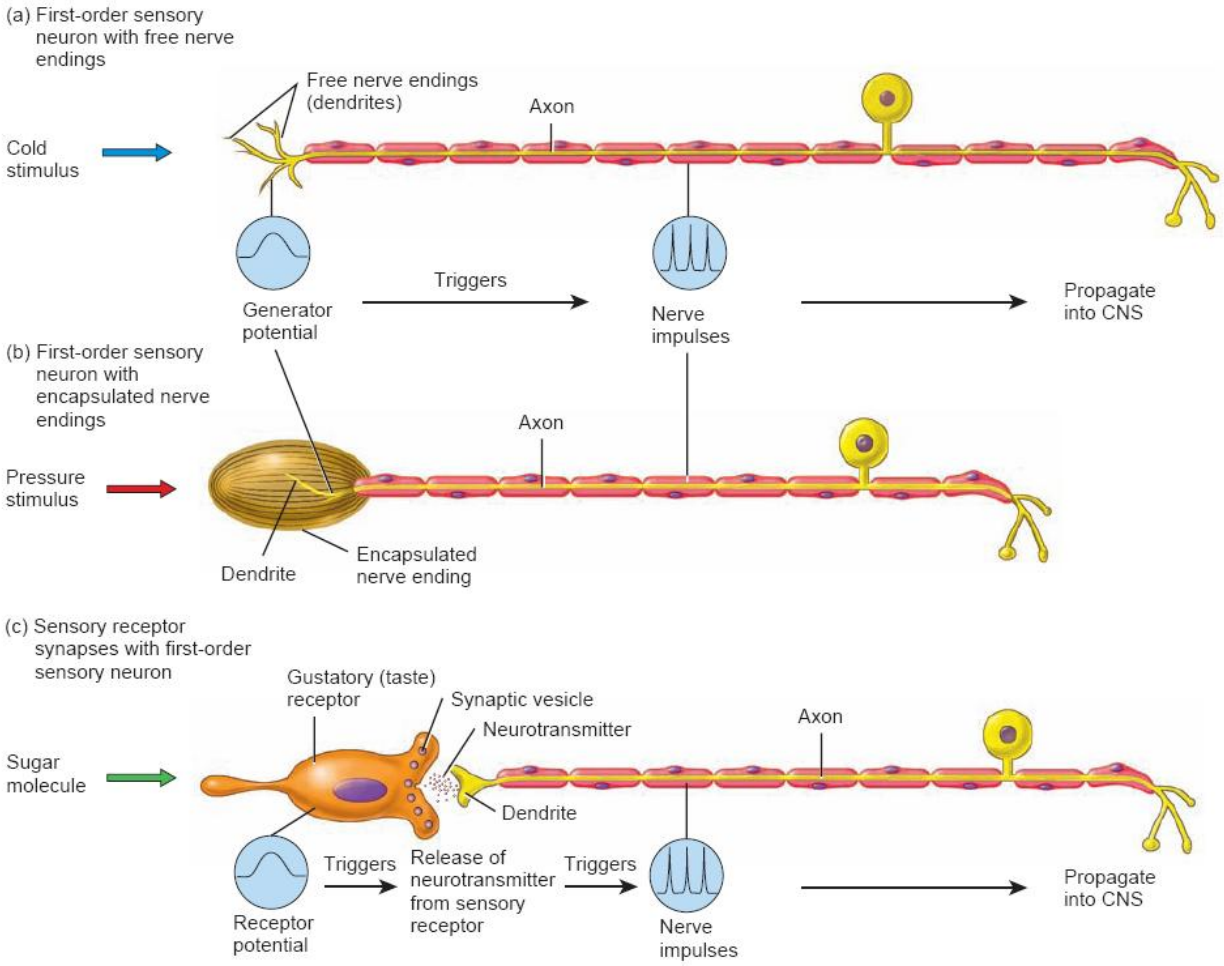

Figure: Types of sensory receptors;

(a) Free nerve endings, (b) An encapsulated nerve ending, (c) A separate receptor cell

- ✓ **Another** way to group sensory receptors is based on the location of the receptors **and <u>the origin</u> of the stimuli** that activate them.

• **Exteroceptors** are located at or near the external surface of the body; they are sensitive to stimuli originating outside the body and provide information about the *external* environment. The sensations of hearing, vision, smell, taste, touch, pressure, vibration, temperature, and pain are conveyed by exteroceptors.

• **Interoceptors** or **viscероceptors** are located in blood vessels, visceral organs, muscles, and the nervous system and monitor conditions in the *internal* environment.
The nerve impulses produced by interoceptors usually are not consciously perceived; occasionally, however, activation of interoceptors by strong stimuli may be felt as pain or pressure.

• **Proprioceptors** are located in muscles, tendons, joints, and the inner ear. They provide information about body position, muscle length and tension, and the position and movement of your joints.

- ✓ **A third way to group sensory receptors is <u>according to the type</u>** of stimulus they detect. Most stimuli are in the form of mechanical energy, such as sound waves or pressure changes; electromagnetic energy, such as light or heat; or chemical energy, such as in a molecule of glucose.

• **Mechanoreceptors** are sensitive to mechanical stimuli such as the deformation, stretching, or bending of cells.
Mechanoreceptors provide sensations of touch, pressure, vibration, proprioception, and hearing and equilibrium. They also monitor the stretching of blood vessels and internal organs.
• **Thermoreceptors** detect changes in temperature.
• **Nociceptors** respond to painful stimuli resulting from physical or chemical damage to tissue.
• **Photoreceptors** detect light that strikes the retina of the eye.
• **Chemoreceptors** detect chemicals in the mouth (taste), nose (smell), and body fluids.
• **Osmoreceptors** detect the osmotic pressure of body fluids.

Classification of Sensory Receptors

BASIS OF CLASSIFICATION	DESCRIPTION
MICROSCOPIC FEATURES	
Free nerve endings	Bare dendrites associated with pain, thermal, tickle, itch, and some touch sensations.
Encapsulated nerve endings	Dendrites enclosed in a connective tissue capsule for pressure, vibration, and some touch sensations.
Separate cells	Receptor cells synapse with first-order sensory neurons; located in the retina of the eye (photoreceptors), inner ear (hair cells), and taste buds of the tongue (gustatory receptor cells).
RECEPTOR LOCATION AND ACTIVATING STIMULI	
Exteroceptors	Located at or near body surface; sensitive to stimuli originating outside body; provide information about external environment; convey visual, smell, taste, touch, pressure, vibration, thermal, and pain sensations.
Interoceptors	Located in blood vessels, visceral organs, and nervous system; provide information about internal environment; impulses produced usually are not consciously perceived but occasionally may be felt as pain or pressure.
Proprioceptors	Located in muscles, tendons, joints, and inner ear; provide information about body position, muscle length and tension, position and motion of joints, and equilibrium (balance).
TYPE OF STIMULUS DETECTED	
Mechanoreceptors	Detect mechanical stimuli; provide sensations of touch, pressure, vibration, proprioception, and hearing and equilibrium; also monitor stretching of blood vessels and internal organs.
Thermoreceptors	Detect changes in temperature.
Nociceptors	Respond to painful stimuli resulting from physical or chemical damage to tissue.
Photoreceptors	Detect light that strikes the retina of the eye.
Chemoreceptors	Detect chemicals in mouth (taste), nose (smell), and body fluids.
Osmoreceptors	Sense the osmotic pressure of body fluids.

6.3. CHARACTERISTICS OF SENSATIONS

Certain characteristics of sensations will help you understand how the sensory areas work with information from the receptors.

1. **Projection**: the sensation seems to come from the area where the receptors were stimulated. If you touch a pen, the sensation of touch seems to be in your hand but is actually being felt by your cerebral cortex. That it is indeed the brain that feels sensations is demonstrated by patients who feel **phantom pain** after amputation of a limb. After loss of a hand, for example, the person may still feel that the hand is really there. Why does this happen?

The receptors in the hand are no longer present, but the severed nerve endings continue to generate impulses. These impulses arrive in the parietal lobe area for the hand, and the brain does what it has always done and creates the projection, the feeling that the hand is still there. For most amputees, phantom pain diminishes as the severed nerves heal, but the person often experiences a phantom "presence" of the missing part. This may be helpful when learning to use an artificial limb.

2. **Intensity**: some sensations are felt more distinctly and to a greater degree than are others. A weak stimulus such as dim light will affect a small number of receptors, but a stronger stimulus, such as bright sunlight, will stimulate many more receptors.

When more receptors are stimulated, more impulses will arrive in the sensory area of the brain. The brain "counts" the impulses and projects a more intense sensation.

3. **Contrast**: the effect of a previous or simultaneous sensation on a current sensation, which may then be exaggerated or diminished. Again, this is a function of the brain, which constantly compares sensations. If, on a very hot day, you jump into a swimming pool, the water may feel quite cold at first. The brain compares the new sensation to the previous one, and since there is a significant difference between the two, the water will seem colder than it actually is.

4. **Adaptation**: becoming unaware of a continuing stimulus. Receptors detect changes, but if the stimulus continues it may not be much of a change, and the receptors will generate fewer impulses. The water in the swimming pool that seemed cold at first seems to "warm up" after a few minutes. The water has not changed temperature, and the receptors for cold have no changes to detect, therefore they generate fewer impulses. The sensation of cold lessens, and we in-

terpret or feel that as increasing warmth. For another example, look at your left wrist (or perhaps the right one). Many of us wear a watch and are probably unaware of its presence on the arm most of the time. The cutaneous receptors for touch or pressure adapt very quickly to a continuing stimulus, and if there is no change, there is nothing for the receptors to detect.

5. **After-image**: the sensation remains in the consciousness even after the stimulus has stopped. A familiar example is the bright after-image seen after watching a flashbulb go off. The very bright light strongly stimulates receptors in the retina, which generate many impulses that are perceived as an intense sensation that lasts longer than the actual stimulus.

6.4. CUTANEOUS SENSES

The dermis of the skin and the subcutaneous tissue contain receptors for the sensations of touch, pressure, heat, cold, and pain. The receptors for pain, heat, and cold are **free nerve endings**, which also respond to any intense stimulus. Intense pressure, for example, may be felt as pain.

The receptors for touch and pressure are **encapsulated nerve endings**, meaning that there is a cellular structure around the nerve ending. The **cutaneous senses** provide us with information about the external environment and also about the skin itself. Much of the information about the environment is not of great importance and is processed at a subconscious level (suppressed by the thalamus), though we can choose to be aware of it.

For example, could you distinguish a cotton T-shirt from denim jeans by touch alone? Probably, but you might not realize that you can do that until you try it by, say, sorting laundry in the dark. If you were walking barefoot, could you tell if you were walking on a carpet, a wood floor, concrete, or beach sand? Yes, you could. But are we usually aware of the sensation from the soles of our feet? If all is going well, probably not.

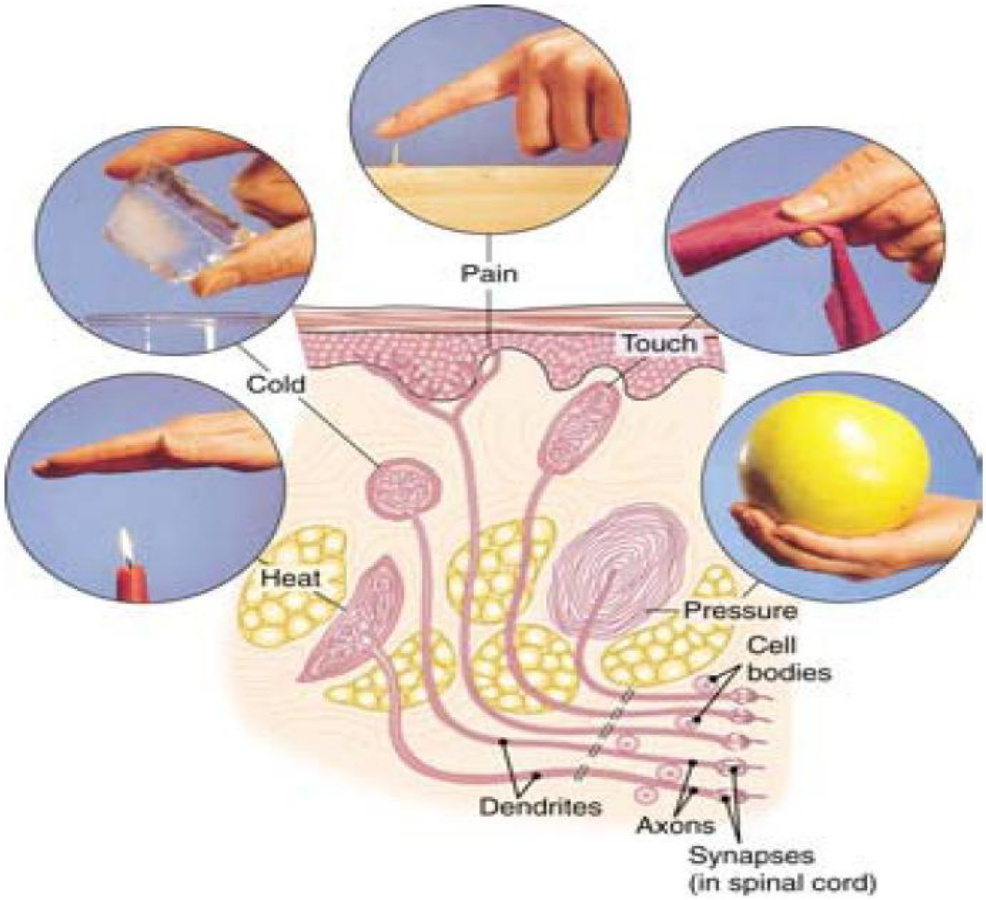

Figure: Sensory receptors in the skin. Synapses are in the spinal cord.

Some people with diabetes develop diabetic **neuropathy**, damage to nerves that impairs sensation, and they may say that a wood floor feels like walking on cotton balls or that the buttons of a shirt feel too large or too small. They are aware of such odd sensations simply because the feelings are odd. For most of us, the touch of the wood floor is not brought to awareness because it is what the brain expects from past experience, but if the floor has splinters or if the beach sand is hot, we are certainly aware. This is information we can bring to our conscious minds if necessary, but usually do not.

As for the skin itself, if you have ever had poison ivy or chickenpox, you may remember the itching sensation of the rash.

An itch is actually a mild pain sensation, which may become real pain if not scratched. Why does scratching help relieve some itches, besides by removing an external irritant? One proposed mechanism is that scratching is a bit more painful than the itch, and the impulses it gener-

ates can distract the brain from the impulses from the itch. Scratching will not help relieve the itch of poison ivy, chickenpox, or a mosquito bite, however, because the irritating chemicals are in the skin, not on it. In such cases, scratching may do more damage and worsen inflammation at the site.

The sensory areas for the skin are in the parietal lobes. You may recall that the sensitivity of an area of skin is determined by the number of receptors present. The number of receptors corresponds to the size of the sensory area in the cerebral cortex. The largest parts of this sensory cortex are for the parts of the skin with the most receptors, that is, the hands and face.

As mentioned previously, sensory areas are not merely passive recipients of impulses. Consider the sensation of wetness. It is a distinct sensation, but there are no receptors for "wet" in the skin. Where does the sensation come from? Where all sensation comes from: the brain. The parietal lobes have learned to associate the simultaneous reception of temperature and pressure impulses with "wet." You can demonstrate this for yourself by putting on a plastic glove and dunking your fingers in a cup of water. Your fingers will feel wet, though they are perfectly dry inside the glove. Wetness is a learned sensation, created by the brain.

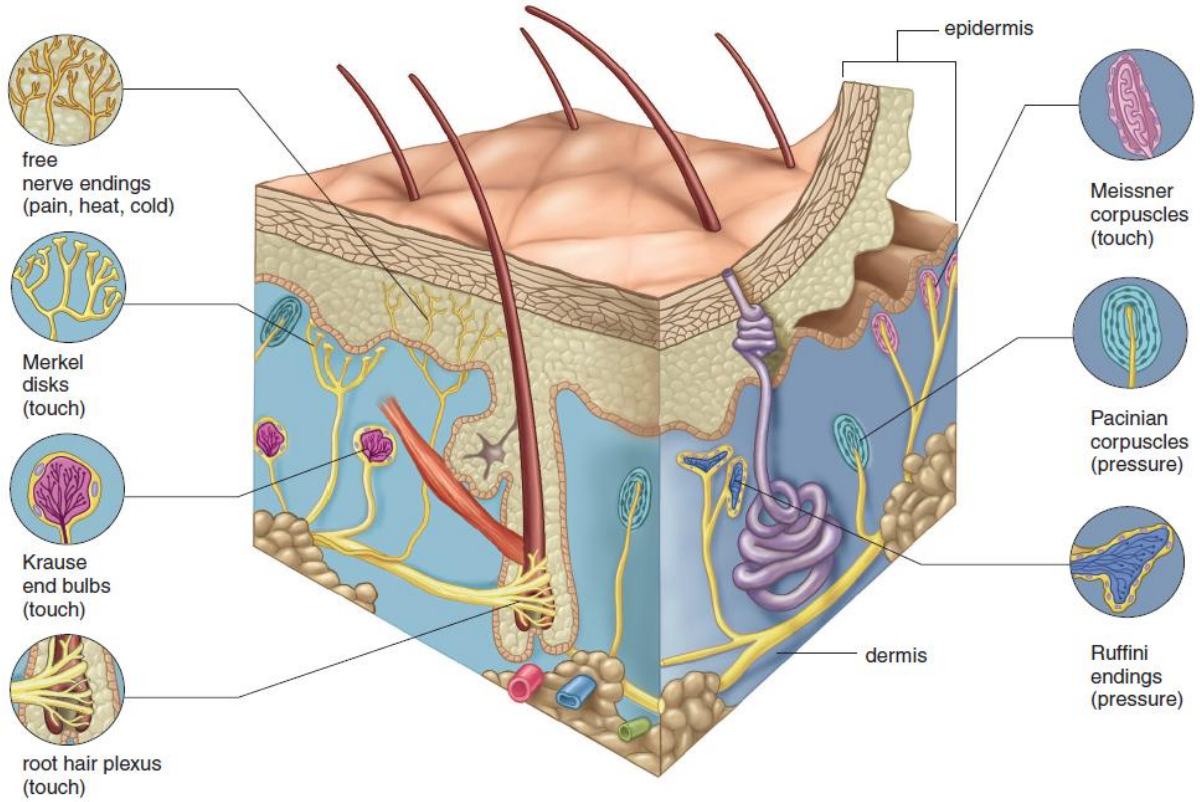

Figure: Cutaneous receptors in a section of the skin.

6.5. REFERRED PAIN

Free nerve endings are also found in internal organs. The smooth muscle of the small intestine, for example, has free nerve endings that are stimulated by excessive stretching or contraction; the resulting pain is called visceral pain. Sometimes pain that originates in an internal organ may be felt in a cutaneous area; this is called **referred pain**. The pain of a heart attack (myocardial infarction) may be felt in the left arm and shoulder, or the pain of gallstones may be felt in the right shoulder. This referred pain is actually a creation of the brain.

Within the spinal cord are sensory tracts that are shared by cutaneous impulses and visceral impulses. Cutaneous impulses are much more frequent, and the brain correctly projects the sensation to the skin. When the impulses come from an organ such as the heart, however, the brain may still project the sensation to the "usual" cutaneous area. The brain projects sensation based on past experience, and cutaneous pain is far more common than visceral pain. Knowledge of referred pain, as in the examples mentioned earlier, may often be helpful in diagnosis.

6.6. MUSCLE SENSE

Muscle sense is also called proprioception or kinesthetic sense. Stretch receptors (also called proprioceptors or muscle spindles) detect stretching of muscles and generate impulses, which enable the brain to create a mental picture to know where the muscles are and how they are positioned. Conscious muscle sense is felt by the parietal lobes. Unconscious muscle sense is used by the cerebellum to coordinate voluntary movements. We do not have to see our muscles to be sure that they are performing their intended actions. Muscle sense also contributes to our ability to distinguish the shape of objects.

6.7 SENSE OF TASTE

The receptors for taste are found in **taste buds**, most of which are in papillae on the tongue.

These **chemoreceptors** detect chemicals in solution in the mouth. The chemicals are foods and the solvent is saliva (if the mouth is very dry, taste is very indistinct). There are five general types of taste receptors: sweet, sour, salty, bitter, and savory. Savory (also called umami or glutamate) is a taste like grilled meat. We experience many more different tastes, however, because

foods are often complex chemicals that stimulate different combinations of receptors, and the sense of smell also contributes to our perception of food.

Some taste preferences have been found to be genetic. People with more than the average number of taste buds find broccoli very bitter, whereas people with fewer taste buds may like the taste. The impulses from taste buds are transmitted by the facial and glossopharyngeal (7^{th} and 9^{th} cranial) nerves to the taste areas in the parietal-temporal cortex. The sense of taste is important because it makes eating enjoyable. Some medications may interfere with the sense of taste, and this sense becomes less acute as we get older. These may be contributing factors to poor nutrition in certain patients and in the elderly.

6.8 SENSE OF SMELL

The receptors for smell (**olfaction**) are **chemoreceptors** that detect vaporized chemicals that have been sniffed into the upper nasal cavities. Just as there are specific taste receptors, there are also specific scent receptors, and research indicates that humans have several hundred different receptors. When stimulated by vapor molecules, **olfactory receptors** generate impulses carried by the olfactory nerves (1st cranial) through the ethmoid bone to the olfactory bulbs. The pathway for these impulses ends in the olfactory areas of the temporal lobes. Vapors may stimulate many combinations of receptors, and it has been estimated that the human brain is capable of distinguishing among 10,000 different scents.

That may seem impressive, but the human sense of smell is very poorly developed compared to those of other animals. Dogs, for example, have a sense of smell about 2000 times more acute than that of people. (It has been said that most people live in a world of sights, whereas dogs live in a world of smells.) As mentioned earlier, however, much of what we call taste is actually the smell of food. If you have a cold and your nasal cavities are stuffed up, food just doesn't taste as good as it usually does.

Adaptation occurs relatively quickly with odors. Pleasant scents may be sharply distinct at first but rapidly seem to dissipate or fade, and even unpleasant scents may fade with long exposure.

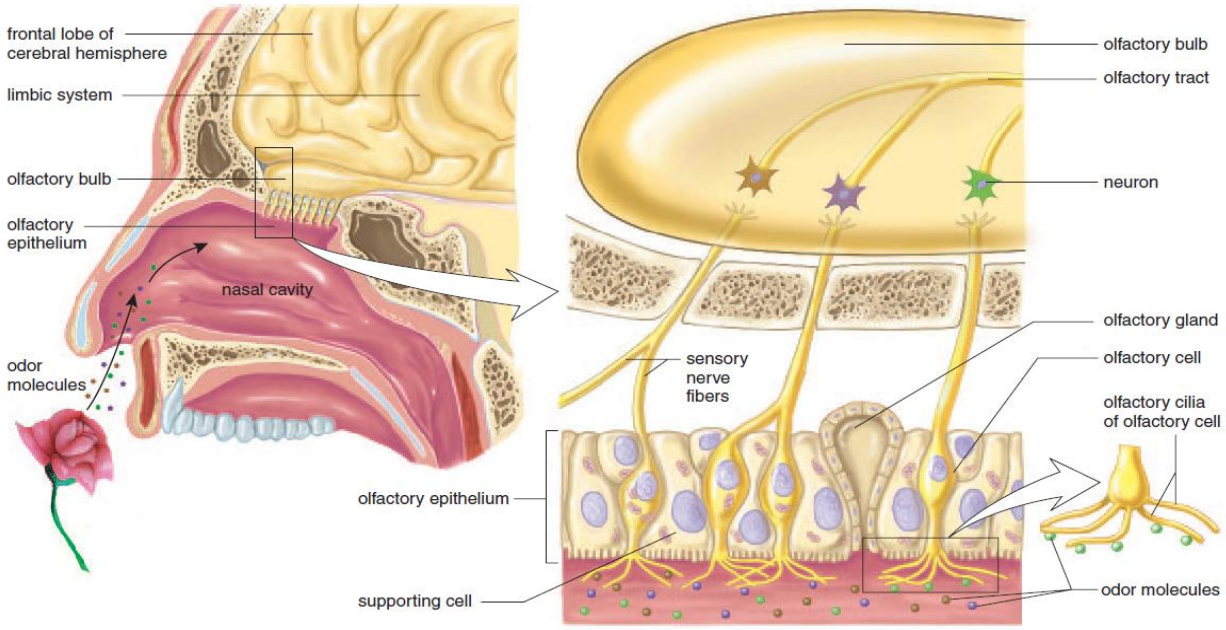

Figure: Olfactory cell location and anatomy.

6.9 HUNGER AND THIRST

Hunger and thirst may be called **visceral sensations**, in that they are triggered by internal changes. Hunger is a sensation that seems to be far more complex than was first thought, but thirst seems to be somewhat simpler. The receptors for both senses are specialized cells in the hypothalamus. Receptors for hunger are believed to detect changes in blood nutrient levels, the blood levels of hormones from the stomach and small intestine, and a hormone released by adipose tissue; all of these chemical signals are collected by the hypothalamus.

The receptors for thirst detect changes in the body water content, which is actually the water-to salt proportion. Naturally we do not feel these sensations in the hypothalamus: They are projected. Hunger is projected to the stomach, which contracts. Thirst is projected to the mouth and pharynx, and less saliva is produced. If not satisfied by eating, the sensation of hunger gradually diminishes, that is, adaptation occurs. The reason is that after blood nutrient levels decrease, they become stable as fat in adipose tissue is used for energy. With little or no digestive activity in the gastrointestinal tract, secretion of hormones diminishes.

With no sharp fluctuations of the chemical signals, the receptors in the hypothalamus have few changes to detect, and hunger becomes much less intense. In contrast, the sensation of thirst, if not satisfied by drinking, continues to worsen. There is no adaptation. As body water is lost, the

amount keeps decreasing and does not stabilize. Therefore, there are constant changes for the receptors to detect, and prolonged thirst may be painful.

6.10 THE EYE

The eye contains the receptors for vision and a refracting system that focuses light rays on the receptors in the retina. We will begin our discussion, however, with the accessory structures of the eye, then later return to the eye itself and the physiology of vision.

1° EYELIDS AND THE LACRIMAL APPARATUS

The eyelids contain skeletal muscle that enables the eyelids to close and cover the front of the eyeball. Eyelashes along the border of each eyelid help keep dust out of the eyes.
The eyelids are lined with a thin membrane called the **conjunctiva**, which is also folded over the white of the eye and merges with the corneal epithelium. Inflammation of this membrane, called **conjunctivitis**, may be caused by allergies or by certain bacteria or viruses, and makes the eyes red, itchy, and watery.
Tears are produced by the **lacrimal glands**, located at the upper, outer corner of the eyeball, within the orbit. Secretion of tears occurs constantly, but is increased by the presence of irritating chemicals (onion vapors, for example) or dust, and in certain emotional situations (sad or happy). Small ducts take tears to the anterior of the eyeball, and blinking spreads the tears and washes the surface of the eye.

Tears are mostly water, with about 1% sodium chloride, similar to other body fluids. Tears also contain **lysozyme**, an enzyme that inhibits the growth of most bacteria on the wet, warm surface of the eye. At the medial corner of the eyelids are two small openings into the superior and inferior lacrimal canals.
These ducts take tears to the **lacrimal sac** (in the lacrimal bone), which leads to the **nasolacrimal duct**, which empties tears into the nasal cavity. This is why crying often makes the nose run.

2° EYEBALL

Most of the eyeball is within and protected by the **orbit**, formed by the lacrimal, maxilla, zygomatic, frontal, sphenoid, and ethmoid bones. The six **extrinsic muscles** of the eye are attached to this bony socket and to the surface of the eyeball. There are four rectus (straight) muscles that move the eyeball up and down or side to side; the name tells you which direction. The medial rectus muscle, for example, pulls the eyeball medially, as if to look at the nose.

The two oblique (slanted) muscles rotate the eye.
The cranial nerves that innervate these muscles are the oculomotor, trochlear, and abducens (3rd, 4th, and 6^{th} cranial nerves, respectively). The very rapid and complex coordination of these muscles in both eyes is, fortunately, not something we have to think about.
The convergence of both eyes on an object is very important to ensure a single image (that is, to prevent double vision) and to give us depth perception and a three-dimensional world.

2.1° Layers of the Eyeball

In its wall, the eyeball has three layers: the outer sclera, middle choroid layer, and inner retina. The **sclera** is the thickest layer and is made of fibrous connective tissue that is visible as the white of the eye. The most anterior portion is the **cornea**, which differs from the rest of the sclera in that it is transparent. The cornea has no capillaries, covers the iris and pupil inside the eye, and is the first part of the eye that **refracts**, or bends, light rays. The **choroid layer** contains blood vessels and a dark blue pigment (derived from melanin) that absorbs light within the eyeball and thereby prevents glare (just as does the black interior of a camera). The anterior portion of the choroid is modified into more specialized structures: the ciliary body and the iris. The **ciliary body** (muscle) is a circular muscle that surrounds the edge of the lens and is connected to the lens by **suspensory ligaments**.

The **lens** is made of a transparent, elastic protein, and, like the cornea, has no capillaries. The shape of the lens is changed by the ciliary muscle, which enables the eye to focus light from objects at varying distances from the eye. Just in front of the lens is the circular **iris**, the colored part of the eye; its pigment is a form of melanin. What we call "eye color" is the color of the iris and is a genetic characteristic, just as skin color is. Two sets of smooth muscle fibers in the iris

change the diameter of the **pupil**, the central opening. Contraction of the radial fibers dilates the pupil; this is a sympathetic response. Contraction of the circular fibers constricts the pupil; this is a parasympathetic response (oculomotor nerves). Pupillary constriction is a reflex that protects the retina from intense light or that permits more acute near vision, as when reading.

The **retina** lines the posterior two-thirds of the eyeball and contains the visual receptors, the rods and cones. **Rods** detect only the presence of light, whereas **cones** detect colors, which, as you may know from physics, are the different wavelengths of visible light. Rods are proportionally more abundant toward the periphery, or edge, of the retina. Our best vision in dim light or at night, for which we depend on the rods, is at the sides of our visual fields. Cones are most abundant in the center of the retina, especially an area called the **macula lutea** directly behind the center of the lens on what is called the visual axis. The **fovea**, which contains only cones, is a small depression in the macula and is the area for best color vision.

An important cause of vision loss for people over 65 years of age is **age-related macular degeneration** (**AMD**), that is, loss of central vision, and some cases seem to have a genetic component. In the dry form of AMD, small fatty deposits impair circulation to the macula, and cells die from lack of oxygen.

In the wet form of AMD, abnormal blood vessels begin leaking into the retina, and cells in the macula die from the damaging effects of blood outside its vessels. The macula, the center of the visual field, is the part of the retina we use most: for reading, for driving, for recognizing people, and for any kind of close work. People of all ages should be aware of this condition and that smoking and exposure to ultraviolet rays are risk factors.

When light strikes the retina, the rods and cones generate impulses. These impulses are carried by **ganglion neurons**, which all converge at the **optic disc** and pass through the wall of the eyeball as the **optic nerve**.

There are no rods or cones in the optic disc, so this part of the retina is sometimes called the "blind spot." We are not aware of a blind spot in our field of vision, however, in part because the eyes are constantly moving, and in part because the brain "fills in" the blank spot to create a "complete" picture.

2.2° Cavities of the Eyeball

There are two cavities within the eye: the posterior cavity and the anterior cavity. The larger, **posterior cavity** is found between the lens and retina and contains **vitreous humor** (or vitreous body). This semisolid substance keeps the retina in place. If the eyeball is punctured and vitreous humor is lost, the retina may fall away from the choroid; this is one possible cause of a **detached retina**. The **anterior cavity** is found between the back of the cornea and the front of the lens, and contains **aqueous humor**, the tissue fluid of the eyeball.

Aqueous humor is formed by capillaries in the ciliary body, flows anteriorly through the pupil, and is reabsorbed by the **canal of Schlemm** (small veins also called the scleral venous sinus) at the junction of the iris and cornea. Because aqueous humor is tissue fluid, you would expect it to have a nourishing function, and it does. Recall that the lens and cornea have no capillaries; they are nourished by the continuous flow of aqueous humor.

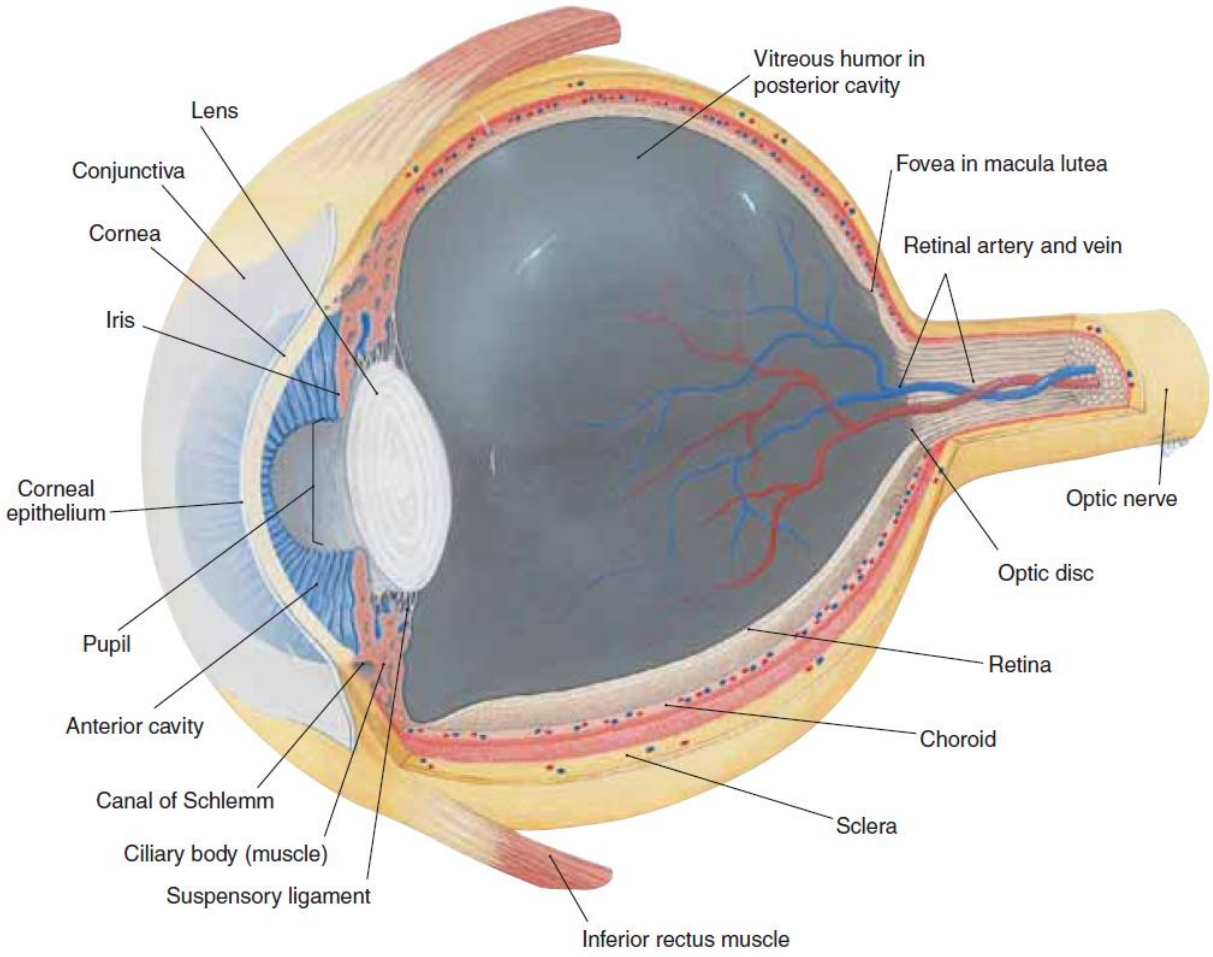

Figure: Internal anatomy of the eyeball.

3° PHYSIOLOGY OF VISION

For us to see, light rays must be focused on the retina, and the resulting nerve impulses must be transmitted to the visual areas of the cerebral cortex in the brain.

Refraction of light rays is the deflection or bending of a ray of light as it passes through one object and into another object of greater or lesser density. The refraction of light within the eye takes place in the following pathway of structures: the cornea, aqueous humor, lens, and vitreous humor. The lens is the only adjustable part of the refraction system. When looking at distant objects, the ciliary muscle is relaxed and the lens is elongated and thin. When looking at near objects, the ciliary muscle contracts to form a smaller circle, the elastic lens recoils and bulges in the middle, and has greater refractive power. When light rays strike the retina, they stimulate

chemical reactions in the rods and cones. In rods, the chemical **rhodopsin** breaks down to form scotopsin and retinal (a derivative of vitamin A).
This chemical reaction generates an electrical impulse, and rhodopsin is then resynthesized in a slower reaction.
Adaptation to darkness, such as going outside at night, takes a little while because being in a well-lit area has broken down most of the rhodopsin in the rods, and resynthesis of rhodopsin is slow. The opposite situation, perhaps being suddenly awakened by a bright light, can seem almost painful. What happens is this: In darkness the rods have resynthesized a full supply of rhodopsin, and the sudden bright light breaks down all the rhodopsin at the same time.

The barrage of impulses generated is very intense, and the brain may interpret any intense sensation as pain. A few minutes later the bright light seems fine because the rods are recycling their rhodopsin slowly, and it is not breaking down all at once. Chemical reactions in the cones, also involving retinal, are brought about by different wavelengths of light. It is believed that there are three types of cones: red-absorbing, blue-absorbing, and green-absorbing cones. Each type absorbs wavelengths over about a third of the visible light spectrum, so red cones, for example, absorb light of the red, orange, and yellow wavelengths.
The chemical reactions in cones also generate electrical impulses. The impulses from the rods and cones are transmitted to **ganglion neurons**; these converge at the optic disc and become the **optic nerve**, which passes posteriorly through the wall of the eyeball. Ganglion neurons also seem to have a photoreceptor chemical (called melanopsin) that may contribute to the daily resetting of our biological clocks. The optic nerves from both eyes come together at the **optic chiasma** (or chiasm), just in front of the pituitary gland. Here, the medial fibers of each optic nerve cross to the other side. This crossing permits each visual area to receive impulses from both eyes, which is important for binocular vision.
The visual areas are in the **occipital lobes** of the cerebral cortex. Although each eye transmits a slightly different picture (look straight ahead and close one eye at a time to see the difference between the two pictures), the visual areas put them together, or integrate them, to make a single image that has depth and three dimensions. This is called **binocular vision**. The visual areas also right the image, because the image on the retina is upside down.

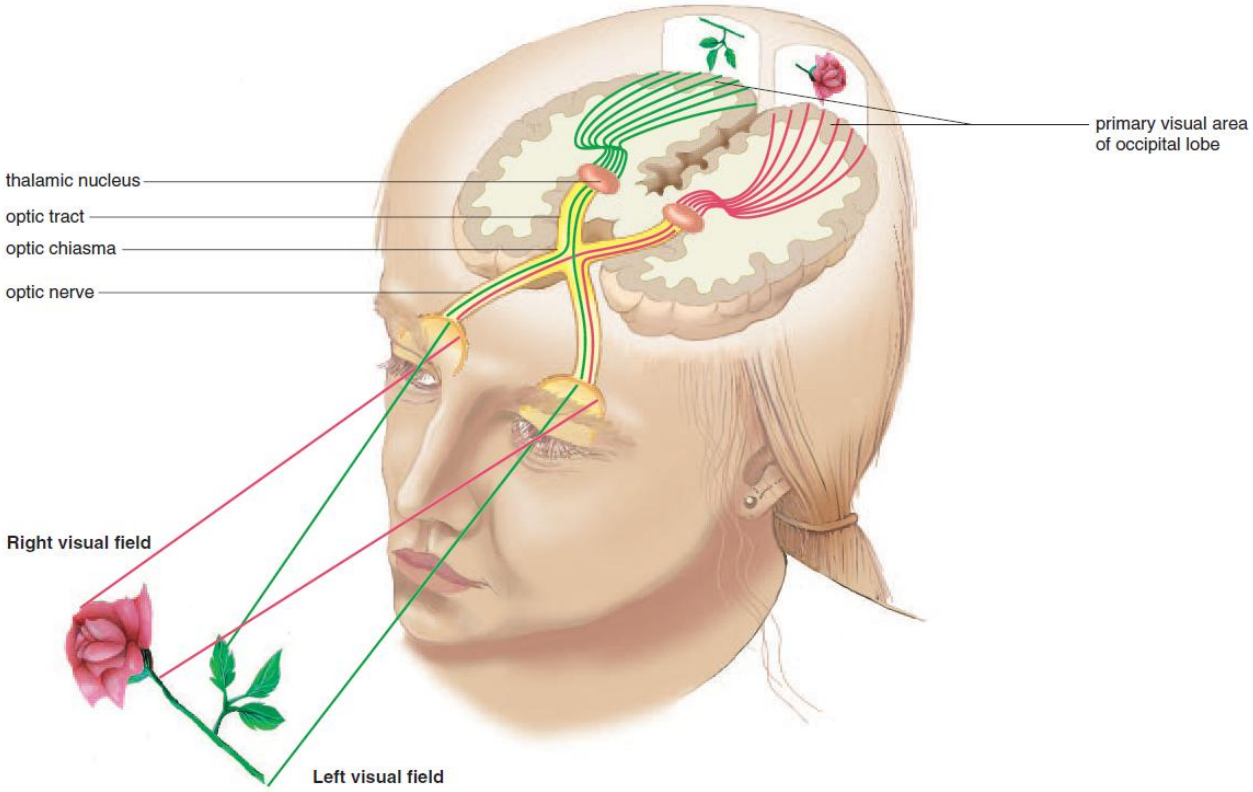

Figure: Optic chiasma. Both eyes "see" the entire visual field. Because of the optic chiasma, data from the right half of each retina go to the right visual area of the cerebral cortex, and data from the left half of the retina go to the left visual area of the cerebral cortex. These data are then combined to allow us to see the entire visual field. Note that the visual pathway to the brain includes the thalamus, which has the ability to filter sensory stimuli.

The image on film in a camera is also upside down, but we don't even realize that because we look at the pictures right side up. The brain just as automatically ensures that we see our world right side up.

Also for near vision, the pupils constrict to block out peripheral light rays that would otherwise blur the image, and the eyes converge even further to keep the images on the corresponding parts of both retinas.

6.11 THE EAR

The ear consists of three areas: the outer ear, the middle ear, and the inner ear. The ear contains the receptors for two senses: **hearing** and **equilibrium**. These receptors are all found in the inner ear.

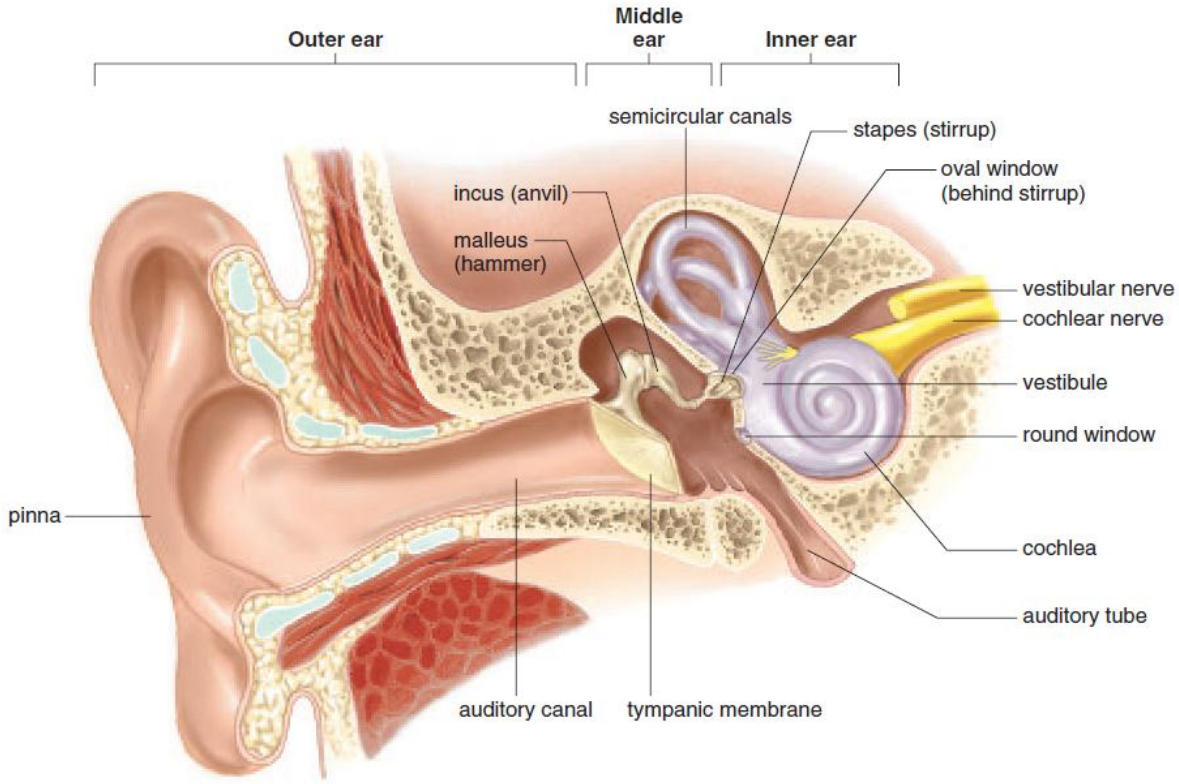

Figure A: Anatomy of the human ear. In the middle ear, the malleus (hammer), the incus (anvil), and the stapes (stirrup) amplify sound waves. In the inner ear, the mechanoreceptors for equilibrium are in the semicircular canals and the vestibule, and the mechanoreceptors for hearing are in the cochlea.

1° OUTER EAR

The **outer ear** consists of the auricle and the ear canal. The **auricle**, or **pinna**, is made of cartilage covered with skin. For animals such as dogs, whose ears are movable, the auricle may act as a funnel for sound waves. For people, however, the flat and stationary auricle is not important. Hearing would not be negatively affected without it, although those of us who wear glasses would have our vision impaired without our auricles. The **ear canal** is lined with skin that contains ceruminous glands. It may also be called the **external auditory meatus**, and is a tunnel into the temporal bone, curving slightly forward and down.

2° MIDDLE EAR

The **middle ear** is an air-filled cavity in the temporal bone. The **eardrum**, or **tympanic membrane**, is stretched across the end of the ear canal and vibrates when sound waves strike it. The-

se vibrations are transmitted to the three auditory bones: the **malleus**, **incus**, and **stapes**. The stapes then transmits vibrations to the fluid-filled inner ear at the **oval window**. The **eustachian tube** (auditory tube) extends from the middle ear to the nasopharynx and permits air to enter or leave the middle ear cavity. The air pressure in the middle ear must be the same as the external atmospheric pressure in order for the eardrum to vibrate properly. You may have noticed your ears "popping" when in an airplane or when driving to a higher or lower altitude. Swallowing or yawning creates the "pop" by opening the eustachian tubes and equalizing the air pressures. The eustachian tubes of children are short and nearly horizontal and may permit bacteria to spread from the pharynx to the middle ear. This is why **otitis media** may be a complication of a strep throat.

3° INNER EAR

Within the temporal bone, the **inner ear** is a cavity called the **bony labyrinth** (a labyrinth is a series of interconnecting paths or tunnels, somewhat like a maze but without dead ends, which is lined with membrane called the **membranous labyrinth**. **Perilymph** is the fluid found between bone and membrane, and **endolymph** is the fluid within the membranous structures of the inner ear. These structures are the cochlea, concerned with hearing, and the utricle, saccule, and semicircular canals, all concerned with equilibrium.

3.1° Cochlea

The **cochlea** is shaped like a snail shell with two-anda- half structural turns. Internally, the cochlea is partitioned into three fluid-filled canals. The medial canal is the cochlear duct, the floor of which is the basilar membrane that supports the receptors for hearing in the **organ of Corti** (**spiral organ**).

The receptors are called hair cells (their projections are not "hair," of course, but rather are specialized microvilli called stereocilia), which contain endings of the cochlear branch of the 8th cranial nerve. Overhanging the hair cells is the tectorial membrane. Very simply, the process of hearing involves the transmission of vibrations and the generation of nerve impulses. When sound waves enter the ear canal, vibrations are transmitted by the following sequence of

structures: eardrum, malleus, incus, stapes, oval window of the inner ear, and perilymph and endolymph within the cochlea.

Imagine the vibrations in the fluids as ripples or waves. The basilar membrane ripples and pushes the hair cells of the organ of Corti against the tectorial membrane. When the hair cells bend, they generate impulses that are carried by the 8th cranial nerve to the brain. As you may recall, the auditory areas are in the **temporal lobes** of the cerebral cortex. It is here that sounds are heard and interpreted. The auditory areas also enable us to determine from which direction a sound is coming. Simply stated, the auditory areas count and compare the number of impulses coming from each inner ear.

For example, if more impulses arrive from the left cochlea than from the right one, the sound will be projected to the left. If the source of a sound is directly above your head, the sound may seem to come from all directions, because each auditory area is receiving approximately the same number of impulses and cannot project the sensation to one side or the other. The final structure in the hearing pathway is the round window. The membrane-covered **round window**, just below the oval window, is important to relieve pressure. When the stapes pushes in the fluid at the oval window, the round window bulges out, which prevents damage to the hair cells.

3.2° Utricle and Saccule

The **utricle** and **saccule** are membranous sacs in an area called the **vestibule**, between the cochlea and semicircular canals. Within the utricle and saccule are hair cells embedded in a gelatinous membrane with tiny crystals of calcium carbonate called **otoliths**. The impulses generated by these hair cells are carried by the vestibular portion of the 8th cranial nerve to the cerebellum, the midbrain, and the temporal lobes of the cerebrum.

The cerebellum and midbrain use this information to maintain equilibrium at a subconscious level. We can, of course, be aware of the position of the head, and it is the cerebrum that provides awareness.

3.3° Semicircular Canals

The three **semicircular canals** are fluid-filled membranous ovals oriented in three different planes. At the base of each is an enlarged portion called the ampulla, which contains hair cells (the crista) that are affected by movement. As the body moves forward, for example, the hair cells are bent backward at first and then straighten. The bending of the hair cells generates impulses carried by the vestibular branch of the 8th cranial nerve to the cerebellum, midbrain, and temporal lobes of the cerebrum. These impulses are interpreted as starting or stopping, and accelerating or decelerating, or changing direction, and this information is used to maintain equilibrium while we are moving. In summary then, the utricle and saccule provide information about the position of the body at rest, while the semicircular canals provide information about the body in motion. Of course, there is some overlap, and the brain puts all the information together to create a single sense of body position.

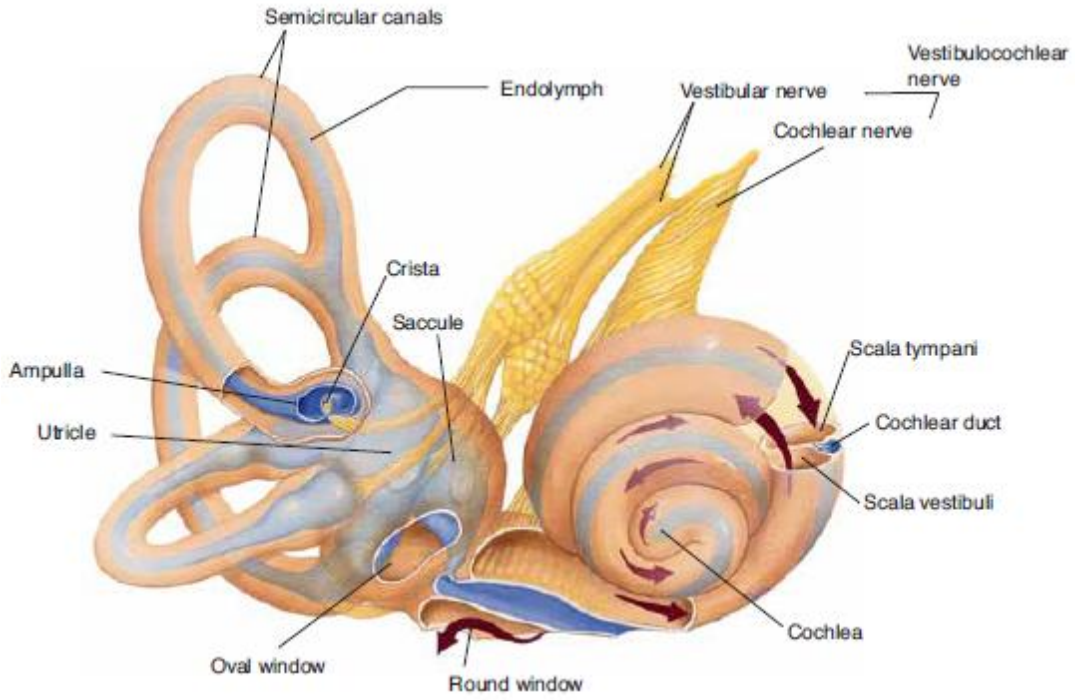

Figure: Inner ear structures. The arrows show the transmission of vibrations during hearing.

6.12. ARTERIAL RECEPTORS

The aorta and carotid arteries contain receptors that detect changes in the blood. The **aortic arch**, which receives blood pumped by the left ventricle of the heart, curves over the top of the

heart. The left and right **carotid arteries** are branches of the aortic arch that take blood through the neck on the way to the brain. In each of these vessels are pressoreceptors and chemoreceptors. **Pressoreceptors** in the carotid sinuses and aortic sinus detect changes in blood pressure. **Chemoreceptors** in the carotid bodies and the aortic body detect changes in the oxygen and carbon dioxide content and the pH of blood.

The impulses generated by these receptors do not give rise to sensations that we feel but rather are information used to make any necessary changes in respiration or circulation. If the blood level of oxygen decreases significantly, this change (hypoxia) is detected by carotid and aortic chemoreceptors. The sensory impulses are carried by the glossopharyngeal (9^{th} cranial) and vagus (10^{th} cranial) nerves to the medulla. Centers in the medulla may then increase the respiratory rate and the heart rate to obtain and circulate more oxygen.

These are the respiratory and cardiac reflexes that mentioned as functions of the glossopharyngeal and vagus nerves. The importance of these reflexes is readily apparent: to maintain normal blood levels of oxygen and carbon dioxide and to maintain normal blood pressure.

AGING AND THE SENSES

All of the senses may be diminished in old age. In the eye, cataracts may make the lens opaque. The lens also loses its elasticity and the eye becomes more farsighted, a condition called presbyopia (a condition in which an elderly person's sight fails gradually, through harden of the lens). The risk of glaucoma increases, and elderly people should be tested for it because treatment is available that can prevent blindness. Macular degeneration, in which central vision becomes impaired first, is a major cause of vision loss for people over 65. Reading and close work of any kind become difficult. In the ear, cumulative damage to the hair cells in the organ of Corti usually becomes apparent some time after the age of 60.

Hair cells that have been damaged in a lifetime of noise cannot be replaced (regrowth of cochlear hair cells has been stimulated in guinea pigs, but not yet in people). The deafness of old age ranges from slight to profound; very often high-pitched sounds are lost first, while hearing may still be adequate for low-pitched sounds. The sense of equilibrium may be diminished; the body is slower to react to tilting, and falls may become more frequent. Both taste and smell become less acute with age, which may contribute to poor nutrition in elderly people.

- **Applications to the nursing care**

1. CATARACTS

The lens of the eye is normally transparent but may become opaque; this cloudiness or opacity is called a **cataract**. Cataract formation is most common among elderly people. With age, the proteins of the lens break down and lose their transparency. Longterm exposure to ultraviolet light (sunlight) seems to be a contributing factor, as is smoking. The cloudy lens does not refract light properly, and blurry vision throughout the visual field is the result. Small cataracts may be destroyed by laser surgery. Artificial lenses are available, and may be surgically implanted to replace an extensively cloudy lens. The artificial lens is not adjustable, however, and the person may require glasses or contact lenses for vision at certain distances.

2. GLAUCOMA

The presence of aqueous humor in the anterior cavity of the eye creates a pressure called intra-ocular pressure. An increase in this pressure is an important risk factor for **glaucoma**, which is now defined as a group of disorders that damage the optic nerve and cause loss of vision. Other risk factors include high blood pressure and diabetes. In the most common form of glaucoma, aqueous humor is not reabsorbed properly into the canal of Schlemm. Increased pressure in the anterior cavity is transmitted to the lens, the vitreous humor, and the retina and optic nerve. As pressure on the retina increases, halos may be seen around bright lights, and peripheral vision is lost. Frequently, however, there are no symptoms.

A person with glaucoma may not notice the shrinking visual field in one eye before vision loss is far advanced. This happens because the brain will suppress a faulty image from one eye that it cannot easily integrate with the normal image of the other eye. When both eyes are affected, the person may not become aware of the gradual loss of peripheral vision, because close work such as reading does not require the edges of the visual fields. Glaucoma may often be controlled with medications that constrict the pupil and flatten the iris, thus opening up access to the canal of Schlemm. If these or other medications are not effective, laser surgery may be used to create a larger drainage canal.

Anyone over the age of 40 should have a test for glaucoma; anyone with a family history of glaucoma should have this test annually, as should those with diabetes or high blood pressure. If diagnosed early, glaucoma is treatable, and blindness can usually be prevented.

3. ERRORS OF REFRACTION

Normal visual acuity is referred to as 20/20; that is, the eye should and does clearly see an object 20 feet away.

Nearsightedness (**myopia**) means that the eye sees near objects well but not distant ones. If an eye has 20/80 vision, this means that what the normal eye can see at 80 feet, the nearsighted eye can see only if the object is brought to 20 feet away. The nearsighted eye focuses images from distant objects in front of the retina, because the eyeball is too long or the lens too thick. These structural characteristics of the eye are hereditary.Correction requires a concave lens to spread out light rays before they strike the eye.

Farsightedness (**hyperopia**) means that the eye sees distant objects well. Such an eye may have acuity of 20/10, that is, it sees at 20 feet what the normal eye can see only at 10 feet. The farsighted eye focuses light from near objects "behind" the retina, because the eyeball is too short or the lens too thin. Correction requires a convex lens to converge light rays before they strike the eye. As we get older, most of us will become more farsighted (**presbyopia**). As the aging lens loses its elasticity, it is not as able to recoil and thicken for near vision, and glasses for reading are often necessary.

Astigmatism is another error of refraction, caused by an irregular curvature of the cornea or lens that scatters light rays and blurs the image on the retina. Correction requires a lens ground specifically for the curvature of the individual eye.

4. NIGHT BLINDNESS AND COLOR BLINDNESS

Night blindness, the inability to see well in dim light or at night, is usually caused by a deficiency of vitamin A, although some night blindness may occur with aging.

Vitamin A is necessary for the synthesis of rhodopsin in the rods. Without sufficient vitamin A, there is not enough rhodopsin present to respond to low levels of light.

Color blindness is a genetic disorder in which one of the sets of cones is lacking or nonfunctional. Total color blindness, the inability to see any colors at all, is very rare. The most common form is red-green color blindness, which is the inability to distinguish between these colors. If either the red cones or green cones are nonfunctional, the person will still see most colors, but will not have the contrast that the non-working set of cones would provide.

So red and green shades will look somewhat similar, without the definite difference most of us see. This is a sex-linked trait; recessive gene is on the X chromosome.

A woman with one gene for color blindness and a gene for normal color vision on her other X chromosome will not be color blind but may pass the gene for color blindness to her children. A man with a gene for color blindness on his X chromosome has no gene at all for color vision on his Y chromosome and will be color blind.

5. DEAFNESS

Deafness is the inability to hear properly; the types are classified according to the part of the hearing process that is not functioning normally:

Conduction deafness: impairment of one of the structures that transmits vibrations. Examples of this type are a punctured eardrum, arthritis of the auditory bones, or a middle ear infection in which fluid fills the middle ear cavity.

Nerve deafness: impairment of the 8th cranial nerve or the receptors for hearing in the cochlea. The 8th cranial nerve may be damaged by some antibiotics used to treat bacterial infections. Nerve deafness is a rare complication of some viral infections such as mumps or congenital rubella (German measles). Deterioration of the hair cells in the cochlea is a natural consequence of aging, and the acuity of hearing diminishes as we get older. For example, it may be more difficult for an elderly person to distinguish conversation from background noise. Chronic exposure to loud noise accelerates degeneration of the hair cells and onset of this type of deafness. Listening to music by way of earphones is also believed to increase the risk of this type of damage.

Central deafness: damage to the auditory areas in the temporal lobes. This type of deafness is rare but may be caused by a brain tumor, meningitis, or a cerebrovascular accident in the temporal lobe.