The Special Senses

The special senses include taste (gustation), smell (olfaction), sight, hearing, and equilibrium, whose sensory receptors occur with complex sensory organs in the head region.

Sense of Taste

Taste buds consist of receptor cells (taste or gustatory cells) and epithelial supporting cells and are found in tiny projections of the tongue (papillae) and scattered in the oral cavity (roof of the mouth) and walls of the pharynx.

Taste cells have gustatory taste hairs (microvilli) which protrude from the taste cell through a taste pore. Taste hair surfaces have receptor sites to which chemicals combine.

The four primary taste sensations are sweet, sour, salty, and bitter and are sensed best at different regions on the tongue. Sweet receptors are on the tip, sour on the sides, salty on the tip and sides, and bitter at the back of the tongue. Before the taste of a particular chemical can be detected, the chemical must be dissolved in the watery fluid supplied by the salivary glands (saliva). Various taste sensations result from the stimulation of one or more sets of taste receptors (chemoreceptors) when various substances combine with specific receptor sites on the taste hair surfaces. Each of the flavors tasted is a result from one of the primary sensations or from some combination of two or more of them.

Taste is a combination of chemicals, sensations or odors, texture (touch), and temperature. Taste receptors undergo sensory adaptation relatively rapidly. The resulting loss of taste can be avoided by moving bits of food over the surface of the tongue to stimulate different receptors at different moments.

Sensory impulses from the taste receptors travel on fibers of the facial (VII), glossopharyngeal (IX), and vagus (X) nerves. These impulses are carried to the medulla oblongata and then to the thalamus, from which they travel to the gustatory cortex in the parietal lobes of the cerebrum.

Sense of Smell

The olfactory organs consist of the receptors and supporting cells in the upper region of the nasal cavity.

The olfactory receptors are chemoreceptors which consist of neurons with cilia and are stimulated by chemicals that enter the nasal cavity as gases and are at least partially dissolved in liquid. They function together with taste receptors and aid in food recognition.

Nerve impulses travel from the axons of olfactory receptors through the olfactory nerve to enlargements called olfactory bulbs which lie on either side of the crista galli of the ethmoid bone. Within the olfactory bulbs, the impulses are analyzed and then travel along olfactory tracts to interpreting centers (olfactory
Olfactory impulses may result when various gaseous molecules combine with specific sites on the cilia of the receptor cells. The olfactory receptors undergo sensory adaptation rapidly, but even though they have adapted to one scent, their sensitivity to other odors remains unchanged.

Sense of Sight

The visual accessory organs include:

1. **eyelids** - protect and lubricate the eyes by blinking.

2. **lacrimal apparatus** - includes the **lacrimal gland** (secretes tears), **lacrimal sac** (stores tears), and the **nasolacrimal ducts** (carry tears to the nasal cavity). Tears lubricate the eye and contain an enzyme (**lysozyme**) which functions as an antibacterial agent that reduces the chances of eye infections.

3. **extrinsic muscles** - consist of six muscles for eye movement. They arise from the bones of the orbit and are inserted by broad tendons on the tough outer surface of the eye.

4. **conjunctiva** - mucosa that lines the inner surface of the eyelids and the outer surface of the eye and aids in lubricating the surface of the eye.

Structure of the Eye

The wall of the eye has an outer, middle, and inner layer or tunic.

1. **outer layer or fibrous tunic** - consists of the **sclera** or white of the eyes (protects and gives the eye its shape), and its transparent anterior portion, or cornea, which refracts or bends light entering the eye. In the back of the eye, the sclera is pierced by the **optic nerve** and blood vessels. The fibrous tunic also functions as a place of attachment for the six extrinsic eye muscles.

2. **middle layer or vascular tunic** - consists of the **choroid coat** which is vascular and contains melanocytes which produce pigment. It provides nutrients to the eye and prevents light scattering within the eye. The layer also contains the **ciliary body** which is the thickest part of the middle layer and it extends forward from the choroid and forms an internal ring around the front of the eye.
inner layer or sensory or nervous tunic - consists of the retina, lens, and iris.

The retina is a nearly transparent sheet of tissue that is continuous with the optic nerve in the back of the eye and extends forward as the inner lining of the eyeball. It ends just behind the margin of the ciliary body.

The retina consists of an outer pigmented layer and an inner nervous layer. The nervous layer contains visual receptor cells or photoreceptors (rods and cones) and ganglion cells whose axons form the optic nerve, which exits by way of the optic disc ("blindspot").

In the central region of the retina there is a yellowish spot (macula lutea), which has a depression in its center (fovea centralis). The fovea centralis is the optic disc where nerve fibers from the retina leave the eye and become parts of the optic nerve.

A central artery and vein also pass through the optic disc which are continuous with the capillary network of the retina. Together with the vessels in the underlying choroid coat, they supply blood to the cells of the inner tunic. There are no receptor cells in the optic disc and it is therefore the blind spot of the eye.

The biconcave lens is a transparent, elastic structure whose shape is controlled by the action of the ciliary muscles and is suspended within the eye by suspensory ligaments. The suspensory ligaments are under tension and as they pull outward, the lens is kept thin and somewhat flattened. If the tension is relaxed, the lens surface becomes more convex. This change is called accommodation and occurs in the lens when it is focused to view a close object. Relaxation occurs when the ciliary muscles contract, causing the suspensory ligaments to relax and when the ciliary muscles relax, the tension on the suspensory ligaments increases.

The iris is a thin, muscular diaphragm composed of connective tissue and smooth muscle fibers and contains blood vessels and melanocytes (pigment cells). It controls the size of the pupil and the amount of light entering the eye. The iris extends forward from the periphery of the ciliary body and lies between the cornea and lens. The iris divides the space separating the two parts into an anterior chamber (between the cornea and lens) and a posterior chamber (between the iris and vitreous body and occupied by the lens).
The eye contains two cavities filled with fluids that help to maintain its shape. The posterior cavity, behind the lens contains vitreous humor (transparent, jellylike fluid) which helps support the eyeball and keep the retina in place. The anterior cavity, anterior to the lens, is divided into an anterior and a posterior chamber. The anterior chamber is between the cornea and iris, and the posterior chamber is between the iris and the ciliary body and lens. The anterior cavity is filled with the aqueous humor (watery fluid) formed by capillaries in the ciliary processes. The aqueous humor is a major factor in maintaining intraocular pressure.

The pupil is a circular opening in the center of the iris. Smooth muscle fibers of the iris are arranged into two groups, a circular set and a radial set. These muscles control the light passing through as it enters the eye. The circular set of muscle fibers acts as a sphincter. When it contracts, the pupil gets smaller, and the intensity of light entering decreases. When the radial muscles contract, the diameter of the pupil increases, and the intensity of the light entering increases.

Vision

When a person sees an object, the object is giving off light or light waves are being reflected from it. These waves enter the eye, and an image of what is seen becomes focused upon the retina. Focusing involves a bending of light waves (refraction). When light passes from an object into the cornea of the eye, light waves are bent primarily by the convex surface of the cornea. Then, light is refracted again by the convex surface of the lens and, to a lesser extent, by the surfaces of the fluids within the chambers of the eye. The light waves converge and are focused sharply on the retina. The image is upside down and reversed left to right. The cornea accounts for most of the refraction, but the lens allows active focusing for different distances.

Visual Receptors

Visual receptor cells are modified neurons of two types:

1. **rods** - responsible for colorless vision in relatively dim light or low-intensity light and they provide night vision.

2. **cones** - responsible for color vision, bright-light, and high-discrimination.
Both the rods and cones are found in a deep portion of the retina, closely associated with a layer of pigmented epithelium. Projections from these receptors extend into the pigmented layer and are loaded with visual pigments. The epithelial pigment of the retina absorbs light waves that are not absorbed by the receptor cells, and together with pigment of the choroid coat, it keeps light from reflecting off the surfaces inside the eye.

Rods and cones contain light-sensitive pigments which decompose when they absorb light energy. The light-sensitive substance in the rods is called rhodopsin (visual purple). In the presence of light, rhodopsin molecules decompose into molecules of a colorless protein, called opsin and a yellowish substance, called retinal (retinene), which is synthesized from vitamin A.

When rhodopsin molecules decompose, an enzyme is activated that initiates a complex series of reactions. The permeability of the rod cell membrane is altered, and a nerve impulse is triggered. The impulse travels away from the retina, along the optic nerve, and into the brain.

In bright light, nearly all of the rhodopsin in the rods is decomposed, and the sensitivity of these receptors is greatly reduced. In dim light, rhodopsin can be regenerated from opsin and retinal faster than it is broken down. This regeneration process requires cellular energy, which is provided by the energy-carrying molecules of ATP.

The light-sensitive pigments of the cones are similar to rhodopsin in that they are composed of retinal combined with an opsin that is different from that in the rods. Three different sets of cones are within the retina, each containing an abundance of one of three different visual pigments. Each contains retinal, but each has a different kind of opsin.

The wavelength of a particular kind of light determines the color perceived from it. The cone pigments include erythrolabe (sensitive to red light waves), chlorolabe (sensitive to green), and cyanolabe (sensitive to blue). The color a person perceives depends upon which set of cones or combination of sets is stimulated by the light in a given image. If all three sets are stimulated, the person sees the light as white, and if none are stimulated (all colors are absorbed), the person sees black.

Rods and cones function differently. The rods are hundreds of times more sensitive to light than the cones, and as a result, rods enable a person to see in relatively dim light. Rods produce colorless vision, but the cones can detect color.

The cones allow persons to have high visual acuity (see sharp images) and rods enable them to see more general outlines of objects. In rods, nerve fibers from many rods may converge, and their impulses may be transmitted to the brain on the same nerve fiber. If a point of light stimulates a rod, the brain cannot tell which one of many receptors has been stimulated. When cones are stimulated, this convergence occurs to a much lesser degree and the brain is able to pinpoint the stimulation more accurately.
The sharpest vision is in the fovea centralis which lacks rods, but contains densely packed cones with few or no converging fibers. The overlying layers of the retina and the retinal blood vessels, are displaced to the sides in the fovea. This displacement more fully exposes the receptors to incoming light.

**Visual Nerve Pathways**

Visual receptors are stimulated only when light reaches them. The axons of the retinal neurons leave the eyes to form the optic nerve. Just anterior to the pituitary gland, these nerves give rise to the x-shaped optic chiasma, and within the chiasma, some of the fibers cross over (fibers from the nasal or medial half cross over, those from the temporal or lateral sides do not). The fibers from the nasal half of the left eye and the temporal half of the right eye form the right optic tract and the fibers from the nasal half of the right eye and the temporal half of the left eye form the left optic tract.

The nerve fibers continue in the optic tracts, and just before they reach the thalamus, a few of them leave to enter the nuclei that function in various visual reflexes. Most of the fibers enter the thalamus and synapse in its posterior portion. From this region, the visual impulses enter nerve pathways (optic radiations), which lead to the visual cortex of the occipital lobe.

**Sense of Hearing**

The ear consists of the **external**, **middle**, and **inner ear**.

1. **external ear** - consists of the outer ear or auricle or pinna, and the external auditory meatus (canal) which collect sound waves created by vibrating objects.

2. **middle ear** - consists of a small air-filled chamber (tympanic cavity) within the temporal bone, an eardrum (tympanic membrane), and three small bones called auditory ossicles. The ossicles are the malleus (hammer), incus (anvil), and stapes (stirrup). The tympanic membrane separates the middle ear from the external ear. The auditory ossicles conduct sound waves from the tympanic membrane to the oval window (opening) of the inner ear. The auditory tubes (eustachian tubes) connect the middle ear to the throat and help maintain equal air pressure on both sides of the eardrums, which is necessary for normal hearing.
3. **inner ear** - consists of a complex system of intercommunicating tubes and chambers - the *osseous* (bony) and *membranous labyrinths*. The bony labyrinth chambers are in the temporal bone and contain perilymph, and the membranous labyrinth ducts and sacs are within the bony labyrinth and contain endolymph.

The bony labyrinth is divided into the *vestibule*, *semicircular canals*, and *cochlea*. The inner ear includes three *semicircular canals*, which function in providing a sense of equilibrium, and the *cochlea* (a spiral-shaped structure) which function in hearing.

The cochlea is divided into two compartments:

a. **scala vestibuli** (upper) - leads from the oval window to the apex of the spiral.

b. **scala tympani** (lower) - extends from the apex of the cochlea to the membrane-bound opening in the walls of the inner ear called the *round window*.

The portion of the membranous labyrinth within the cochlea is called the *cochlear duct*. It lies between the bony compartment and ends as a closed sac at the apex of the cochlea. The cochlear duct is separated from the scala vestibuli by a vestibular membrane (*Reissner’s membrane*) and from the scala tympani by a *basilar membrane*. The basilar membrane contains thousands of stiff, elastic fibers, whose lengths vary, becoming progressively longer from the base of the cochlea to its apex.

An *organ of Corti*, which contains hearing receptors, is located on the upper surface of the basilar membrane and stretches from the apex to the base of the cochlea. The receptor cells are arranged in rows, and they possess numerous hairlike processes that project into the endolymph of the cochlear duct. Above the hair cells is a *tectorial membrane*, which is attached to the bony shelf of the cochlea. It passes over the receptor cells and makes contact with the tips of their hairs. The receptors are stimulated by vibrations in the fluids of the inner ear.
Sound

Sounds are created by vibrating objects, and the vibrations are transmitted through matter in the form of sound waves. The auricle helps collect sound waves traveling through air and directs them into the auditory meatus.

Sound waves that enter the auditory meatus cause pressure changes on the eardrum, which moves back and forth in response and produces vibrations of the sound wave source. The malleus is attached to the eardrum, and when the eardrum vibrates, the malleus vibrates in unison. The malleus is connected to the incus which then vibrates and passes the movement on to the stapes to which the incus is attached. The stapes is held by ligaments to the oval window which leads to the inner ear. Vibration of the stapes at the oval window causes motion of a perilymph fluid of the vestibule within the inner ear, which is responsible for stimulating the hearing receptors. These vibrations have increased in force because the ossicles transmit vibrations from a relatively large surface of the eardrum to a much smaller area at the oval window, resulting in a more concentrated vibrational force.

Sound vibrations entering the perilymph at the oval window travel along the scala vestibuli and pass through the vestibular membrane and into the endolymph of the cochlear duct, where they cause movements in the basilar membrane.

After passing through the basilar membrane, the vibrations enter the perilymph of the scala tympani, and their forces are dissipated into the air of the tympanic cavity by movements of the membrane covering the round window (bulges outward). The round window separates the perilymph of the cochlea from the air space of the middle ear.

As sound vibrations pass through the inner ear, the hairs move back and forth against the tectorial membrane, and the resulting mechanical deformation of the hairs stimulates the receptor cells. Various receptor cells have slightly different sensitivities to the deformation of these hairs. A sound that produces a particular frequency of vibration excites certain receptor cells, and a sound involving another frequency stimulates a different set of hair cells.

Although the hearing receptor cells are epithelial cells, they act somewhat like neurons. When they are at rest, the membrane is polarized and when stimulated, the membrane becomes depolarized, its ion channels open, and becomes more permeable to calcium ions. The receptor cell has no dendrites, however, it has vesicles containing neurotransmitters in the cytoplasm near its base. In the presence of calcium ions, some of these vesicles fuse with the cell membrane and release neurotransmitters. The neurotransmitter stimulates the nearby ends of sensory nerve fibers, and in response they transmit impulses along auditory nerve fibers to the cochlear branch of the vestibulocochlear nerve and then to the auditory cortex of the temporal lobe of the brain. Some auditory nerve fibers cross over, so that the impulses arising from each ear are interpreted on both sides of the brain.
Sense of Equilibrium

The equilibrium receptors of the inner ear are called the vestibular apparatus and are located in a bony chamber (vestibule) between the semicircular canals and cochlea.

There are two types of equilibrium:

1. **Static equilibrium** - concerned with maintaining the stability of the head and body when they are motionless. The receptors are the macula which are located in two chambers of the vestibule called the saccule and utricle. A macula consists of hair cells that project upward into a gelatinous mass that contains grains of calcium carbonate (otoliths) embedded in it. Movement of the head forward, backward, or to the side cause the otolith membrane to move, pulling and bending the hair cells and initiating action potentials in the vestibular nerve fibers. The resulting nerve impulses travel into the CNS along the vestibular branch of the vestibulocochlear nerve. These impulses inform the brain as to the position of the head. The brain acts on this information by sending motor impulses to skeletal muscles, and they contract or relax appropriately so that balance is maintained.

2. **Dynamic equilibrium** - concerned with balancing the head and body when they are moved or rotated suddenly. Suspended in the perilymph of the bony portion of each semicircular canal is a membranous canal that ends in a swelling (ampulla). The sensory organ of the semicircular canals are located in the ampulla. The receptor, the crista ampullaris within the semicircular duct, responds to angular movements in one plane. It consists of a tuft of hair cells whose microvilli are embedded in the gelatinous cupula. Hair cells are stimulated by rapid turns of the head or body which cause the endolymph to flow in the opposite direction, bending the cupula and exciting the hair cells. Impulses travel along the vestibular branch of the vestibulocochlear nerve to the brain. The cerebellum interprets impulses from the semicircular canals allowing the brain to predict the consequences of rapid body movements and by stimulating skeletal muscles appropriately, the brain can prevent loss of balance.