The Special Senses

We receive information about our environment through sensory nerves located in a number of organs – the skin, eyes, ears, taste buds and olfactory organs. In order for us to perceive a sensation in our brain, energy must first stimulate a nerve causing it to depolarize. This is called a transduction. Different sensory nerves respond to different forms of energy – light, chemicals, vibration (mechanical), etc. Certain sensory organs have evolved for these nerves to better respond to the sources of energy.

Gustation and Olfaction

Our senses of taste (gustation) and smell (olfaction) depend on chemorecptors that respond to chemicals in an aqueous solution. The receptor organs for taste are called taste buds and are concentrated on the tongue though a few may be found on the soft palate, the inside of the cheeks, and even the epiglottis. Tastebuds on the tongue are found on papillae, minute "bumps" on the tongue that give the tongue a rough texture. There may be many taste buds on a papilla. The taste bud consists of several dozen epithelium cells of two types:

- gustatory cells which are arranged like sections of an orange. From the ends of these project long microvilli called gustatory hairs which extend through a taste pore to the surface.
- Deep to the gustatory cells are basal cells which divide into new gustatory cells. Because gustatory cells are subjected to so much erosion, these cells divide rapidly, replacing gustatory cells about every week or so.

In order for the sensation of taste to occur certain chemicals bind to the gustatory hairs. This causes a depolarization of the cell membrane which then synapses with sensory nerve dendrites of cranial nerves VII and IX, attached to the gustatory cell. For a chemical to bind to the gustatory hairs, it must first be in an aqueous solution (dissolved in saliva).

There are five basic taste sensations:

- <u>Sweet.</u> The sweet sensation is triggered by a number of organic molecules, mostly sugars but some alcohols and amino acids, and by some lead compounds.
- <u>Sour.</u> This taste is produced by the H+ ions in acids.
- <u>Salt.</u> The taste of salt is produced by certain metal ions such as Na+.
- <u>Bitter.</u> The bitter taste comes from plant alkaloids such as caffeine and nicotine and some other nonalkaloid chemicals.
- <u>Umami.</u> This "beefy" taste comes from a few amino acids.

Most taste buds respond to more than one of these and our taste sensation is usually a mixture of several of these. All of the other rich sensations we have while eating (e.g. chocolate) are really perceived through olfaction. (p467)

Our organs of smell consist of two patches of epithelial tissue not much larger than a postage stamp located near the top of the nasal cavity. It contains millions of olfactory receptor cells, bipolar neurons ending in olfactory cilia. The cilia (nonmotile) are cellular extensions bathed in mucus to which chemicals bind. These cells are surrounded by supporting cells. At the base of the epithelium are basal cells. Bundles of axons of the olfactory receptor cells pass through the foramina of the cribriform plate of the ethmoid bone and then synapse with neurons of the olfactory bulbs of cranial nerve I.

To smell something the chemical must first become aerosolized, it must be volatile. It must then dissolve in the mucus before binding to the olfactory cilia. The chemical binding causes the bipolar neurons to depolarize. There are many (at least a thousand) different receptor proteins on the membranes of the olfactory cilia. A receptor protein may respond to several different chemicals and each chemical may bind to several different kinds of proteins. The average person can detect about 4,000 different odors. (pp 465 – 466)

Light Reception

Gross Anatomy of the Eye
Our upper and lower eyelids meet at the medial and lateral canthi. Some people, most notably those of oriental descent have a fold of skin, the epicanthal fold, covering the medial canthus. The eyelashes are innervated with sensitive nerve endings that initiate the blinking reflex when stimulated. Among the glands associated with the eyelids are modified sweat glands called ciliary glands located between the follicles of the eyelashes. The conjunctiva is a transparent membrane that covers the anterior surface of the eye and then folds back to cover the inside of the eyelid. The space between these two parts is called the conjunctival sac. Pinkeye, or conjunctivitis, is a highly contagious infection that may be caused by any of a number of bacteria and viruses.

The lacrimal apparatus consists of the lacrimal gland located superior and lateral to each eye. Its product, tears, are secreted through ducts to the superior part of the conjunctival sac. Two puncta above and below the medial canthus collect the tears and transport them through the lacrimal canals to the lacrimal sac contained within the lacrimal fossa of the lacrimal bone. From there, the tears pass through the nasolacrimal duct into the nasal cavity. (pp 561 – 562)

There are six extrinsic eye muscles. Four, the lateral rectus, medial rectus, superior rectus and the inferior rectus, when contracted, move the eyeball laterally, medially, superiorly and inferiorly respectively. The inferior oblique rotates the eye upwards and laterally. The superior oblique is unique in that its tendon passes through a pulley-like structure, called the trochlea, that causes the eye to rotate downward and laterally. (p563) The lateral rectus is controlled by cranial nerve VI and the superior oblique is controlled by cranial nerve IV. The four remaining are controlled by cranial nerve III. Dilopia is a condition of double vision where the extrinsic eye muscles are not coordinated, as may be the case during alcohol intoxication. Strabismus is a condition in which one of the eyes is “lazy” and rotates medially or laterally. The brain will disregard information from this eye and rely entirely on the focusing eye. Treatment may invole a patch over the good eye forcing the “lazy” eye to do the work of seeing thereby strengthening the eye muscles. (pp 447 – 449)

The wall of the eyeball has three layers:
- The fibrous tunic consists of the sclera, the white of the eye forming the posterior 5/6 of the eye and the cornea, the anterior 1/6 that is transparent and bulges out from the sclera. The sclera protects and shapes the eyeball and provides attachment sites for the extrinsic eye muscles. The cornea is well-innervated with pain receptors.
- The vascular tunic (or uvea) contains the choroid, a vascularized membrane whose vessels provide nourishment to the other tunics. The coroid covers most of the inside of the eye except the anterior portion and contains many melanocytes. The melanin pigment absorbs light and helps prevent the scattering and reflection of light within the eye. Anteriorly the choroids becomes thickened as the ciliary body. This contains the ciliary muscles which attach to the lens of the eye via the suspensory ligaments. These muscles hold the lens in place and control its shape, important in focusing light. The iris, the colored part of the eye, surrounds a space called the pupil. Smooth muscles within the iris constrict and dilate the pupil.
- The sensory tunic, or retina, is two-layered. There is an outer pigmented layer in which Vitamin A is stored (vitamin A is also stored in the liver). This layer also absorbs light and prevents scattering. The neural layer contains the photoreceptors (rods & cones), bipolar cells, ganglion cells. The photoreceptors are embedded within the pigmented layer and they synapse with the bipolar neurons which synapse with the innermost ganglion neurons. The axons of the ganglion neurons are bundled together and form the optic nerve. Where the optic nerve exits the eye is the optic disc, a blind spot because it lacks photoreceptors and light focused on it cannot be seen. The macula lutea, located at the very posterior part of the retina, contains the fovea centralis which is packed with cones and which is the area of greatest visual acuity. Cones decrease in number from the macula to the periphery of the retina. Macular degeneration of the eye leads to visual impairment in some people (usually over 50) preventing them from reading and performing fine, discriminating visual work. (pp 449 – 451)

The Lens (cataracts are a clouding of the lenses) is held in place just in back of the iris by the suspensory ligament and focuses light on to the retina. With age it becomes more dense, more convex and less elastic. Aqueous humor, a fluid similar to blood plasma, fills the anterior segment, the space in front of the lens. It is produced from capillaries in the ciliary bodies and, after flowing through the pupil, drains back to venous blood through a small canal at the scleral-corneal junction. Blockage of drain causes glaucoma putting pressure on retina which may result in blindness. The Vitreous humor is there from birth and is not regenerated. It is a clear gel that fills the posterior segment behind the lens. It transmits light, supports the lens, and contributes to intraocular pressure. (pp 453 – 454)

Physiology of Vision
Electromagnetic radiation is energy consisting of waves of various lengths, from thousandths of a nanometer to meters (gamma rays and X-rays to radio waves) Our eyes respond to visible light (400 – 700 nm). Light rays are bent by the convex lens and focused on a focal point forming a real image that is upside-down and backwards and must be reversed by our brains. The point beyond which the lens does not change is normally 20 feet. If the object being focused on is leass than 20 ft., certain eye adjustments are made. These include the accommodation of lenses, making the lenses bulge thereby shortening the focal length (the decreasing loss of accommodation is called presbyopia). The pupils constrict to prevent divergent light from entering the eye. Convergence of the eyeballs also occurs to focus on close objects. Myopia, nearsightedness, and hyperopia, farsightedness, occur when the object is focused in front of, or behind the retina respectively. Emmetropia occurs if the light is being focused properly. Corrective lenses refocus the light to its proper focal length on the retina. The lens or cornea may have distorted curvatures leading to a blurring of images. This is called astigmatism. (pp 454 – 457)

Photoreception
There are two types of photoreceptors: Rods (more numerous) used for dim light and peripheral vision and Cones, used in bright light and high acuity color vision. The photoreceptors synapse with bipolar neurons which also synapse with the ganglion cells of the retina. Light travels through the retina, excites the photoreceptors initiating an action potential which flows back to the ganglion cells and from the optic nerve to the brain. Within the rods are discs with phospholipid bilayer membranes. In these membranes is a light-absorbing pigment called rhodopsin, made up of retinal (vitamin A derivative) and opsin (a protein). Bleaching the pigment occurs when light causes the retinal to change shape and detach from the opsin. The activated opsin initiates a cascade of chemical reactions ending with the opening of Na^+ channels, thus a transduction. In cones, there are three different opsins responding to blue, red and green wavelengths. Stimulation of one or more kinds of cones allows the perception of the color spectrum. (pp 458 – 460)

Hearing and Equilibrium

The outer ear consists of the pinna and the external auditory canal which is lined with modified sebaceous glands called ceruminous glands that secrete ear wax or cerumin. At the boundary between the outer and middle ear is the tympanic membrane or eardrum. Within the middle ear are the three ossicles: the malleus, the incus and the stapes. These bones are suspended by ligaments and the small end of the malleus communicates with tympanic membrane. Also in the middle ear is one end of the pharyngotympanic tube, also called the Eustacian tube, which maintains external atmospheric pressure within the middle ear.

The stapes communicates with the oval window of the inner ear (also called the labyrinth). On the other side of the oval window is the fluid filled vestibule containing two membranous sacs: the saccule and the utricle. Posterior to the vestibule are the three organs of equilibrium, the semicircular canals each oriented to the three planes of space. The swollen end of each of these canals contains the crista ampullaris, the receptor that responds to changes in position.

Anterior to the vestibule is the cochlea (Latin for snail) within which is the receptor organ for hearing: the organ of Corti. The spiral-shaped cochlea is divided into three long ducts or scalae called the scala vestibule (superior), the scala media or cochlear duct, and the scala tympani (inferior) that end at the round window. Separating the scala media from the scala vestibuli is the vestibular membrane. Separating the scala media from the scala tympani is the basilar membrane. A branch of cranial nerve VIII, the cochlear nerve, innervates the cochlea. The Organ of Corti consists of the cochlear hair cells and supporting cells resting on the basilar membrane. Some of the hairs are imbedded in the tectorial membrane. (pp 469 – 473)

Properties of Sound
Sound waves are vibrations in the air (or other media) and as waves have the properties of frequency (which we interpret as pitch) and amplitude (which we interpret as volume). We can also distinguish sounds by their quality. Loudness is measured in decibels (dB) and frequency is measured in Hertz (Hz). The threshold of pain is about 130 dB. (p 474)

Physiology of Hearing
Sound waves travel through the outer ear and cause the tympanic membrane to vibrate. This in turn sets the ossicles to vibrate at the same frequency. If a noise is too loud, tiny muscles attached to the malleus and the stapes contract reflexively to keep the ossicles from vibrating too violently. The stapes vibrates the oval window, which in turn sets up a wave in the fluid (perilymph) in the scala vestibule. If frequencies are within the hearing range, these vibrations are transferred to the vestibular membrane and then to the basilar membrane. Vibrations in the basilar membrane causes these hairs to bend which results in the initiation of an action potential. Vibrations continue through the scala tympani until the energy is dissipated through the round window (the relief valve).

Tinnitus is a ringing in the ears without any sound stimulus and may be caused by a number of things including middle ear infection and cochlear nerve degeneration.
Meniere’s Syndrome affects both equilibrium and hearing. It can result in severe vertigo, nausea and tinnitus.
Conduction deafness results when sound conduction is obstructed. Sensoneurial deafness results from damage to the hair cells or nerve cells. (pp 475 – 477)

Static Equilibrium
The sensory receptors for static equilibrium are two maculae, one in the wall of the saccule and one in the wall of the utricle. They respond to *changes* in speed and direction (but not rotation). Each macula contains hair cells and supporting cells. The hairs of the hair cells are imbedded in a gelatinous otolithic membrane. On top of this membrane are many calcium carbonate crystals called otoliths, which add weight to the membrane. In the utricle the hairs are vertical and so respond to acceleration (or deceleration) in the horizontal plane. In the saccule the hairs are horizontal and so respond to vertical changes in velocity. Bending the hairs results in depolarization. (pp 478)

Dynamic Equilibrium
The crista ampullaris is a slightly elevated region in each of the semicircular canals that bears hair cells imbedded in a gelatinous substance called the cupula. When the head is rotated, the fluid in the canals moves briefly in the direction opposite to the rotation deflecting the hairs that results in depolarization. Dizziness results when you stop and the fluid in the canals does not. (p 479)