The Special Senses

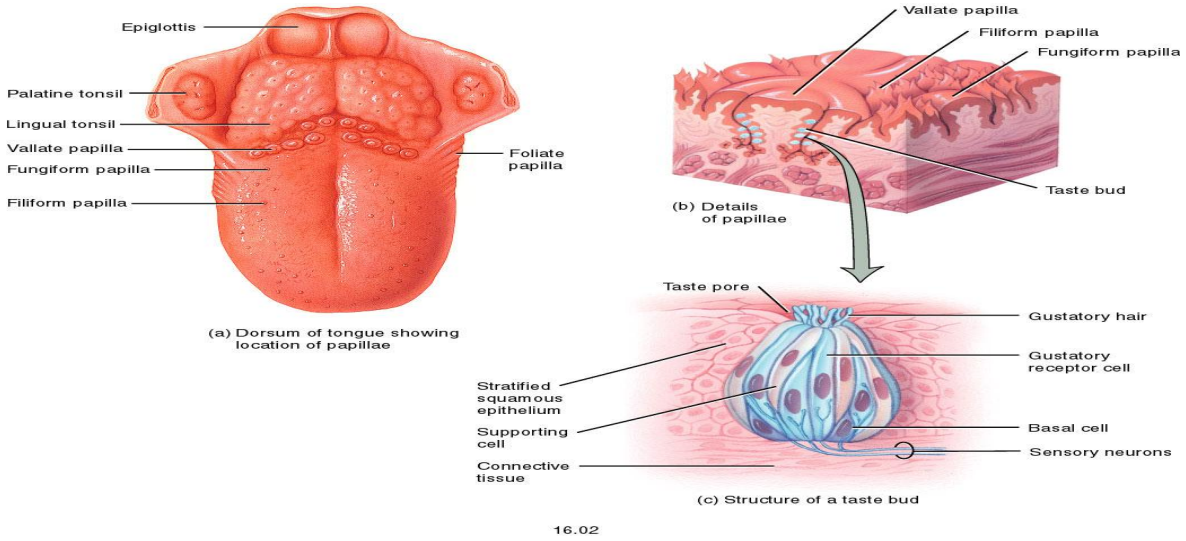
Chemical Senses

- Chemical senses – gustation (taste) and olfaction (smell)
- Their chemoreceptors respond to chemicals in aqueous solution
- Taste – to substances dissolved in saliva
- Smell – to substances dissolved in fluids of the nasal membranes

Taste Buds

- The 10,000 or so taste buds are mostly found on the tongue
- Found in papillae of the tongue mucosa
- Papillae come in three types: filiform, fungiform, and circumvallate
- Fungiform and circumvallate papillae contain taste buds

Anatomy of a Taste Bud



- Each gourd-shaped taste bud consists of three major cell types
- Supporting cells – insulate the receptor
- Basal cells – dynamic stem cells
- Gustatory cells – taste cells

Taste Sensations

- There are four basic taste sensations
- Sweet – sugars, saccharin, alcohol, and some amino acids
- Salt – metal ions
- Sour – hydrogen ions
- Bitter – alkaloids such as quinine and nicotine

-Umami- savory/meaty

Physiology of Taste

- In order to be tasted, a chemical:
- Must be dissolved in saliva
- Contact gustatory hairs
- Binding of the food chemical:
- Depolarizes the taste cell membrane, releasing neurotransmitter
- Initiates a generator potential that elicits an action potential

Taste Transduction

- The stimulus energy of taste is converted into a nerve impulse by:
- Na^+ influx in salty tastes
- H^+ and blockage of K^+ channels in sour tastes
- Gustducin in sweet and bitter tastes

Gustatory Pathways

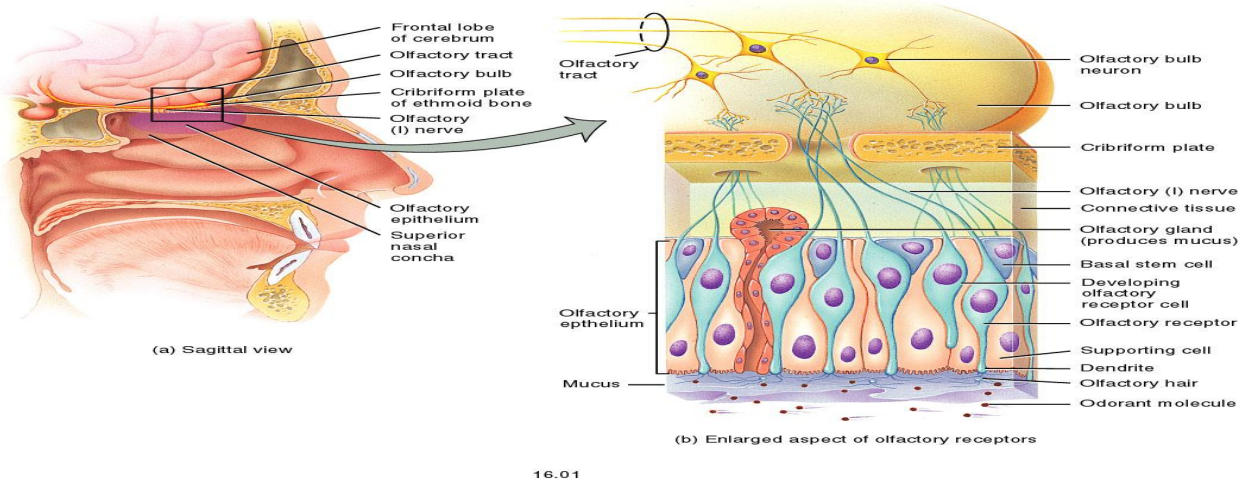
- Cranial Nerves VII and IX carry impulses from taste buds to the solitary nucleus of the medulla
- These impulses then travel to the thalamus, and from there fibers branch to the:
- Gustatory cortex (taste)
- Hypothalamus and limbic system (appreciation of taste)

Influence of Other Sensations on Taste

- Taste is 80% smell

- Thermoreceptors, mechanoreceptors, nociceptors also influence tastes
- Temperature and texture enhance or detract from taste

Sense of Smell



- The organ of smell is the olfactory epithelium, which covers the superior nasal concha
- Olfactory receptor cells are bipolar neurons with radiating olfactory cilia
- They are surrounded and cushioned by supporting cells
- Basal cells lie at the base of the epithelium

Physiology of Smell

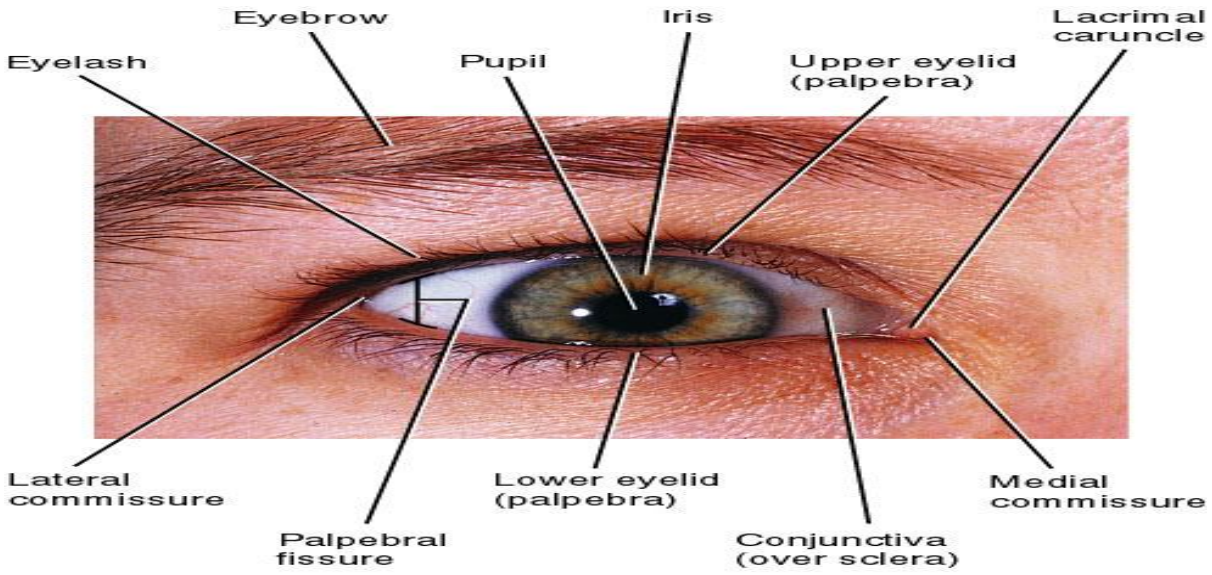
- Olfactory receptors respond to several different odor causing chemicals
- When bound to ligand these proteins initiate a G protein mechanism, which uses cAMP as a second messenger
- cAMP opens sodium channels, causing depolarization of the receptor membrane that then triggers an action potential

Olfactory Pathway

- Olfactory receptor cells synapse with mitral cells
- Glomerular mitral cells process odor signals
- Mitral cells send impulses to:

- The olfactory cortex
- The hypothalamus, amygdala, and limbic system

Eye and Associated Structures



16.04

- 70% of all sensory receptors are in the eye
- Photoreceptors – sense and encode light patterns
- The brain fashions images from visual input
- Accessory structures include:
- Eyebrows, eyelids, conjunctiva
- Lacrimal apparatus and extrinsic eye muscles

Eyebrows

- Coarse hairs the overlie the supraorbital margins
- Functions include:
- Shading the eye
- Preventing perspiration from reaching the eye

- Orbicularis muscle – depresses the eyebrows
- Corrugator muscles – move the eyebrows medially

Palpebrae (Eyelids)

- Protect the eye anteriorly
- Palpebral fissure – separates eyelids
- Canthi - medial and lateral angles (commissures)
- Lacrimal caruncle – contains glands that secrete a whitish, oily secretion ("Sandman's eye sand")
- Tarsal plates of connective tissue support the eyelids internally
- Levator palpebrae superioris – gives the upper eyelid mobility

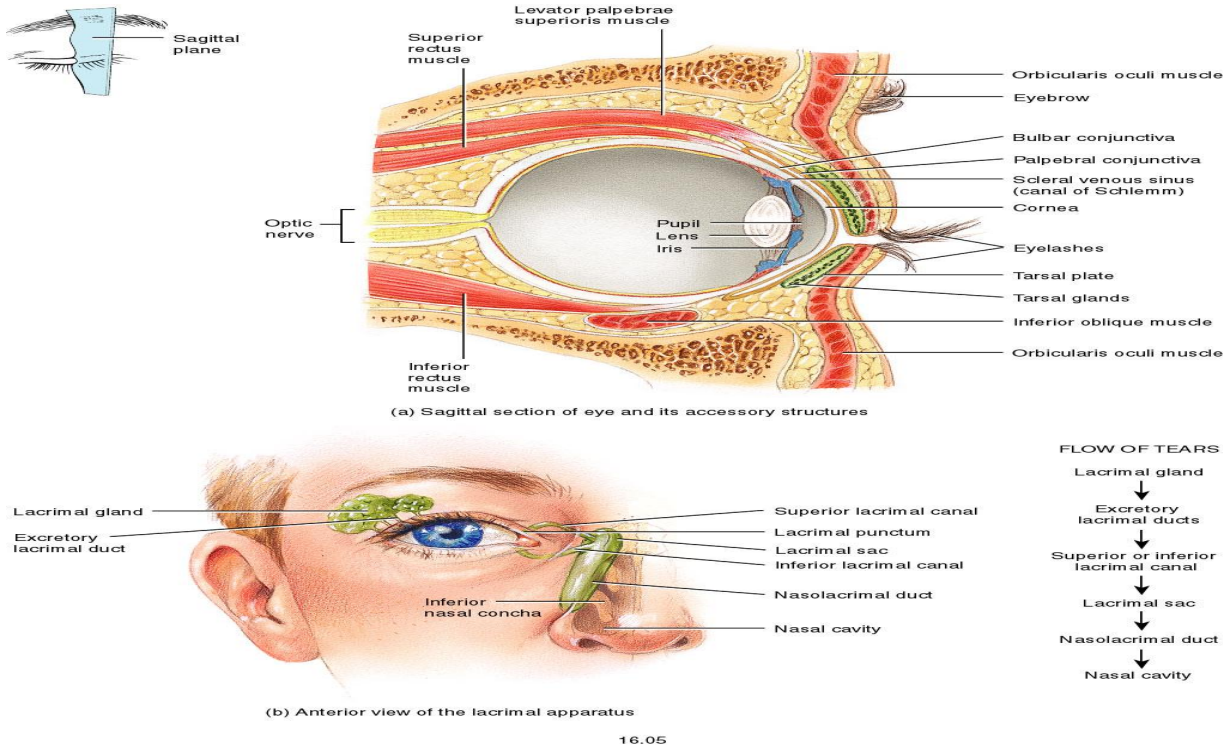
Accessory Structures of the Eye

- Eyelashes
- Project from the free margin of each eyelid
- Initiate reflex blinking
- Lubricating glands associated with the eyelids
- Meibomian glands and sebaceous glands
- Ciliary glands

Conjunctiva

- Transparent membrane that:
- Lines the eyelids as the palpebral conjunctiva
- Covers the whites of the eyes as the ocular conjunctiva
- Lubricates and protects the eye

Lacrimal Apparatus



- Consists of the lacrimal gland and associated ducts
- Lacrimal glands secrete tears
- Tears
- Contain mucus, antibodies, and lysozyme
- Enter the eye via superolateral excretory ducts
- Exit the eye medially via the lacrimal punctum
- Drain into the nasolacrimal duct

Extrinsic Eye Muscles

- Six straplike extrinsic eye muscles
- Enable the eye to follow moving objects
- Maintain the shape of the eyeball
- The two basic types of eye movements are:
- Saccades – small, jerky movements
- Scanning movements – tracking an object through the visual field

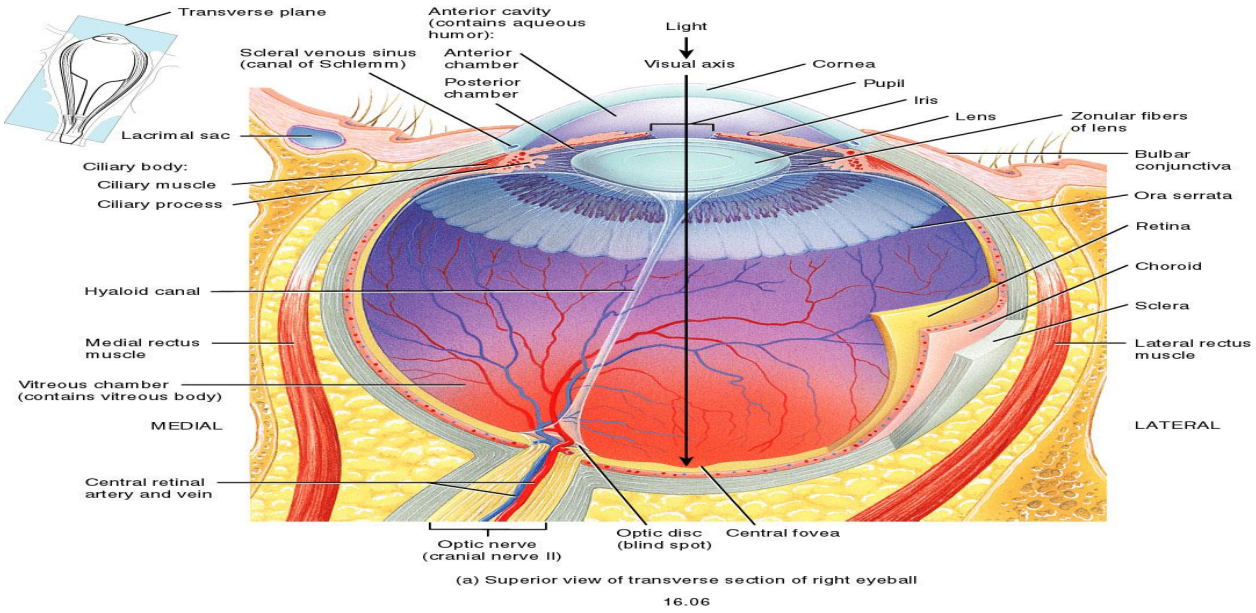
Summary of Cranial Nerves and Muscle Actions

- **Names, actions, and cranial nerve innervation of the extrinsic eye muscles**

Inferior rectus		Eye downwards	
Inferior oblique		Rotate eye lat	
Superior rectus	Occulomotor	Eye upwards	
Medial rectus		Eye medially	
Lateral rectus	abducens	Eye laterally	
Superior oblique	Trochlear	Ratate eye medi	

Also levator palpabrae superioris – elevates upper eye lid by occulomotor

Structure of the Eyeball



(a) Superior view of transverse section of right eyeball

16.06

- A slightly irregular hollow sphere with anterior and posterior poles
- The wall is composed of three tunics – fibrous, vascular, and sensory
- The internal cavity is fluid filled with humors – aqueous and vitreous
- The lens separates the internal cavity into anterior and posterior segments

Fibrous Tunic

- Forms the outermost coat of the eye and is composed of:
- Opaque sclera (posterior)
- Clear cornea (anterior)
- Sclera – protects the eye and anchors extrinsic muscles

- Cornea – lets light enter the eye

Vascular Tunic (Uvea): Choroid Region

- Has three regions: choroid, ciliary body, and iris
- Choroid region
- A dark brown membrane that forms the posterior portion of the uvea
- Supplies blood to all eye tunics

Vascular Tunic: Ciliary Body

- A thickened ring of tissue surrounding the lens
- Composed of smooth muscle bundles (ciliary muscles)
- Anchors the suspensory ligament that holds the lens in place

Vascular Tunic: Iris

- The colored part of the eye
- Pupil – central opening of the iris
- Regulates the amount of light entering the eye during:
- Close vision and bright light – pupils constrict
- Distant vision and dim light – pupils dilate
- Changes in emotional state – pupils dilate when the subject matter is appealing or requires problem solving skills

Sensory Tunic: Retina

- A delicate two-layered membrane
- Pigmented layer – the outer layer that absorbs light and prevents its scattering
- Neural layer, which contains:
- Photoreceptors that transduce light energy
- Bipolar cells and ganglion cells
- Amacrine and horizontal cells

The Retina: Ganglion Cells and the Optic Disc

- Ganglion cell axons:
- Run along the inner surface of the retina
- Leave the eye as the optic nerve
- The optic disc:
- Is the site where the optic nerve leaves the eye
- Lacks photoreceptors (the blind spot)

The Retina: Photoreceptors

- Rods:
- Respond to dim light
- Are used for peripheral vision
- Cones:
- Respond to bright light
- Have high-acuity color vision
- Are found in the macula lutea
- Are concentrated in the fovea centralis

Blood Supply to the Retina

- The neural retina receives it blood supply from two sources
- The outer third receives its blood from the choroid
- The inner two-thirds are served by the central artery and vein
- Small vessels radiate out from the optic disc and can be seen with an ophthalmoscope

Inner Chambers and Fluids

- The lens separates the internal eye into anterior and posterior segments
- The posterior segment is filled with a clear gel called vitreous humor that:
- Transmits light
- Supports the posterior surface of the lens

- Holds the neural retina firmly against the pigmented layer
- Contributes to intraocular pressure

Anterior Segment

- Composed of two chambers
- Anterior – between the cornea and the iris
- Posterior – between the iris and the lens
- Aqueous humor
- A plasma-like fluid that fills the anterior segment
- Drains via the canal of Schlemm
- Supports, nourishes, and removes wastes

The Lens

- A biconvex, transparent, flexible, avascular structure that:
- Allows precise focusing of light onto the retina
- Is composed of epithelium and lens fibers
- Lens epithelium – anterior cells that differentiate into lens fibers
- Lens fibers – cells filled with the clear protein crystalline
- With age, the lens becomes more compact and dense and loses its elasticity

Light

- Electromagnetic radiation – all energy waves from short gamma rays to long radio waves
- Our eyes respond to a small portion of this spectrum called the *visible spectrum*
- Different cones in the retina respond to different wavelengths of the visible spectrum

Refraction and Lenses

- When light passes from one transparent medium to another its speed changes and it refracts (bends)

- Light passing through a convex lens (as is in the eye) is bent so that the rays converge to a focal point

- When a convex lens forms an image, the image is upside down and reversed right to left

Focusing Light on the Retina

- Pathway of light entering the eye: cornea, aqueous humor, lens, vitreous humor, and the neural layer of the retina to the photoreceptors

- Light is refracted:

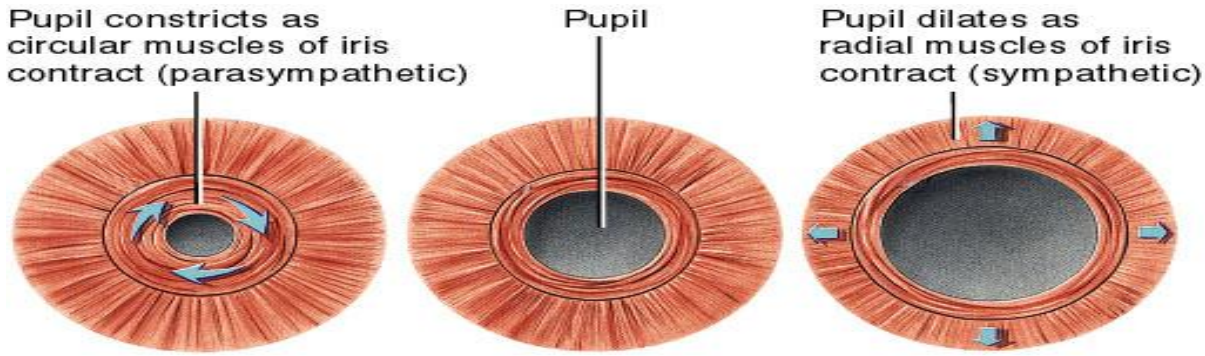
- At the cornea

- Entering the lens

- Leaving the lens

- The lens curvature and shape allow for fine focusing of an image

Focusing for Distant Vision



- Light from a distance needs little adjustment for proper focusing

- Far point of vision – the distance beyond which the lens does not need to change shape to focus (20ft)

Focusing for Close Vision

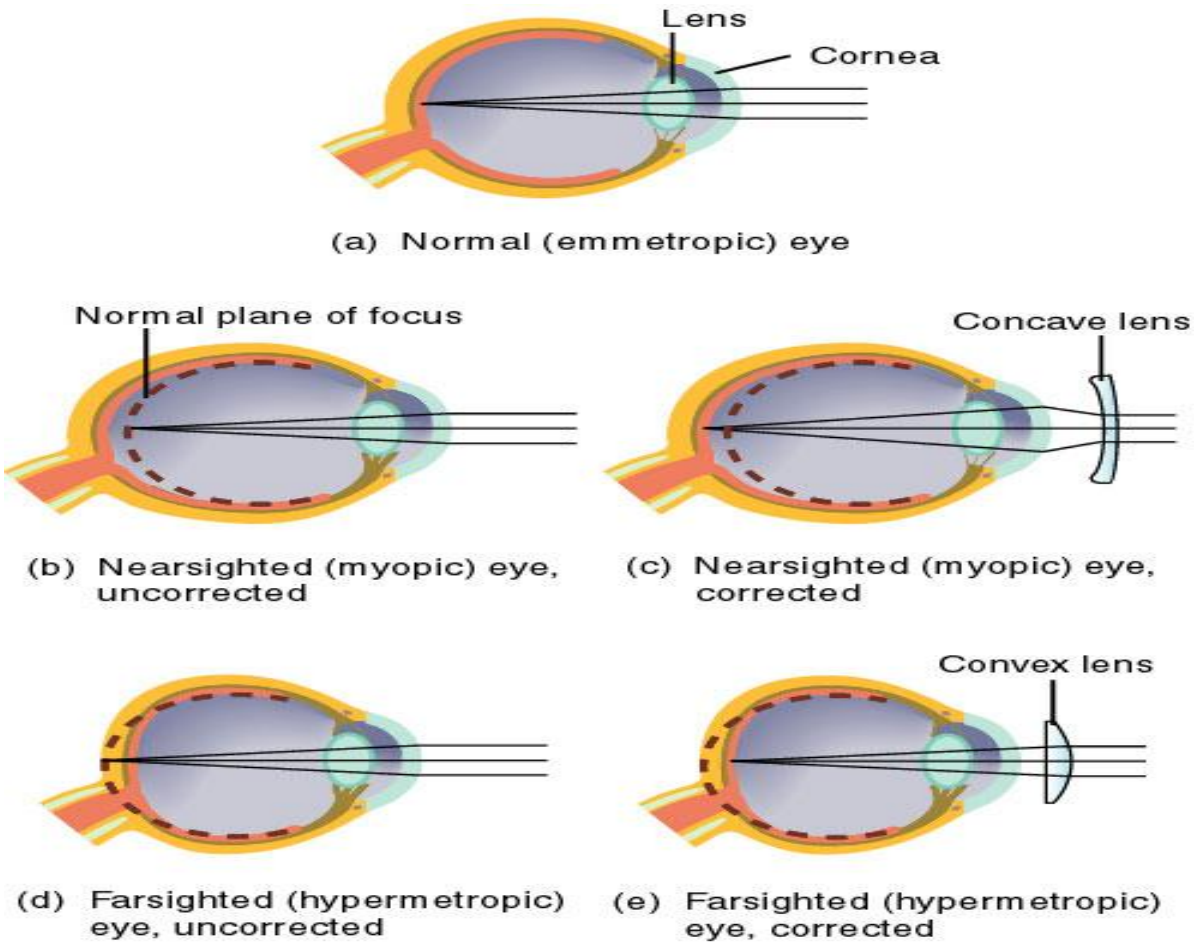
- Close vision requires:

- Accommodation – changing the lens shape by ciliary muscles to increase refractory power

- Constriction – the pupillary reflex constricts the pupils to prevent divergent light rays from entering the eye
- Convergence – medial rotation of the eyeballs toward the object being viewed

Problems of Refraction

- Emmetropic eye – normal eye with light focused properly
- Myopic eye (nearsighted) – the focal point is in front of the retina
- Corrected with a concave lens
- Hyperopic eye (farsighted) – the focal point is behind the retina
- Corrected with a convex lens



16.12

Photoreception: Functional Anatomy of Photoreceptors

- Photoreception – process by which the eye detects light energy

- Rods and cones contain visual pigments (photopigments)
- Arranged in a stack of disk-likeinfoldings of the plasma membrane that change shape as they absorb light

Rods

- Functional characteristics
- Sensitive to dim light and best suited for night vision
- Absorb all wavelengths of visible light
- Perceived input is in gray tones only
- Sum visual input from many rods feed into a single ganglion cell
- Results in fuzzy and indistinct images

Cones

- Functional characteristics
- Need bright light for activation (have low sensitivity)
- Pigments that furnish a vividly colored view
- Each cone synapses with a single ganglion cell
- Vision is detailed and has high resolution

Chemistry of Visual Pigments

- Retinal – a light-absorbing molecule
- Combines with opsins to form visual pigments
- Similar to and is synthesized from vitamin A
- Two isomers: 11-*cis* and all-*trans*
- Isomerization of retinal initiates electrical impulses in the optic nerve

Excitation of Rods

- The visual pigment of rods is *Rhodopsin* (opsin + 11-*cis* retinal)
- Light phase
- Rhodopsin breaks down into all-*trans* retinal + opsin (bleaching of the pigment)

- Dark phase
- All-*trans* retinal converts to 11-*cis* form
- 11-*cis* retinal is also formed from vitamin A
- 11-*cis* retinal + opsin regenerate rhodopsin

Excitation of Cones

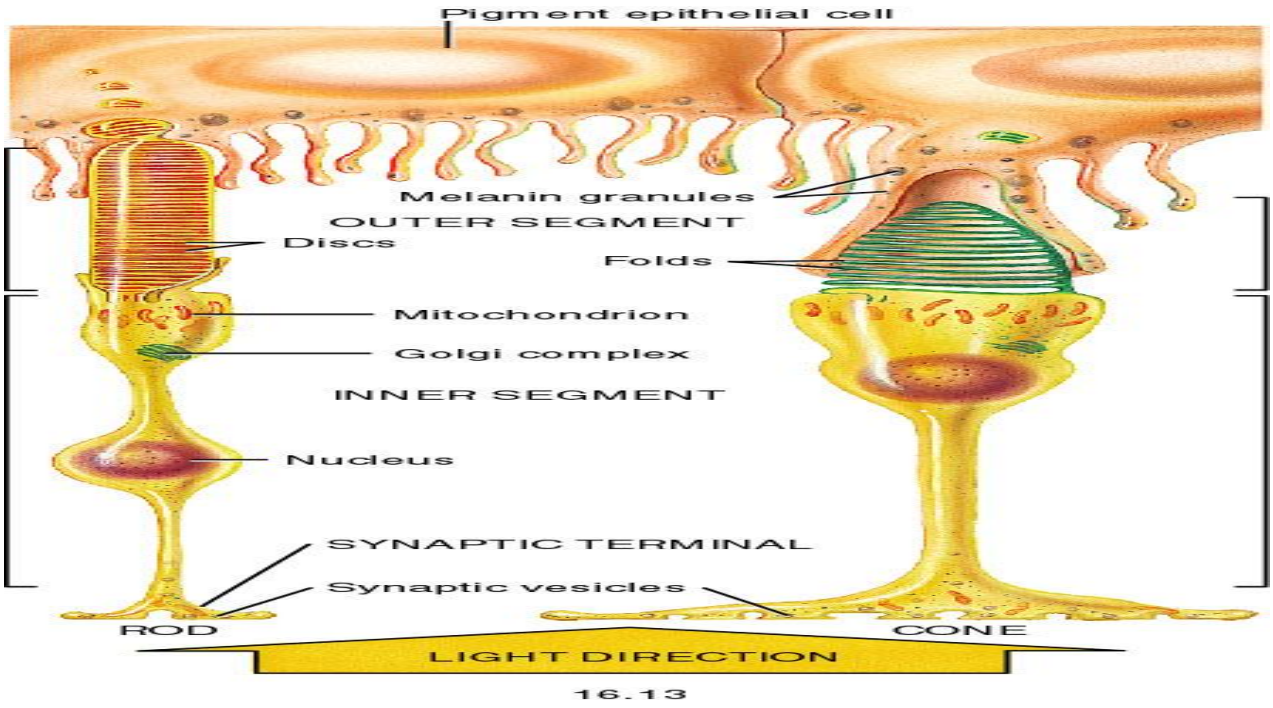
- Visual pigments in cones are similar to rods (retinal + opsins)
- There are three types of cones: blue, green, and red
- Intermediate colors are perceived by activation of more than one type of cone
- Method of excitation is similar to rods

Phototransduction

- Light energy splits rhodopsin into all-*trans* retinal, releasing activated opsin
- The freed opsin activates the G protein transducin
- Transducin catalyzes activation of phosphodiesterase enzyme (PDE)
- PDE hydrolyzes cGMP to GMP and releases it from sodium channels
- Without bound cGMP, sodium channels close, the membrane hyperpolarizes, and neurotransmitter cannot be released

Adaptation

- Adaptation to bright light (going from dark to light) involves:
- Dramatic decreases in retinal sensitivity – rod function is lost
- Switching from the rod to the cone system – visual acuity is gained
- Adaptation to dark is the reverse
- Cones stop functioning in low light
- Rhodopsin accumulates in the dark and retinal sensitivity is restored



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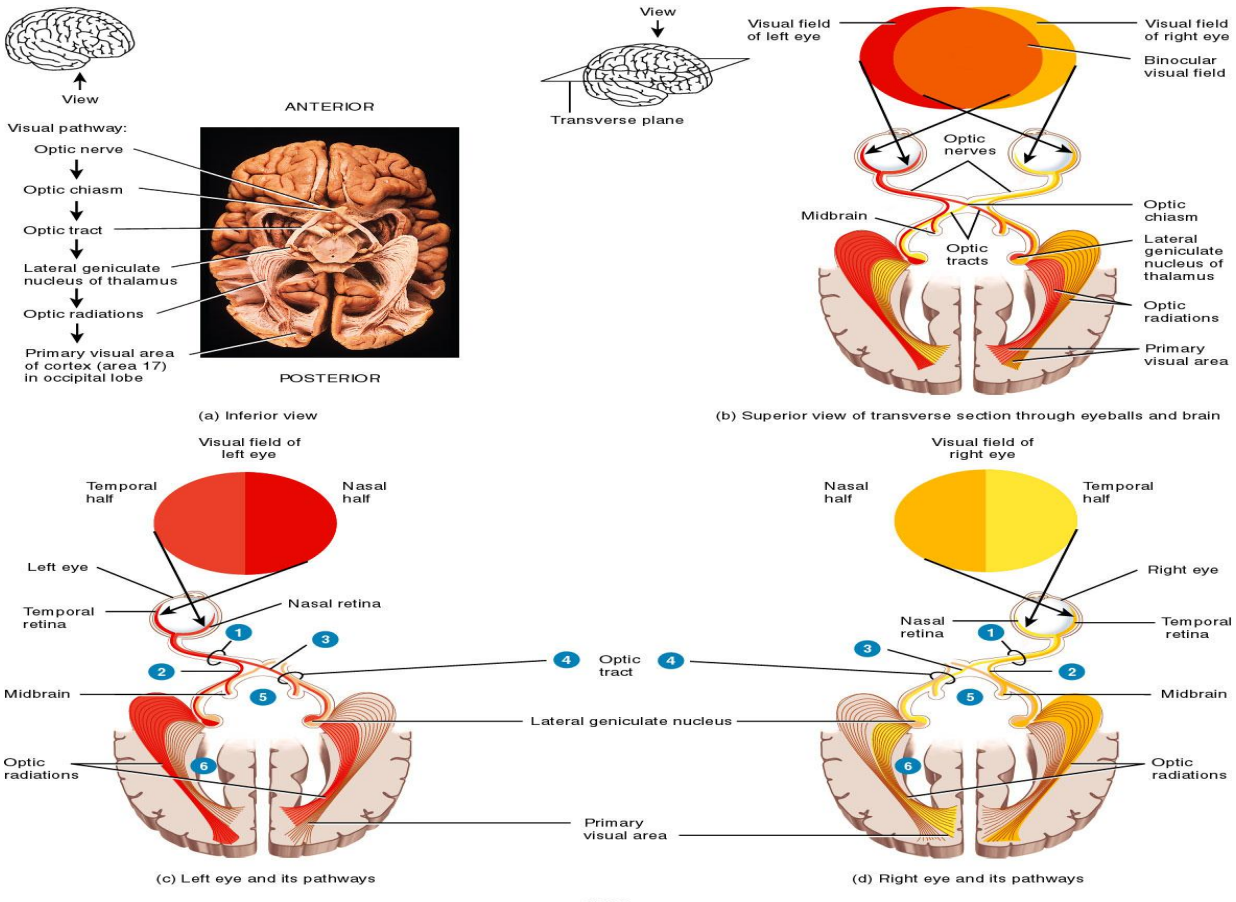
Visual Pathways



16.16

- Axons of retinal ganglion cells form the optic nerve

- Medial fibers of the optic nerve decussate at the optic chiasm
- Most fibers of the optic tracts continue to the lateral geniculate body of the thalamus
- Other optic tract fibers end in superior colliculi (initiating visual reflexes) and pretectal nuclei (involved with pupillary reflexes)
- Optic radiations travel from the thalamus to the visual cortex

Depth Perception

- Achieved by both eyes viewing the same image from slightly different angles
- Three-dimensional vision results from cortical fusion of the slightly different images
- If only one eye is used, depth perception is lost and the observer must rely on learned clues to determine depth

Retinal Processing: Receptive Fields of Ganglion Cells

- On-center fields
- Stimulated by light hitting the center of the field
- Inhibited by light hitting the periphery of the field
- Off-center fields have the opposite effects
- These responses are due to receptor types in the “on” and “off” fields

Thalamic Processing

- The lateral geniculate nuclei of the thalamus:
- Relay information on movement
- Segregate the retinal axons in preparation for depth perception
- Emphasize visual inputs from regions of high cone density
- Sharpen the contrast information received by the retina

Cortical Processing

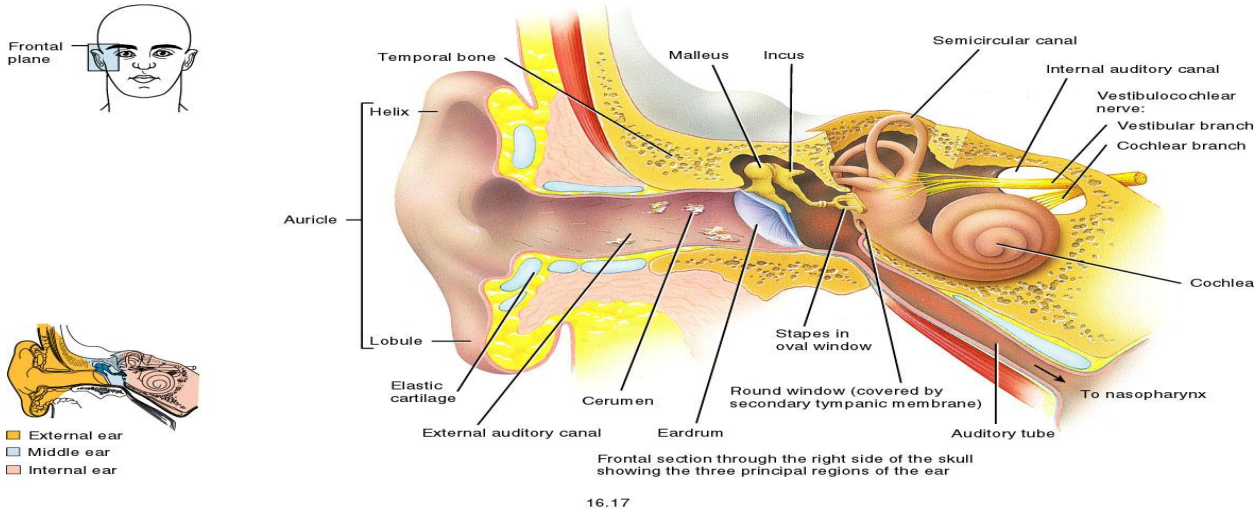
- Striate cortex processes
- Basic dark/bright and contrast information
- Prestriate cortices (association areas) processes

- Form, color, and movement
- Visual information then proceeds anteriorly to the:
- Temporal lobe – processes identification of objects
- Parietal cortex and postcentralgyrus – processes spatial location

Image Problems

- Cataracts
- Age-related macular disease
- Presbyopia (loss of lens elasticity)
- Color Blindness
- Light and dark adaptation

The Ear: Hearing and Balance



- The three parts of the ear are the inner, outer, and middle ear
- The outer and middle ear are involved with hearing
- The inner ear functions in both hearing and equilibrium
- Receptors for hearing and balance:
- Respond to separate stimuli
- Are activated independently

Outer Ear

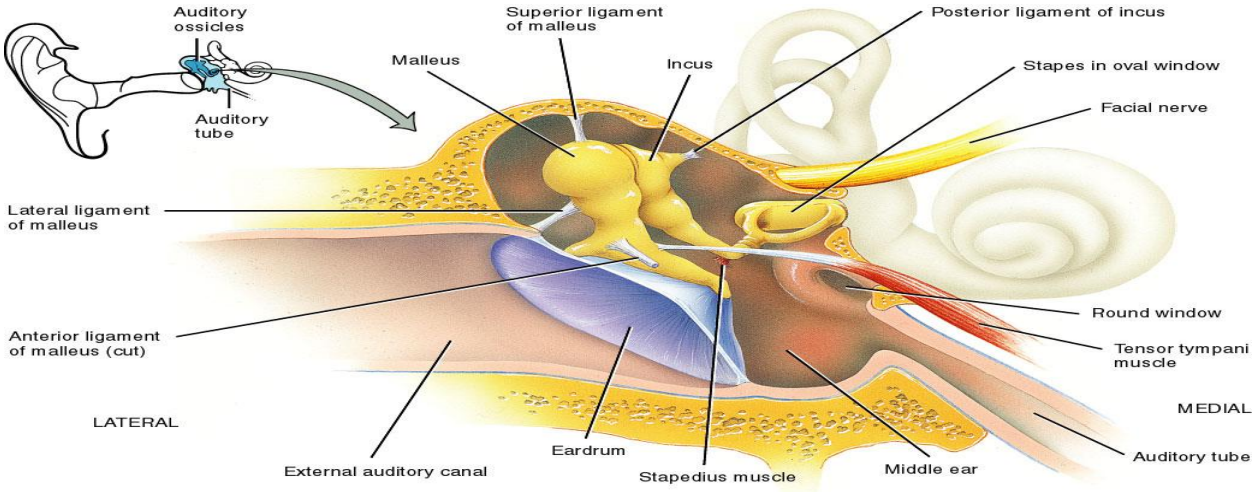
- The auricle (pinna) is composed of:
- Helix (rim)
- The lobule (earlobe)
- External auditory canal
- Short, curved tube filled with ceruminous glands
- Tympanic membrane (eardrum)
- Thin connective tissue membrane that vibrates in response to sound
- Transfers sound energy to the middle ear ossicles
- Boundary between outer and middle ears

Middle Ear (Tympanic Cavity)

- A small, air-filled, mucosa-lined cavity
- Flanked laterally by the eardrum
- Flanked medially by the oval and round windows
- Epitympanic recess – superior portion of the middle ear
- Pharyngotympanic tube – connects the middle ear to the nasopharynx
- Equalizes pressure in the middle ear cavity with the external air pressure

Ear Ossicles

- The tympanic cavity contains three small bones: the malleus, incus, and stapes
- Transmit vibratory motion of the eardrum to the oval window
- Dampened by the tensor tympani and stapedius muscles



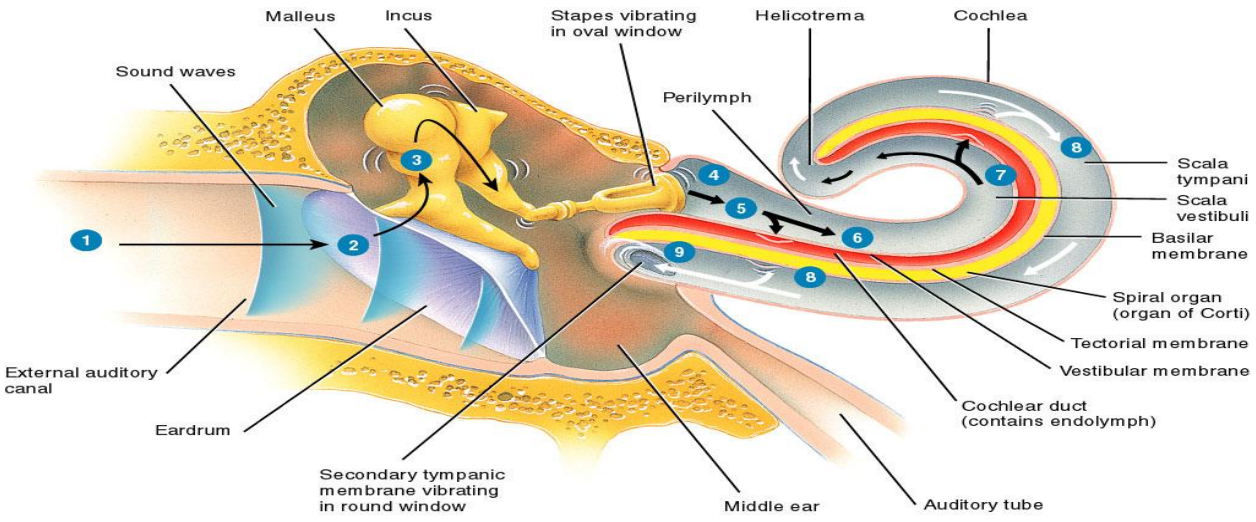
Frontal section showing location of auditory ossicles

16.18

•Loudness is perceived by:

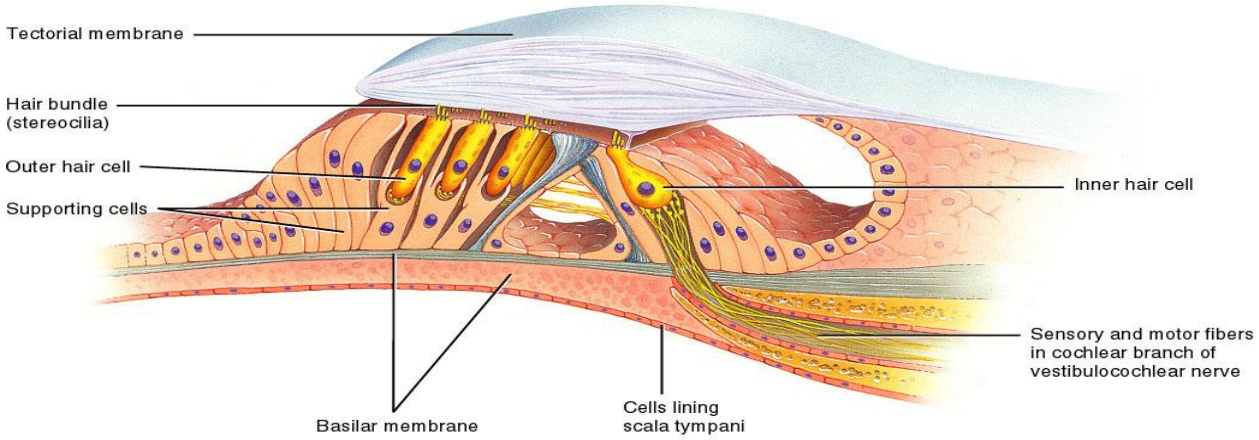
- •Varying thresholds of cochlear cells
- •The number of cells stimulated

The Organ of Corti



16.21

- Is composed of supporting cells and outer and inner hair cells
- Afferent fibers of the cochlear nerve attach to the base of hair cells
- The stereocilia (hairs):
- Protrude into the endolymph
- Touch the tectorial membrane



(d) Enlargement of spiral organ (organ of Corti)

16.20d

Excitation of Hair Cells in the Organ of Corti

- Bending cilia:
- Opens mechanically-gated ion channels
- Causes a graded potential and the release of a neurotransmitter (probably glutamate)
- The neurotransmitter causes cochlear fibers to transmit impulses to the brain, where sound is perceived

Auditory Pathway to the Brain

- Impulses from the cochlea pass via the spiral ganglion to the cochlear nuclei
- From there, impulses are sent to the:
- Superior olivary nucleus
- Inferior colliculus (auditory reflex center)
- From there, impulses pass to the auditory cortex
- Auditory pathways decussate so that both cortices receive input from both ears

Auditory Processing

- Pitch is perceived by:
- The primary auditory cortex
- Cochlear nuclei
- Loudness is perceived by:

- Varying thresholds of cochlear cells
- The number of cells stimulated
- Localization is perceived by superior olivary nuclei that determine sound

Deafness

- Conduction deafness – something hampers sound conduction to the fluids of the inner ear (e.g., impacted earwax, perforated eardrum, osteosclerosis of the ossicles)
- Sensorineural deafness – results from damage to the neural structures at any point from the cochlear hair cells to the auditory cortical cells
- Tinnitus – ringing or clicking sound in the ears in the absence of auditory stimuli
- Meniere's syndrome – labyrinth disorder that affects the cochlea and the semicircular canals, causing vertigo, nausea, and vomiting

Mechanisms of Equilibrium and Orientation

- Vestibular apparatus – equilibrium receptors in the semicircular canals and vestibule
- Maintain our orientation and balance in space
- Vestibular receptors monitor static equilibrium
- Semicircular canal receptors monitor dynamic equilibrium

Anatomy of Maculae

- Maculae – the sensory receptors for static equilibrium
- Contain supporting cells and hair cells
- Each hair cell has stereocilia and kinocilium embedded in the otolithic membrane
- Otolithic membrane – jellylike mass studded with tiny $CaCO_3$ stones called otoliths
- Uticular hairs respond to horizontal movement
- Saccular hair respond to vertical movement

Effect of Gravity on Utricular Receptor Cells

- Otolithic movement in the direction of the kinocilia:
- Depolarizes vestibular nerve fibers

- Increases the number of action potentials generated
- Movement in the opposite direction :
- Hyperpolarizes vestibular nerve fibers
- Reduces the rate of impulse propagation
- From this information, the brain is informed of the changing position of the head

Crista Ampullaris and Dynamic Equilibrium

- The crista ampullaris (or crista):
- Is the receptor for dynamic equilibrium
- Is located in the ampulla of each semicircular canal
- Responds to angular movements
- Each crista has support cells and hair cells that extend into a gel-like mass called the cupula
- Dendrites of vestibular nerve fibers encircle the base of the hair cells

Transduction of Rotational Stimuli

- Cristae respond to changes in velocity of rotatory movements of the head
- Directional bending of hair cells in the cristae causes either:
- Depolarizations and rapid impulses reach the brain at a faster rate
- Hyperpolarizations and fewer impulses reach the brain
- The result is that the brain is informed of rotational movements of the head

Balance and Orientation Pathways

- There are three modes of input for balance and orientation
- Vestibular receptors
- Visual receptors
- Somatic receptors
- These receptors allow our body to respond reflexively

Developmental Aspects

- All special senses are functional at birth
- Chemical senses – few problems occur until the fourth decade, when these senses begin to decline
- Vision – optic vesicles protrude from the diencephalon during the 4th week of development
- These vesicles indent to form optic cups and their stalks form optic nerves
- Later, the lens forms from ectoderm
- Vision is not fully functional at birth
- Babies are hyperopic, see only gray tones, and eye movements are uncoordinated
- Depth perception and color vision is well developed by age five and emmetropic eyes are developed by year six
- With age the lens loses clarity, dilator muscles are less efficient, and visual acuity is drastically decreased by age 70
- Ear development begins in the 3rd week
- Inner ears develop from oticplacodes, which invaginate into the otic pit and otic vesicle
- The otic vesicle becomes the membranous labyrinth, and the surrounding mesenchyme becomes the bony labyrinth
- Middle ear structures develop from the pharyngeal pouches
- The branchial groove develops into outer ear structures

Words to know

Cataract, Glaucoma, Deafness, Conjunctivitis, Otitis media, Anosmia, Astigmatism, Keratitis, Otalgia, Tinnitus, Vertigo, Myopia, Presbyopia, Meniere's syndrome-inner ear disease that cause episodes of vertigo, Blepharitis Hypermetropia (inflammation of eyelinds causes farsighted)