Anatomy of the Ear
▪Ear has three regions
▪outer
▪middle
▪inner
▪outer and middle are concerned with the transmission of sound to the inner ear
▪inner ear converts sound to fluid motion and then to electrical impulses (action potentials)

The Physiology of the Ear

Outer Ear
▪Auricle (pinna)- flap of elastic cartilage
▪External auditory canal
▪Tympanic membrane (eardrum)- semitransparent thin fibroelastic connective tissue membrane, covered by epidermis on the external side and a simple low cuboidal mucous epithielium on the inner side

External Auditory Canal

Middle Ear
▪**Ossicle**s (malleus, incus, stapes)
▪ Oval window
▪Round window
▪Opening into the Eustachian tube

Inner Ear
▪**Vestibular apparatus** for balance and equilibrium
▪**Cochlea** for hearing

Sound
▪Results from the motion of air molecules which oscillate.
▪Compression and rarefaction with ea. pressure pulse --> pressure waves.
▪Sound waves travel in all directions from their source.

Ears and Hearing
▪Waves are characterized by frequency and intensity.
▪Frequency:
▪Measured in hertz (cycles per second).
▪Greater the frequency the higher the pitch.
▪Intensity:
▪Directly related to amplitude of sound waves.
▪Measured in decibels.

Outer Ear
▪The shape of the outer ear (auricle) increases the intensity of the intermediate frequencies: those that are most important for preception of speech sounds
▪Sound waves are funneled by the auricle into the external auditory meatus.

▪External auditory meatus channels sound waves to the tympanic membrane.
▪Increases sound wave intensity.
Middle Ear Bones
▪The **ossicles** (the smallest bones in the bondy) amplify the sound 20 X due to leverage
▪advantage: sensitivity to soft sounds
▪-disadvantage; possible damage to sensory cells from loud sounds

Middle Ear (Cavity between tympanic membrane and cochlea)

▪**Malleus**
▪Attached to tympanic membrane.
▪Vibrations of membrane are transmitted to the stapes.
▪**Incus**:
▪Anvil.
▪**Stapes**:
▪Attached to oval window.
▪Vibrates in response to vibrations in tympanic membrane.

Muscles of the Middle Ear
▪**Stapedius**
▪the **smallest skeletal muscle** in the human body.
▪**connects to the stapes** (the stirrup)
▪when it contracts, **it reduces the action of the stapes** (i.e., it reduces amplification)
▪**contracts just before speaking and chewing** because our own speaking and chewing actually could be loud enough to damage the sensitive mechanisms of the inner ear if the sounds were further amplified.
▪innervated by a branch of the Facial Nerve (CN VII).
Muscles of the Middle Ear
▪**Tensor tympani**
▪**inserts on the malleus** and **acts to <u>tense</u> the tympanic membrane** reducing the effectiveness of sound transmission, protecting the inner ear during loud sounds.
▪innervation from a branch of the mandibular nerve (V3 of CN V).

Bony Labyrinth of Cochlea
Membranous labyrinth of Cochlea

Cochlear Physiology
Cochlea
▪**Vibrations of stapes and oval window displace perilymph** fluid within **scala vestibuli**.
▪**Vibrations pass to the scala tympani.** As sound frequency increases, pressure waves of the perilymph are transmitted **through the vestibular membrane and through the basilar membrane.**

▪**Movements of perilymph** travel to the base of cochlea where they **displace the round window.**

Organ of Corti
■Sensory hair cells located on the **basilar membrane.**
■**Stereocilia** of the outer hair cells are embedded in the **tectorial membrane**.

Stereocilla
Organ of Corti
Stereocilla
Organ of Corti
▪When the cochlear duct is displaced, a shearing force is created, moving and bending the stereocilia.
▪Ion channels open, depolarizing the hair cells, releasing glutamate that stimulates the sensory neuron.
▪Greater bending of stereocilia, the increased frequency of AP produced.
▪Nerve impulses in cochlear nerve travel to brain stem and on to the auditory areas of cerebral cortex, where it is interpreted as sound.

Vestibular Apparatus and Equilibrium
▪Vestibular apparatus maintains the body (mainly the head) at equilibrium (at balance) and stabilizing the eyes relative to the environment
▪Static equilibrium- maintenance of the position of the body (mainly the head) relative to the force of gravity
▪Dynamic equilibrium- maintenance of the position of the body (mainly the head) in response to sudden movements such as rotation, acceleration, and deceleration.
▪Consists of 2 parts:
▪Otolithic organs
▪Utricle and saccule- static equilibrium
▪Semicircular canals- dynamic equilibrium
Vestibular apparatus
▪ Bony labyrinth surrounds membranous labyrinth filled with **endolymph** (like ECF).
▪Between bony labyrinth and membrane of membranous labyrinth is **perilymph** (like CSF)

Vestibular apparatus:
Otolithic organs
■Utricle and saccule
▪Saccule connected to utricle by duct.
■Each sensory area consist of a **macule** that contains the sensory mechanisms

Utricle
▪an irregular, oblong membranous sac located on the medial wall of the vestibule.
▪lies horizontally
▪More sensitive to horizontal acceleration.

▪macula consist of sensory hair cells and supporting cells (sustentacular cells)
Utricle
▪Each sensory hair cell has one kinocilium and many stereocilia
▪The stereocilia and kinocilium are embedded in a gelatinous membrane, the ***otolithic membrane***, which sits on top of the sensory cells.
▪The membrane is produced by the sustentacular cells.
▪On the surface of the otolithic membrane are ***otoliths* (or otoconia),** crystals of Ca^{++} carbonate which are composed of calcium carbonate and protein.
▪These otoliths sensitive to horizontal movements
Saccule
▪a flattened, irregularly-shaped membranous sac also located in the medial wall of the bony vestibule.
▪*saccular macula*, having the same struture as the utricle, lies perpendicular and verticle to the macula of the utricle.
▪More sensitive to vertical (saggital plane, up and down forward and back) acceleration.
▪has two small openings are present in the saccule.
▪One is the opening of a duct, called the *endolymphatic duct*, that communicates with the utricle.
▪The other opening communicates with the duct of the cochlea via the *ductus reuniens*.

Semicircular Canals
▪Provide information about rotational acceleration.
▪Project in 3 different planes.
▪Each canal contains a semicircular duct. At the base is the **crista ampullaris**.
▪= enlarged swellings at base of each canal communicating with utricles

Endolymph Movement in Canals
Movement of Cupula Relative to Body Movement

The Eye
Outer Tunic
▪**Sclera**.
▪Tough connective tissue layer. covers most of eyeball and forms visible white part of eye.
▪Protective
▪**Cornea.**
▪Anterior transparent portion of sclera.
▪Window which helps focus light
▪Most blindness from cloudy cornea

Middle Tunic
▪Choroid
▪Ciliary body
▪Iris
▪Lens

Choroid
■Highly pigmented layer which contains many blood vessels to nourish retina.
■Posterior 5/6 of eyeball
■Anterior portion becomes specialized into ciliary body and iris.
Ciliary body
■Rings eye forward from choroid.
■Controls lens shape for accommodation.
■Produces aqueous humor (fluid which nourishes non-vascular tissues of cornea and lens).
Iris
■Anterior to ciliary body.
■Gives eye its color.
■Controls size of pupil and how much light enters eye.

Lens
■For focusing light on retina.
■Separates interior of eye into 2 compartments.
■Anterior cavity has **aqueous humor**
■Larger posterior cavity between lens and retina has **vitreous humor.**
Posterior Cavity
■Vitreous humor in posterior cavity is semifluid, jellylike substance.
■Enables eye to retain its spherical shape.
■ Failure to drain will --> increased pressure inside of eye = **glaucoma**. Pushes lens backward into vitreous humor, which is, in turn, pushed into retina. Can cause damage and blindness if not treated.

Inner Tunic
■Consists of retina.
■Retina has 4 layers
▪Pigmented epithelium
▪Receptor cells (rods and cones)
▪Layer of bipolar neurons. Horizontal and amacrine neurons here too.
▪Layer of ganglion cells.

Vision
■Eyes transduce energy in the electromagnetic spectrum into APs.
■Only wavelengths of 400 – 700 nm constitute visible light.
■Neurons in the retina contribute fibers that are gathered together at the optic disc, where they exit as the optic nerve.
Refraction
▪Light that passes from a medium of one density into a medium of another density (bent).
▪Refractive index (degree of refraction) depends upon:
▪Comparative density of the 2 media.
▪Curvature of interface between the 2 media.

▪Refractive index of air = 1.00
▪Refractive index of cornea = 1.38
▪Image is inverted on retina.

Accommodation

▪Ability of the eyes to keep the image focused on the retina as the distance between the eyes and object varies.

Changes in the Lens Shape

▪Ciliary muscle can vary its aperture.
▪Distance > 20 feet:
▪Relaxation places tension on the suspensory ligament.
▪Pulls lens taut.
▪Lens is least convex.
▪Distance decreases:
▪Ciliary muscles contract.
▪Reduces tension on suspensory ligament.
▪Lens becomes more rounded and more convex.

Visual Acuity

▪Sharpness of vision.
▪Depends upon resolving power:
▪Ability of the visual system to resolve 2 closely spaced dots.
▪**Myopia** (nearsightedness):
▪Image brought to focus in front of retina.
▪**Hyperopia** farsightedness):
▪Image brought to focus behind the retina.

Visual Acuity

▪Astigmatism:
▪Asymmetry of the cornea and/or lens.
▪Images of lines of circle appear blurred.
▪Corrected by cylindrical lens.

Retina

▪Consists of single-cell-thick pigmented epithelium
▪Photoreceptor neurons:
▪Rods and cones.
▪Layers of other neurons
▪Neural layers are forward extension of the brain.
▪Neural layers face outward, toward the incoming light.
▪Light must pass through several neural layers before striking the rods and cones.

Retina

▪Rods and cones synapse with other neurons.
▪AP conducted outward in the retina.
▪Outer layers of neurons that contribute to optic nerve called ganglion cells.

Retina

▪Neurons receive synaptic input from bipolar cells, which receive input from rods and cones.
▪Horizontal cells synapse with photoreceptors.
▪Amacrine cells synapse with several ganglion cells.

Effect of Light on Rods

- Rods are activated when light produces chemical change in rhodopsin.
- Bleaching reaction:
- Rhodopsin dissociates into retinene (rentinaldehyde) and opsin.
- 11-cis retinene is converted to all-trans form.
- Initiates changes in ionic permeability to produce AP in ganglionic cells.
- Provide black-and-white vision.

Dark Adaptation

- Gradual increase in photoreceptor sensitivity when entering a dark room.
- Maximal sensitivity reached in 20 min.
- Increased amounts of visual pigments produced.
- Slight increased pigment in cones.
- Greater increased rhodopsin in rods.
- 100,00-fold increase in light sensitivity in rods.

Electrical Activity of Retinal Cells

- Ganglion cells and amacrine cells are only neurons that produce AP.
- In dark, photoreceptors release inhibitory NT that hyperpolarizes bipolar neurons.
- Light inhibits release of inhibitory NT.
- Dark current:
- Rods and cones contain many Na^+ channels that are open in the dark.
- Causes slight membrane depolarization in dark.

Electrical Activity of Retinal Cells

- Na^+ channels rapidly close in response to light.
- cGMP required to keep the Na^+ channels open.
- Opsin dissociation causes the alpha subunits of G-proteins to dissociate.
- G-protein subunits bind and activate phosphodiesterase, converting cGMP to GMP.
- Na^+ channels close when cGMP converted to GMP.

Cones and Color Vision

- Cones less sensitive than rods to light.
- Cones provide color vision and greater visual acuity.
- High light intensity bleaches out the rods, and color vision with high acuity produced by cones.

Cones and Color Vision

- Trichromatic theory of color vision:
- 3 types of cones:
- Blue, green and red.
- According to the region of visual spectrum absorbed.

Cones and Color Vision

- Eachtype of cone contains retinene associated with photopsins.
- Photopsin protein is unique for each of the 3 cone pigments.
- Each cone absorbs different wavelengths of light.

Visual Acuity and Sensitivity

- Each eye oriented so that image falls within fovea centralis.
- Fovea only contains cones.
- Degree of convergence of cones is 1:1.
- Peripheral regions contain both rods and cones.
- Degree of convergence of rods is much lower.
- Visual acuity greatest and sensitivity lowest when light falls on fovea.

Neural Pathways from Retina

- Right half of visual field project to left half of retina of both eyes.
- Left half of visual field project to right half of retina of both eyes.
- Left geniculate body receives input from both eyes from the right half of the visual field.
- Right geniculate body receives input from both eyes from left half of visual field.
- Neurons project to striate cortex.

Eye Movements

- Superior colliculus coordinate:
- Smooth pursuit movements:
- Track moving objects.
- Keep image focused on the fovea.
- Saccadic eye movements:
- Quick jerky movements.
- Occur when eyes appear still.
- Move image to different photoreceptors.

Neural Processing of Visual Information

- Receptive field:
- Part of visual field that affects activity of particular ganglion cell.
- On-center fields:
- Responses produced by light in the center of visual fields.
- Off-center fields:
- Responses inhibited by light in the center and stimulated by light in the surround.