

EAR = A SERIES OF MECHANICAL TRANSDUCERS

Vibration of air (sound) is converted into a *vibration* of a membrane, which is converted into a *vibration* of a solid, which is converted into a *vibration* of fluids, which is converted into a *vibration* of yet another membrane...

...which results in an electrical signal to the Brain.

Outer (external) Ear

Auricle (pinna) functions to collect sound.

1. helix (rim)
2. tragus

Auditory canal

1. skin of canal innervated by CN X (Vagus)
 - a. ceruminous glands (wax)
 - b. sebaceous glands
 - c. hairs
2. tympanic membrane (aka "ear drum") at base of canal
3. external auditory canal = cartilage + meatus (bone)
4. TMD = Importance in TMJ dysfunction (shared nerves)

Middle Ear

Location: temporal bone

- *most massive, yet fragile bone in head*

1. squamous portion - squamosal suture
2. petrosal portion - support / protect inner & middle ear
3. ear drum stretched across external auditory meatus
4. internal auditory meatus (CN VII + CN VIII)

Boundaries of middle ear

1. Lateral - tympanic membrane collects sound waves
2. Medial - bony wall separating mid-ear from inner ear
3. Superior - petrous portion of temporal bone
4. Posterior - pneumatized (mastoid antrum)
5. Anterior - opening of the auditory (Eustachian) tube

Auditory tube - aka *Eustachian tube*

1. auditory tube connects throat with middle ear
2. equalizes pressure across tympanic membrane
3. mid-ear is at an **important** anatomical intersection
 - a. ear drum + pharynx + mastoid + inner ear
 - b. infection easily spreads throughout
 - **mastoiditis** = infection of mastoid air cells
 - **otitis media** = infection of middle ear
4. infectious material can be "trapped" in middle ear
 - a. inflamed auditory tube swells shut
 - b. fluid builds-up in cavity and pressure is very painful
 - c. **myringotomy** = "tubes" through ear drum to relieve fluid/pressure from mid-ear

Auditory ossicles (n = 3)

1. **malleus** (hammer), **incus** (anvil), **stapes** (stirrups)
2. carry vibrations from ear drum > oval window
3. suspended/connected by ligament/muscle
 - a. tensor tympani muscle attaches to malleus
 - b. stapedius muscle attaches to stapes
4. tympanic reflex
 - a. tensor tympani tenses the ear drum
 - b. stapedius "locks-down" the ossicular chain
= dampens vibrations from excessively loud sounds

Inner Ear

Osseous labyrinth (bone)

1. found within petrous portion of the temporal bone
2. molded around membranous labyrinth

Membranous labyrinth (membrane)

1. hollow tubes/chambers within osseous labyrinth
2. endolymph fills each canal/chamber
3. perilymph - space btw. oss. & memb. labyrinths

Hair cell - functional unit of hearing & equilibrium

1. hair cells are located throughout inner ear
2. complex shape and function
 - a. stereocilia - small, numerous
 - b. kinocilium - large, single
3. movement of stereocilia = signal

Vestibular portion of the Inner Ear

Semicircular canals

1. three canals
 - a. lateral, anterior, posterior
 - b. filled with endolymph
2. each canal has a swelling at its base (ampulla)
3. each ampulla exhibits a **cupula**
 - a. hair cells aligned in a ridge = crista
 - b. tips of hair cells are embedded in gel = cupula
4. cupulae are distorted by endolymph movement
= sensitive to changes in position (rotation)
5. vestibular part of CN VIII - *Vestibulocochlear*

Vestibular apparatus

1. vestibule: utricle & saccule: each has a macula
2. maculae = hair cells covered by a thick gel
3. gel is ornamented w/ calcium carbonate crystals
4. 'otoliths' provide mass/inertia across tops of hair cells
5. movement between gel/otoliths & head = signal
= maculae are sensitive to gravity & linear acceleration

Vertigo - receptor overload:

1. spinning induces endolymph to flow
2. flow is interrupted by abrupt movement
3. dizziness and nausea

Vertigo - mismatch of audio/visual information:

1. vestibular apparatus senses movement
2. visual system says "stationary"
3. vestibular nuclei in the brain stem are confused
4. nausea

Vertigo & vestibular nystagmus

1. spinning induces endolymph to flow
2. if spinning continues:
 - a. endolymph returns to a resting state (stops flowing)
 - b. eyes become accustomed to tracking moving objects
 - c. **because**... *eye movement & vestibular systems are interlaced through the superior colliculi*
3. if spinning stops suddenly:
 - a. endolymph is suddenly re-accelerated
 - b. dizziness and nausea ensues
 - c. eyes will race in direction of previous spin (nystagmus) until the endolymph calms down

Cochlear portion of the inner ear

Sound

1. vibration of air molecules (sound waves)
2. high-pitched tones = high frequency vibration
 - high frequencies have short wave-lengths
 - short wave-lengths travel short distances (pin-drop)
3. low-pitched tones = low frequency vibration
 - low frequencies have long wave-lengths
 - long wave-lengths travel long distances (thunder)

Hearing

Ability ~ size of pinnae, ossicles, & cochlea

- *Gophers* 20-2000 Hz
- *Humans* 20-20000 Hz
- *Bats* 9000-200000 Hz

Cochlea (organ of hearing)

1. region of inner ear responsible for hearing (CN VIII)
2. part of the membranous labyrinth
3. cochlear duct = coiled tube resembling a snail's shell
 - a. 5mm chicken, 30mm human, 60mm elephant
 - b. filled with endolymph
4. basal membrane = floor of cochlear duct
5. "unwound"? = U-shaped tube (see diagram)
6. cochlear duct lies between vestibular/tympanic ducts
 - a. vestibular duct - from oval window to the helicotrema
 - b. tympanic duct - from round window to the helicotrema
 - c. vestibular & tympanic ducts connect at helicotrema
7. helicotrema (helical extremity) = tip of cochlea
8. two membrane-covered "holes" at the cochlear "base":
 - a. oval window (stapes)
 - b. round window

Sound transduction

1. sound vibrates the ear drum which vibrates ossicles
2. stapes vibrates within the oval window
3. this vibrates the perilymph within the vestibular duct
4. vibrations go around helicotrema into tympanic duct
5. pressure causes Round window to bulge outwards
6. vibration of perilymph distorts the Basal membrane

Organ of Corti (auditory receptor)

1. hair cells - distributed along basal membrane of cochlea
2. cells sandwiched against overlying tectorial membrane
3. signal = distortion of basal membrane
4. distortion stimulates the cochlear part of CN VIII > cochlear nucleus (brain stem) > inferior colliculus (mesencephalon) > temporal lobe of cerebral cortex

Problem:

Hair-cells are generic in size, shape & function....

Place-theory

- Each frequency registers at a different "place" along BM
- low frequencies register near tip of BM
 - high frequency sound registers near base of BM

How?

Each sound (wave-length) has a "**sweet-spot**" along BM:

1. basilar membrane (BM) is ribbon-like
 - thick/stiff at the bottom
 - thin/floppy @ tip of cochlea (helicotrema)
2. combination of wave-length/location = sound!
3. high pitch/short wavelength - short distance = base of BM
4. low pitch/long wavelength = long distance = tip of BM

From before.....

Vibration of air (sound) is converted into a vibration of a membrane, which is converted into a vibration of a solid, which is converted into a vibration of fluids, which is converted into a vibration of yet another membrane...

....which stimulates CN VIII

Putting it all together....

Vibration of air is converted into a vibration of the **tympanic membrane**, which is converted into vibration of the **ossicular chain of bones**, which is converted into a vibration of **perilymph**

(oval window), which is converted into a vibration of the **basement memb./organ of corti**

...which stimulates the

Cochlear portion of the vestibulocochlear nerve!