QUICK ACADEMIC STUDY
THE AUDITORY PROCESS

E. LENN

OUTER EAR

Most lateral part of the auditory system. The main function of the outer ear is resonance.

CONCEPT: RESONANCE

Property of an object or cavity that produces a maximum vibratory response at a particular frequency (resonant frequency) that is dependent on its size and shape.

CONCEPT: TRANSDUCTION

Change in sound energy from one form to another

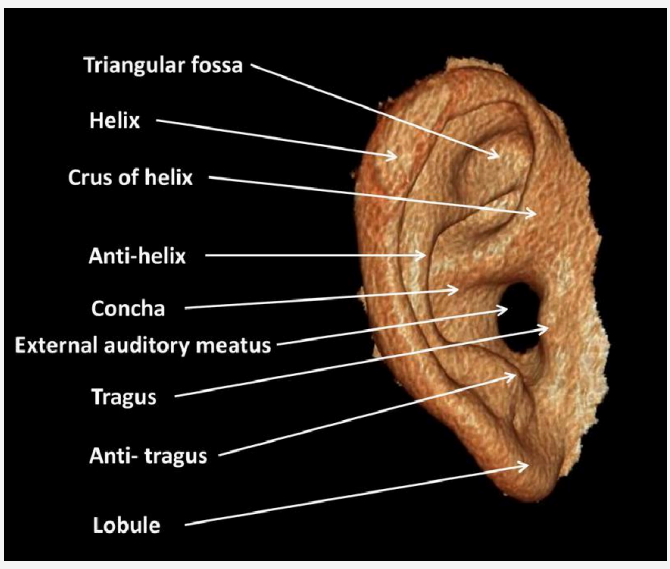
AURICLE (PINNA)

Main components: Helix, antihelix, tragus, antitragus, earlobe, triangular fossa, concha

EAR CANAL
(EAC-external auditory canal)
length = 0.025m; Skin found here is specialized; cells grow side-by-side and grow outward of the ear in a migrating pattern. This pushes the earwax out. Goes from auricle to tympanic membrane

CERUMEN (**earwax**): helps protect, lubricate, and clean the ear canal

HELIX: top folds of skin going around. No real function. Lots of anatomical variation found here



https://www.semanticscholar.org/paper/High-resolution-CT-of-external-ear-and-external-How-Paruthikunnan-Ravikanti/24413c60f4b15048c284dc22796e8599f24ee7b5/figure/0

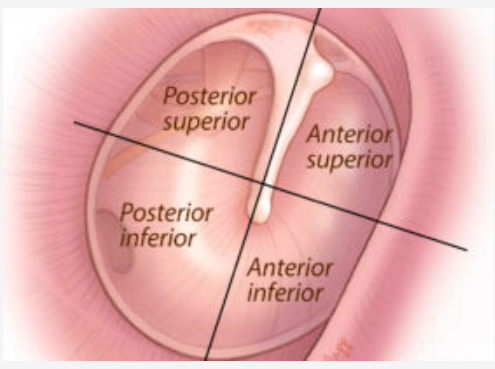
MIDDLE EAR

Tympanic membrane (eardrum), ossicular chain (malleus, stapes, incus). two muscles (stapedius and tensor tympani muscle, and eustachian tube.

TYMPANIC MEMBRANE (EARDRUM)

Separates ear canal from middle ear; transduces acoustic vibrations entering ear canal into mechanical vibrations in the middle ear ossicles

Pic below: how TM is divided anatomically



PARS TENSA
tense part of TM; skin is pulled taught due to pull of malleus

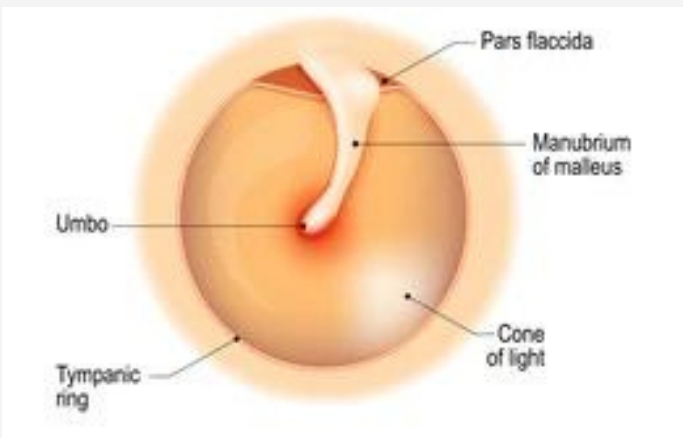
PARS FLACCIDA
(Shrapnell's membrane)
soft spot with more mobility; it's doesn't have 3 layers here as other fibrous portions and is not pulled as taut.

UMBO
central location on the tympanic membrane where the tip of the manubrium of the malleus is attached.

CONE OF LIGHT
reflection of light when viewed with otoscope

TYMPANIC RING
outside part of TM

***NOTE ON MALLEUS ANGLE**
Malleus is enbedded in TM at an angle
1/2 o'clock in right ear &
10/11 o'clock for the left ear



-Pic: https://otosurgeryatlas.stanford.edu/otologic-surgery-atlas/tympanoplasty/tympanic-membrane-perforations/
-Pic: https://www.shutterstock.com/image-vector/anatomy-humans-eardrum-tympanic-membrane-myringa-1104415538
-Book:Audiology: Science to Practice by Kramer & Brown
-SLHS 305 lecture videos - C. Ruby

CONCEPT: CURVED MEMBRANE ADVANTAGE

One of the middle ear mechanical amplification methods resulting from the cone shape of the tympanic membrane, which tends to focus its movement in such a way that it moves the malleus with more force than if the tympanic membrane was flat.

THE AUDITORY PROCESS CONT. 2

CONCEPT: TRANSFER FUNCTION OF MIDDLE EAR

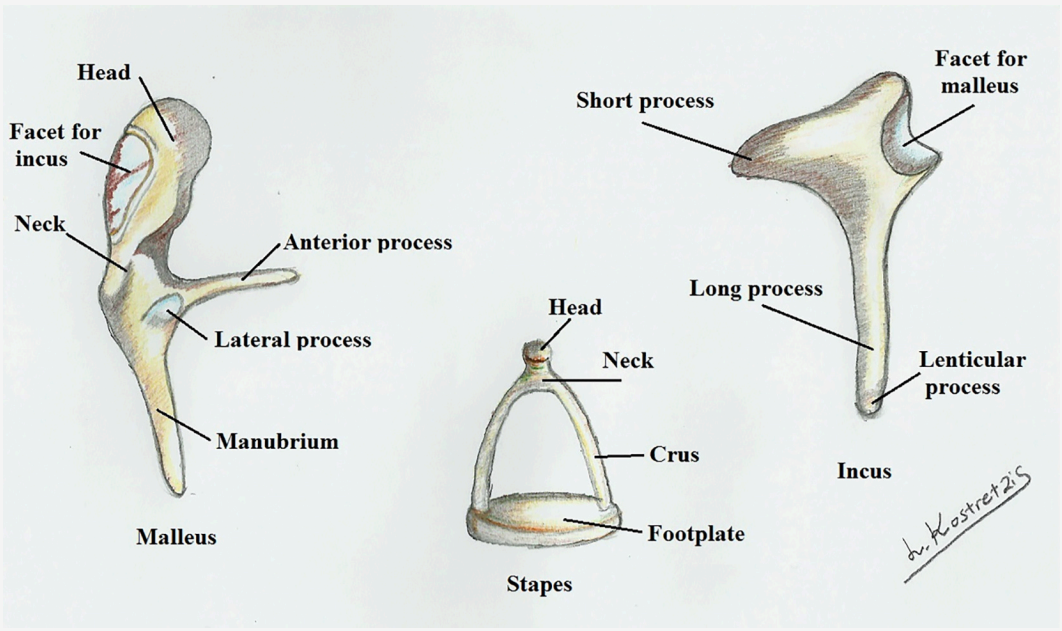
Experimental measurements that document changes in pressure as a function of frequency that occur between one point and another point for example, middle ear transfer function measures changes from tympanic membrane and the oval window membrane.

OSSICULAR CHAIN

Malleus, (manubrium, lateral process neck, head), incus (body, short process, long process, lenticular process), stapes (head, anterior and posterior crura, footplate) *footplate is attached to the oval window which connects to the inner ear

OSSICLES

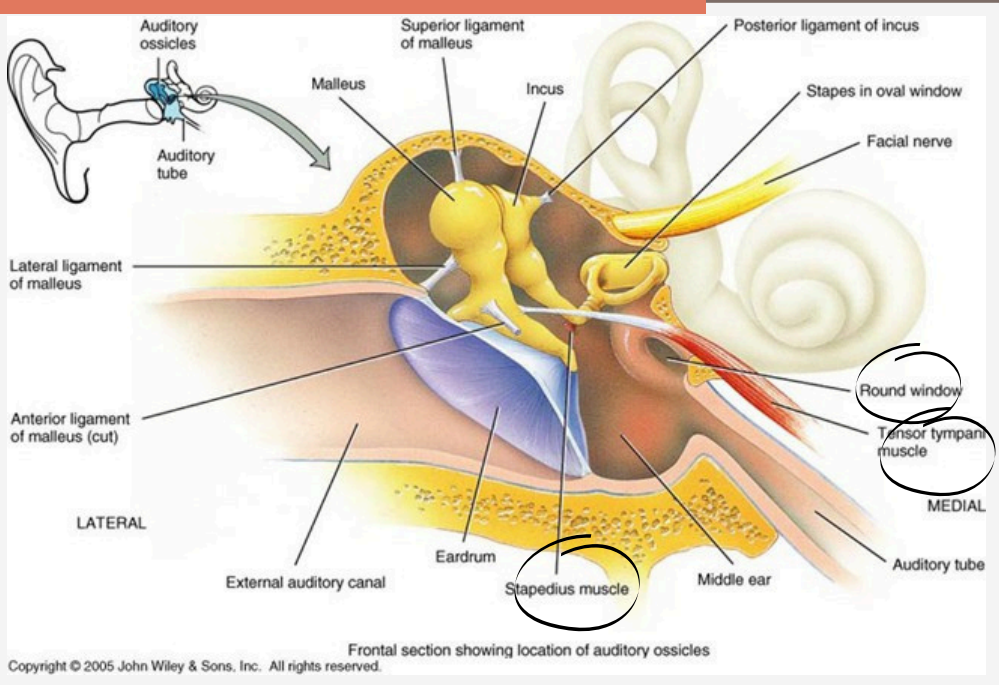
Smallest bones in the body – the malleus, incus, and stapes- these bones articulate with each other to transduce mechanical vibrations from the tympanic membrane to the inner ear. Located in the middle ear. *Note: crus is same as crura.



CONCEPT: LEVER ADVANTAGE

One of the middle ear mechanical amplification methods that is due to the fact that the manubrium of the malleolus is longer than the long process of the incus in the ossicular chain.

MIDDLE EAR CONT.



EUSTACHIAN TUBE
(*auditory tube in above picture)
connects the middle ear to the nasopharynx; comprised mostly of cartilage that is normally close and is opened by action of the tensor veli palatini muscle during chewing and swallowing to equalize air pressure in the middle ear to that of the surrounding environment.

TENSOR TYMPANI MUSCLE
connects to malleus; filled with nerves of the 5th cranial nerves

STAPEDIUS MUSCLE
arises from medial wall of the middle ear cavity and attaches to the head (neck) of the stapes; filled with nerves of the 7th cranial nerve (facial); involved in human acoustic reflex used in clinical assessments

ROUND WINDOW
membrane-covered round-shaped opening between the middle ear and the cochlea (scala tympani); allows for vibrations to enter the fluid-filled cochlea through reciprocal action with the oval window.

-Pic: https://www.jocmr.org/tables/jocmr2369w-g001.jpg
Pic: John Wiley & Sons 2005
-Book:Audiology: Science to Practice by Kramer & Brown
-SLHS 305 lecture videos - C. Ruby

THE AUDITORY PROCESS CONT. 3

CONCEPT: IMPEDANCE MISMATCH

Situation in which two systems have different impedances so that there is an inefficient transfer of energy, for example, vibrations in air are not efficiently transferred to fluid.

CONCEPT: AREA RATIO ADVANTAGE

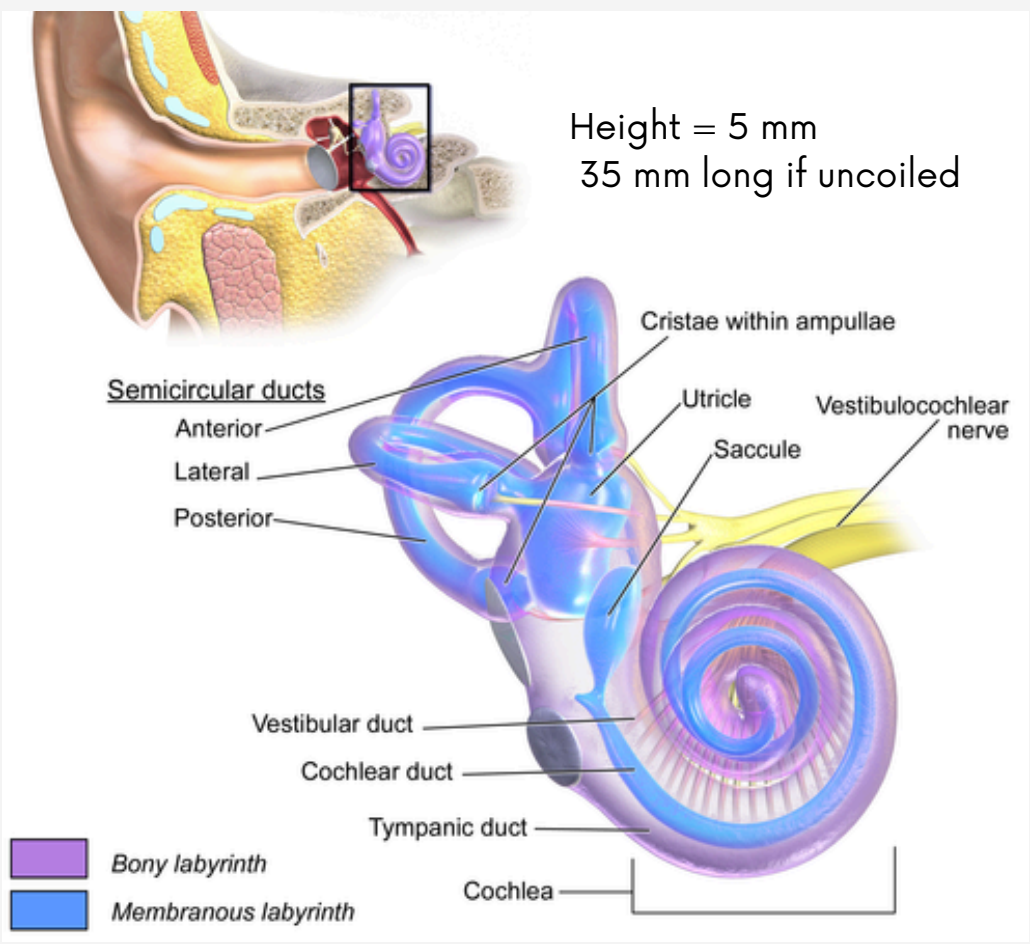
One of the middle ear mechanical amplification methods due to the larger size (area) of the tympanic membrane compared with the oval window.

INNER EAR

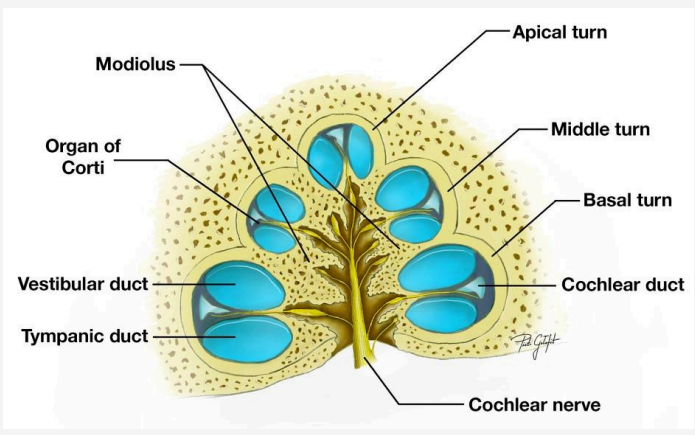
Embedded in the temporal bone.Includes the cochlea, vestibular organs with its three semicircular canals, and two otoliths (saccule and utricle).

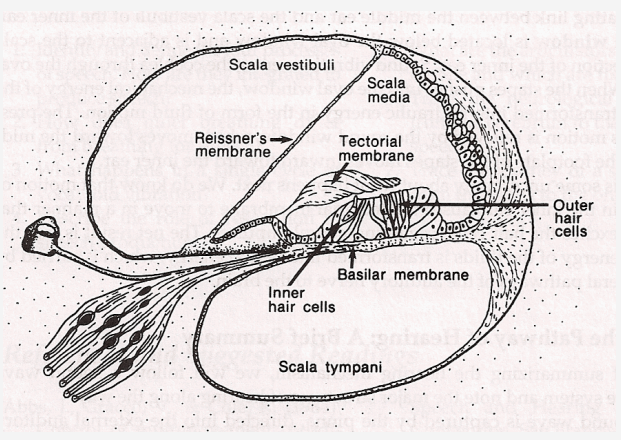
COCHLEA

Embedded in the temporal bone. Includes the cochlea, vestibular organs with its three semicircular canals, and two otoliths (saccule and utricle).



-Semi-circular canals: responsible for rotational movement in cochlea





MODIOLUS: stem or middle part of cochlea; nerve runs through here that forms cochlear portion of 8th cranial nerve, exiting through the internal auditory canal

SCALA MEDIA: filled with endolymph; contains organ of Corti

SCALA VESTIBULI: filled with perilymph & goes to oval window to top (apex); enters the helicotrema

SCALA TYMPANI: filled with perilymph; helicotrema goes to scala tympani and then courses down the spiral of cochlea and then goes out to the round window

ORGAN OF CORTI: contains a lot of sensory cells and supports sensory cells; is found within scala media

BASILAR MEMBRANE (BM): divides the scale of media from the scala tympani; it is one of the key parts of hearing; designed to pick up different frequencies

REISSNER'S MEMBRANE: divides scala media and scala vestibuli

STRIA VASCULARIS: line of cells that help maintain the ionic charge in the scala media endolymph fluid. If ionic charge isn't there, it makes it transduction a lot harder

STRIA VASULARIS: highly vascularized system of cells along the outer wall of the scala media in the cochlea that maintains the ionic charge of the endolymph.

Pic: https://en.wikipedia.org/wiki/Saccule
Pic: https://radiopaedia.org/cases/cochlea-diagram
Pic:http://www.csun.edu/~vcoao0el/webct/de361s81_folder/tsld003.html

THE AUDITORY PROCESS CONT. 4

COCHLEA CONT.

BONY LABYRINTH: space inside temporal bone

MEMBRANEOUS LABYRINTH: found inside of bony labyrinth

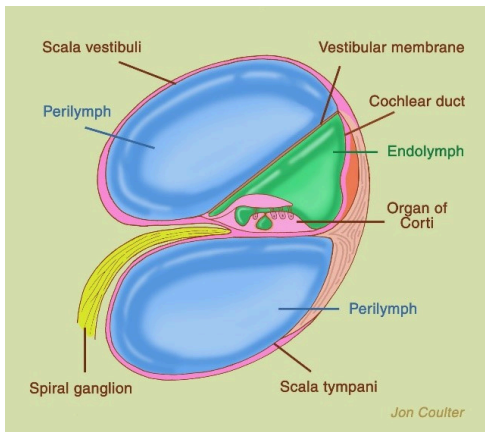
ENDOLYMPH: within the membranous labyrinth; has high potassium (K+), low sodium (Na+)

PERILYMPH: within the boney labyrinth; has high sodium (Na+), low potassium (K+)

DUCTUS REUNIONS: passageway that connects the endolymph of the cochlea to the otolith organs.

ENDOLYMPHATIC SAC: reservoir for extra endolymph fluid

COCHLEAR NERVE: portion of the 8th cranial nerve consisting of nerve fibers from the cochlea



ACTIVE COCHLEA PROCESS

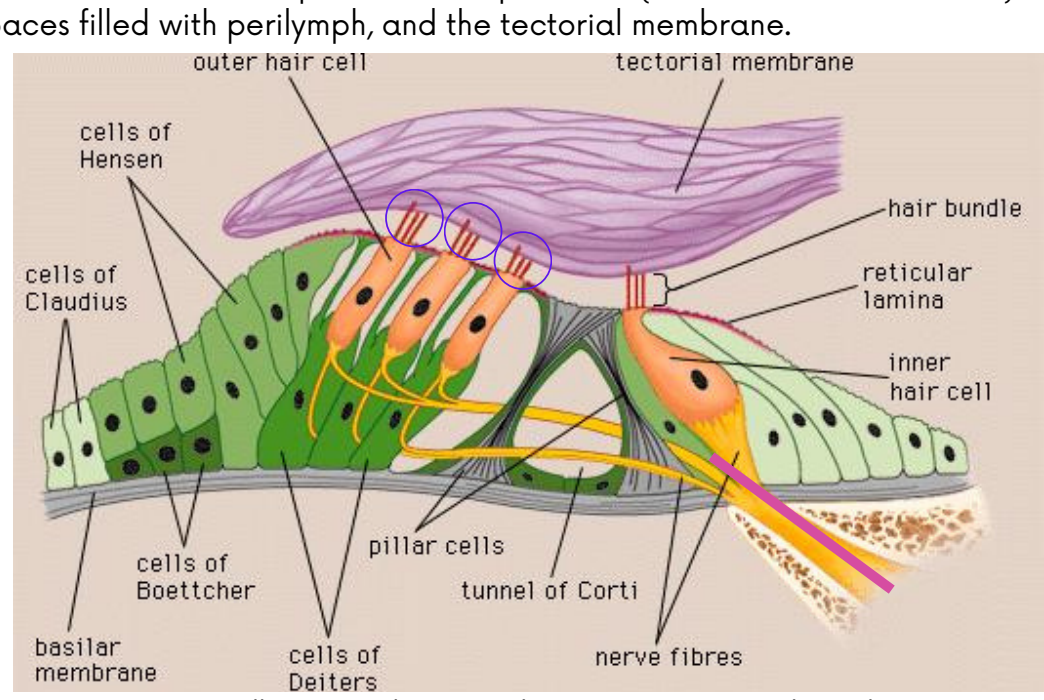
Physiological process present in a healthy normal cochlea related to the motility of the outer hair cells, and which is responsible for enhanced displacement of the traveling wave, good sensitivity, and relatively sharp frequency selectivity (tuning).

PASSIVE COCHLEA PROCESS

Process of cochlear transduction that is related to the physical parameters of the basilar membrane (e.g., narrower and stiffer at the base), which produce the tonotopic traveling waves well documented by Bekesy; when measured without the active process of the outer hair cells, the passive process is more broadly tuned and less sensitive.

ORGAN OF CORTI

Sensory organ of hearing that lies within the scala media along the basilar from the base of apex of the cochlea; composed of receptor cells (inner and outer hair cells), support cells, spaces filled with perilymph, and the tectorial membrane.



HENSEN CELLS: support cells; import. because they connect tectorial membrane

CLAUDIUS CELLS: support cells; even out connection

DEITER CELLS: also support cells

*All above support cells sit on top of basilar membrane

HABENULA PERFORATUM: hole that nerve goes through (8th nerve cells)

OUTER HAIR CELLS (OHC): 12,000 lining up and going up cochlea; sit on top of supporting Deiter cells which have phlangeal processes that extend to the tops of the hair cells to fill any space between the tops of the OHCs

STEREOCILIA (circled in purple): arranged in "w" on top OHCs; cylinder shape; linked together (tip and cross links); if one stereocilia moves, so do the others; opens ionic channels that alter the ionic flow to the hair cell

INNER HAIR CELLS (IHCs): auditory sensory hair cells; there are 3500 IHCs arranged in a single row

INNER PILLER CELLS: support cells that form inner "leg" of triangular shaped tunnel of Corti (also called inner rods of Corti)

TECTORIAL MEMBRANE: thin membrane overlying the stereocilia of hair cells in the organ of Corti; attached medially to the spiral limbus and laterally to the Hensen cells; stereocilia of the outer hair cells are embedded in the undersurface of the tectorial membrane, whereas those of the inner hair cells are not embedded

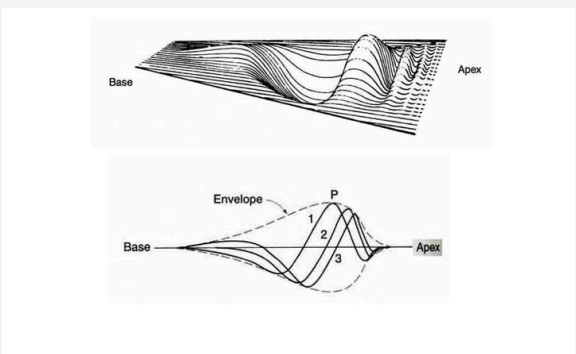
RETICULAR LAMINA: upper surface of the organ of Corti, formed by the tight mosaic of the tops of all the cells, including the phalangeal processes, tops of the pillars, and the cuticular plates of the hair cells, boundary between endolymph above the reticular lamina and perilymph below the reticular lamina (in the spaces of the organ of Corti)

OSSEOUS SPIRAL LAMINA (pink line in diagram): shelf of bone that extends from modiolus and winds along cochlea from base to apex; serves as inner attachment of BM

http://media-2.web.britannica.com/eb-media/00/14300-004-5FF07709.jpg

THE AUDITORY PROCESS CONT. 5

CONCEPT: TRAVELING WAVE

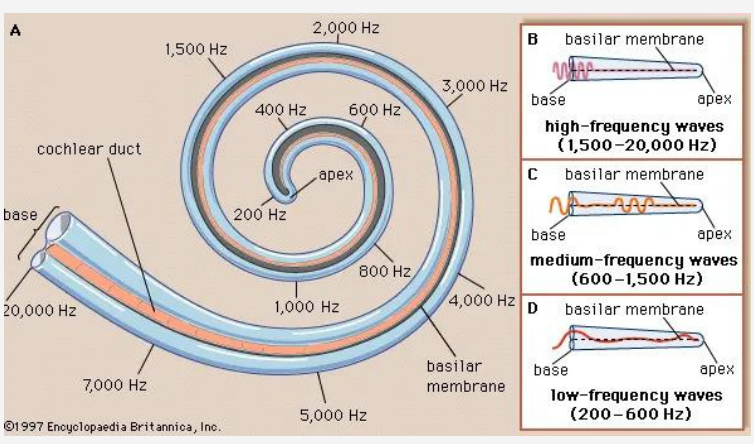


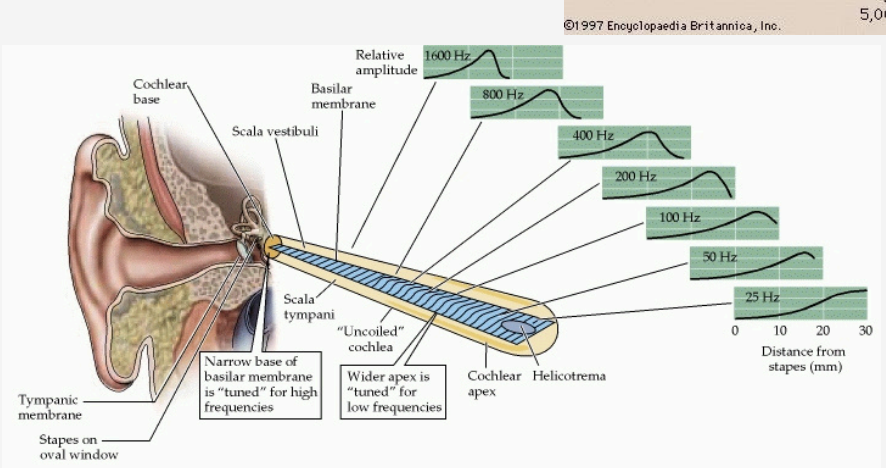
Displacement pattern along the basilar membrane that is essential in sound processing, characterized by initial displacements near the base and progressing to its maximum displacement; basically the deflection/movement of the BM (this is fluid filled).

Pic: https://www.cns.nyu.edu/~david/courses/perception/lecturenotes/pitch/pitch.html

CONCEPT: TONOTOPIC ARRANGEMENT

Tonotopic organization allows cochlea to start mechanically process the sound; dividing sounds (high and low frequencies)





-Base is more sensitive to higher frequencies, while apex is more sensitive to lower frequencies

-A traveling wave will react differently depending on the input frequency and the intensity it is given

HELICOTREMA: space at the apex of the coiled bony labyrinth in the cochlea where the scala tympani and scala vestibuli are continuous with each other due to the ending of the scala media

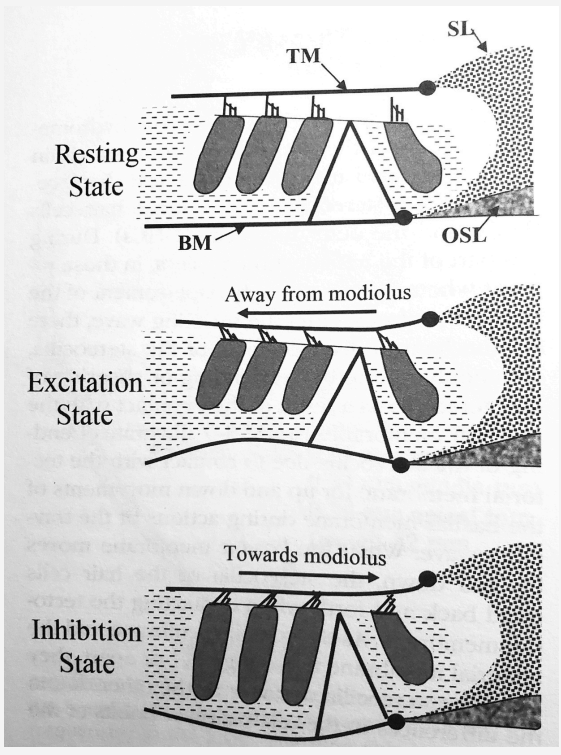
Pic: https://www.britannica.com/science/ear/Transmission-of-sound-within-the-inner-ear
Pic: https://www.ncbi.nlm.nih.gov/books/NBK10946/

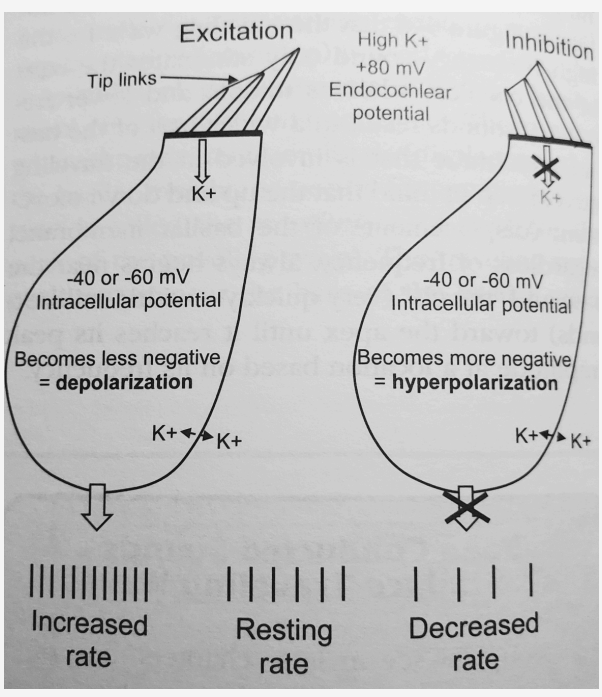
TRANSDUCTION THROUGH INNER HAIR CELLS

RESTING STATE
(no sound)
Basilar membrane is not moving at all; no traveling waves; outer hair cells connected to tectorial membrane; inner hair cells are not embedded in tectorial membrane

EXCITATION STATE
(depolarization)
Basilar membrane moves upwards to apex; tectorial membrane moves away from the modiolus and the stereocilia are sheering away from modiolus; *note - depolarized = becoming less negative

INHIBITION STATE
(hyperpolarization)
Basilar membrane moves towards the base or away from the apex; tectorial membrane moves towards modiolus; prevents flow of potassium and hyperpolarization occurs





ENDOCOCHLEAR POTENTIAL (EP): 80 mV electrical potential (charge) in the endolymph of the scala media due to the high concentration of potassium (K+); maintained by the stria vascularis

INTRACELLULAR POTENTIAL: electrical potential that is present inside the cochlear hair cells; -40mV for inner hair cells and -60 mV for outer hair cells

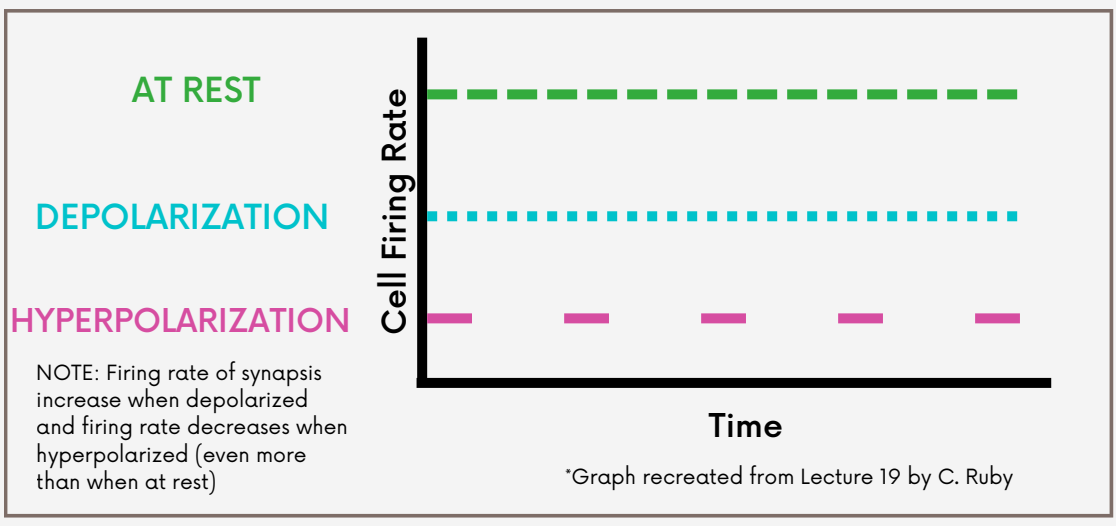
*Note: mV = millivolts

-Inner hair cells have more innervation than outer hair cells

Pics: Kramer pg. 92

THE AUDITORY PROCESS CONT. 6

AUDITORY NERVE FIBERS



INTERSPIKE INTERVALS (ISIs): time intervals that occur between discharges of an auditory nerve fiber.

*Note: Discharge rate and interspike are the same thing

GRADED POTENTIAL: nerves won't fire until there's enough pulses being sent in; this causes the all-or-none discharge. This nerve that fires creates a discharge (neuronal spike); spikes occur in different locations based on frequency. Spikes occur at same amplitude

DISCHARGE RATE: number of discharges per second that a neuron produces in response to a specified sound

INTERSPIKE INTERVAL: how much time in between spikes

PERIOD OF HISTOGRAM: recording of the firing pattern from a neuron, displayed as a function of the period of the stimulus.

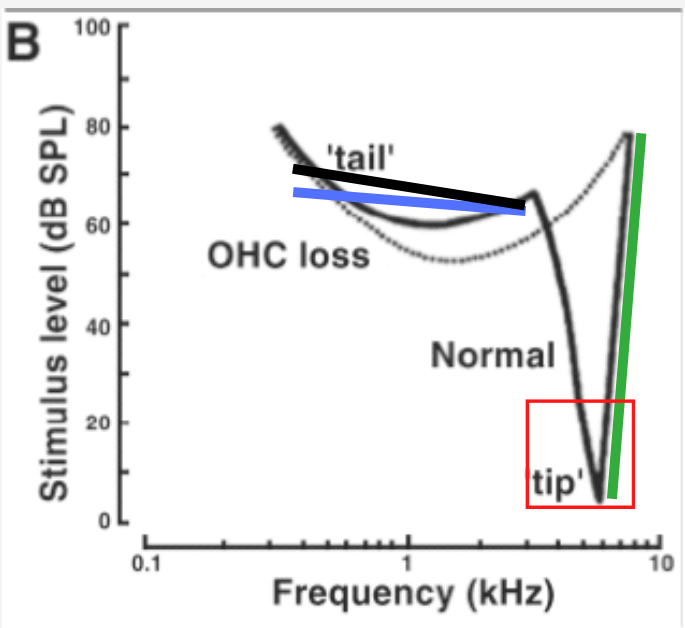
TUNING CURVES

Representation of the frequency selectivity of the auditory system, generated for a variety of physiologic and psychoacoustic measures; shows the different intensity by frequency combinations that produce some criterion threshold response; characterized by a tip region (around the characteristic frequency), a low frequency tail, and steep high frequency slope.

Low frequency tail

High frequency slope

Tip region

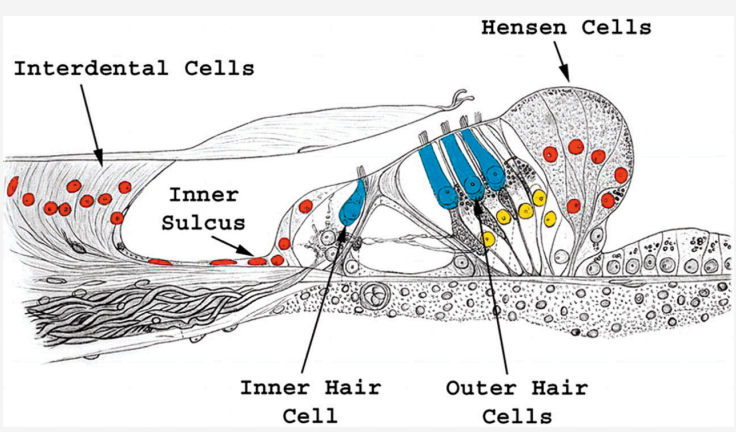


LOW FREQUENCY TAIL: part of a tuning curve that shows a relatively wide range of across frequencies lower than the center frequency that can produce a response when stimulated at moderate to high intensities

HIGH FREQUENCY SLOPE: part pf a tuning curve that shows a steep slope for frequencies higher than the center frequency

BROADLY TUNED: loss of frequency selectivity in damaged ears; loss of tip region of tuning curve

CHARACTERISTIC FREQUENCY: frequency where the basilar membrane or auditory nerve fiber is most sensitive; most sensitive point of a tuning curve



SOME NOTES ON OHC

-OHCs contract/elongate with electrical stimulation (**motility of the outer hair cells)**

-OHCs pulls TM and acts like an amplifier (**active process of the cochlea on page 4**); tip of the tuning curve comes from this and allows us to hear sharper

-One level of intensity doesn't mean that the level of output will be the same

-When there's hearing loss and outer hair cell damage, our tuning curve isn't as sharp and we need things to be louder

-Otoacoustic emissions is a regular diagnostic test to see about testing cochlea function

Plc: http://www.ssc.education.ed.ac.uk/courses/pictures/dnov10x.gif
Pic: https://www.jneurosci.org/content/jneuro/23/11/4395/F4.large.jpg?width=800&height = 600& carousel=1

THE AUDITORY PROCESS CONT. 7

AUDITORY NEURAL PATHWAYS

QUICK REFERENCE NOTES

-8th nerve (8th CN – cranial nerve) has two different parts; vestibular and cochlear branch

-V**estibular** branch of 8th cranial nerve deals with **balance**

-C**ochlear** branch of 8th cranial nerve deals with **hearing**

-Apex nerve courses through the middle, while base has hair nerves on the outside (both sides)

-Tonotopic organization is able to maintain itself through cochlear branch of 8th cranial nerve (see page 5)

-If the nerve gets pinched, there could be different types of hearing loss depending on what nerves are being pinched (usually this is going to be the outer nerves – cochlea branch)

-20-40 dB is the range of where nerves are sensitive

-Dynamic range is 120 dB (loudest noise we could tolerate)

-Liberman postulates that we have different neurons responsible for different intensities

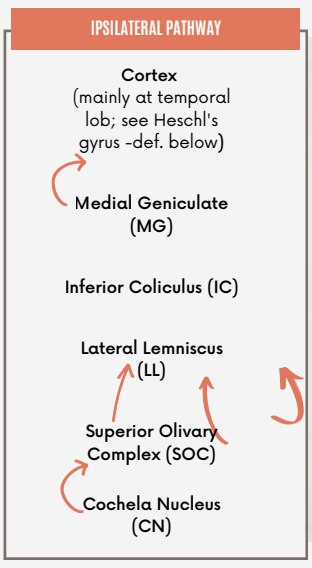
-Some nerves good 0-20, 20-40, 40-60. Nerves are bunched up and respond for different intensities. *Note: could be a mixture of different theories

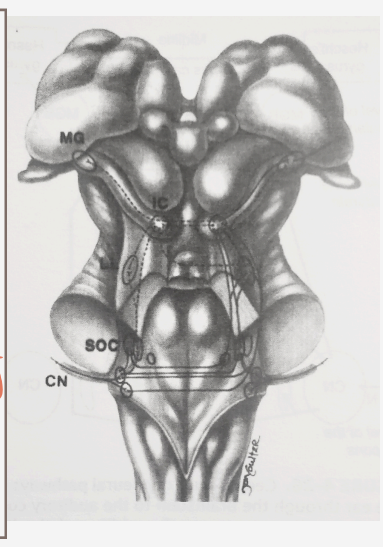
AUDITORY NERVOUS SYSTEM PATHWAYS

VESTIBULOCOCHLEAR / COCHLEOVESTIBULAR NERVE: 8th cranial nerve, composed of the vestibular nerve and the cochlear (or auditory) nerve; also called cochleovestibular nerve

INTERNAL AUDITORY CANAL: opening in the posterior wall of the petrous part of the temporal lobe through which the vestibulocochlear (VIII) nerve and facial (VII) nerve exit

HESCHL'S GYRUS: ridge along the upper surface of the temporal lobe that is the primary auditory reception area of the cortex





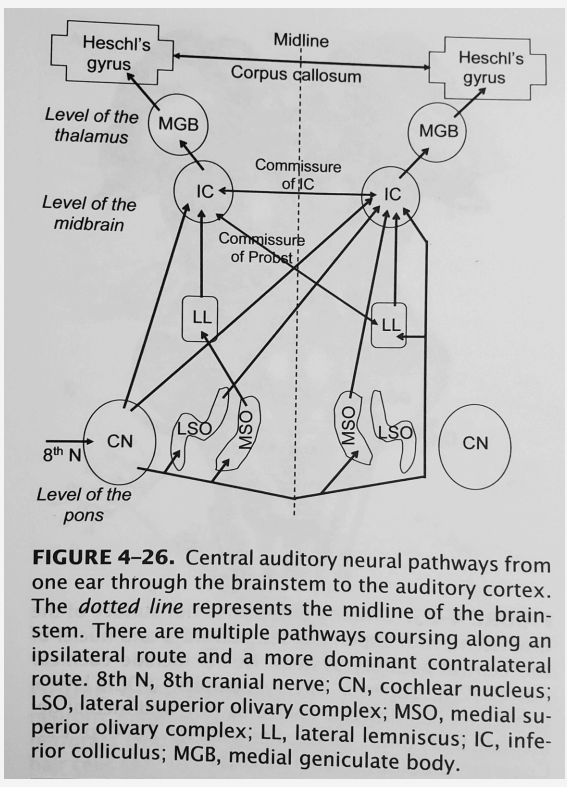


FIGURE 4–26. Central auditory neural pathways from one ear through the brainstem to the auditory cortex. The *dotted line* represents the midline of the brainstem. There are multiple pathways coursing along an ipsilateral route and a more dominant contralateral route. 8th N, 8th cranial nerve; CN, cochlear nucleus; LSO, lateral superior olivary complex; MSO, medial superior olivary complex; LL, lateral lemniscus; IC, inferior colliculus; MGB, medial geniculate body.

Contralateral: crosses brain stem midline

-If connected to OHCs, they come from the olivary complex and goes through cochlea nucleus and out cochlea

-If connected to INCs, they come from the lateral superior olivary complex and through cochlea nucleus and out to cochlea

-About 1200 neurons going form brainstem level out to the cochlea

Efferent pathway: carry out; the route of nerve fibers carrying impulses away from a nerve center; efferent pathway on inner hair cells, but not directly (unlike afferent neurons on outer hair cells)

Afferent pathway = transport of nerve impulses from the receptor organs to nerve center

-Afferent pathway from organ of Corti going through cochlea nucleus and through brainstem (this pathway much more complicated); there are about 30,000 neurons. Much more robust. 95% connect to inner hair cell; they synapse directly to the hair cell body

Spiral ganglion: nerves spiraling through cochlea

Nucleus: specialized nerve bodies

Commissures: ways in which neural pathways cross the brainstem

-**Lateral** is more on **outside**; **medial** is more inside towards **midline** (middle of brainstem)

-Pics from Audiology Science to Practice, 3rd Ed. Kramer pgs. 77-78

THE AUDITORY PROCESS CONT. 8

PLACE THEORY

Theory of frequency coding based a tonotopic arrangement along the basilar membrane for sounds of different frequencies.

-Tonotopicity can be measured (pro)
-doesn't always match perception fully (con)
-e.g. case of the missing fundamental

FREQUENCY THEORY

Theory of frequency coding based on the processing of discharge patterns in the afferent auditory nerve fibers.

-looks at spike coming from nerves
-correlate between inner spike interval (ISI) and period of a sound (pro)
e.g. if 1000 hz tone with period of 1 ms, nerves will mostly have ISI of 1 millisecond (not all time)
-nerves can't fire so quickly past mid-range; 200 spikes per sec. (stops around 2000 Hz); cannot fully mirror frequencies past 2000 Hz

PHASE LOCKING

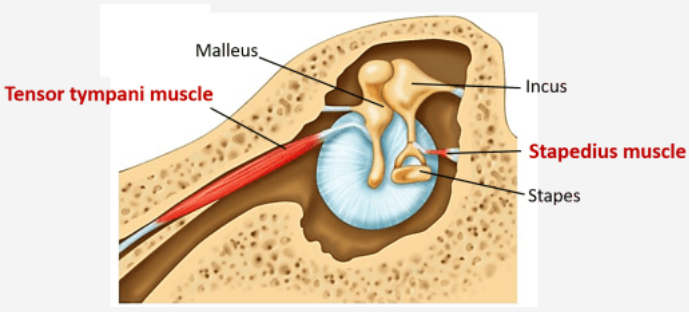
Characteristic pattern of neural discharges in which they always fire during the same phase of the stimulus.

-when BM is deflected (excited or inhibited state); when there is a complex wave form, we will only get spikes received from the exitory state signal; can help us hear things better

*NOTE: this could be a combination of Place Theory and Frequency Theory

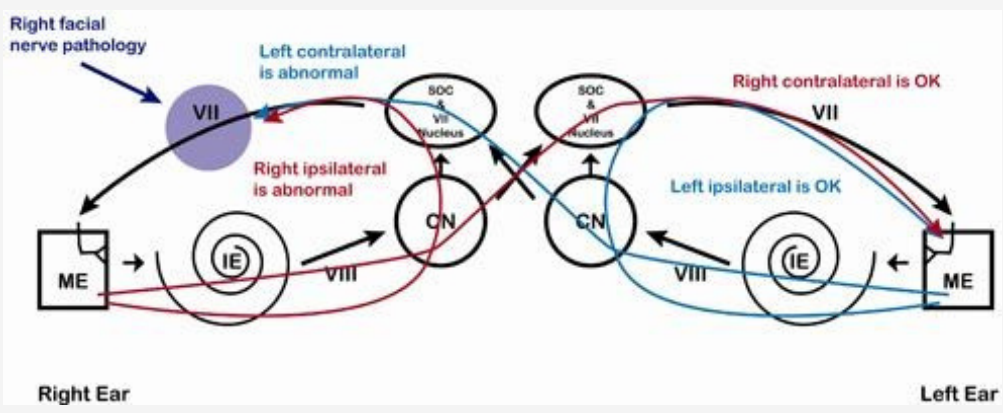
CONCEPT: ACOUSTIC REFLEX

Occurs when muscle squints (contracts) to make sound a little more dampened (e.g. like squinting eyes when it's bright outside). This can happen in two different ways, ipsilateral (of same side) and contralateral (of opposite side).



TENSOR TYMPANI & STAPEDIUS MUSCLES

-Reduces gain 10-20dB
-Often happens in lower frequency <1000Hz
-Triggered by loud sounds
-Delay of about 20-100 milliseconds; cannot act fast enough to stop damage
*Why does this happen? Possibly to help reduce distortions of the ossicular chain



***HOW IS THIS TESTED? Loud noise is played on one side (ipsi). This should stimulate the other side (contra). If there is damage across facial nerve, the VIII cranial nerve (e.g. tumor); then one would expect some kind of break and a reaction would not occur.**

CONTRALATERAL ACOUSTIC REFLEX: acoustic reflex obtained from the ear on the opposite side from the ear being stimulated; due to the contralateral pathway of the bilateral acoustic reflex

-Pic: https://i1.wp.com/www.anatomyqa.com/wp-content/uploads/2018/06/muscles-of-tympanic-cavity.png?resize=604%2C226
-Pic: https://i.pinimg.com/originals/a2/24/d1/a224d13997717aeafa68c0060d91bbf2.jpg

VESTIBULAR SYSTEM

VESTIBULAR SYSTEM: deals with balance. Detects acceleration (change in velocity)

SEMI-CIRCULAR CANALS (see cochlea page 3): orthogonal (this means the orientation) to each other (there are three); allow us to understand rotation; can detect rotational acceleration

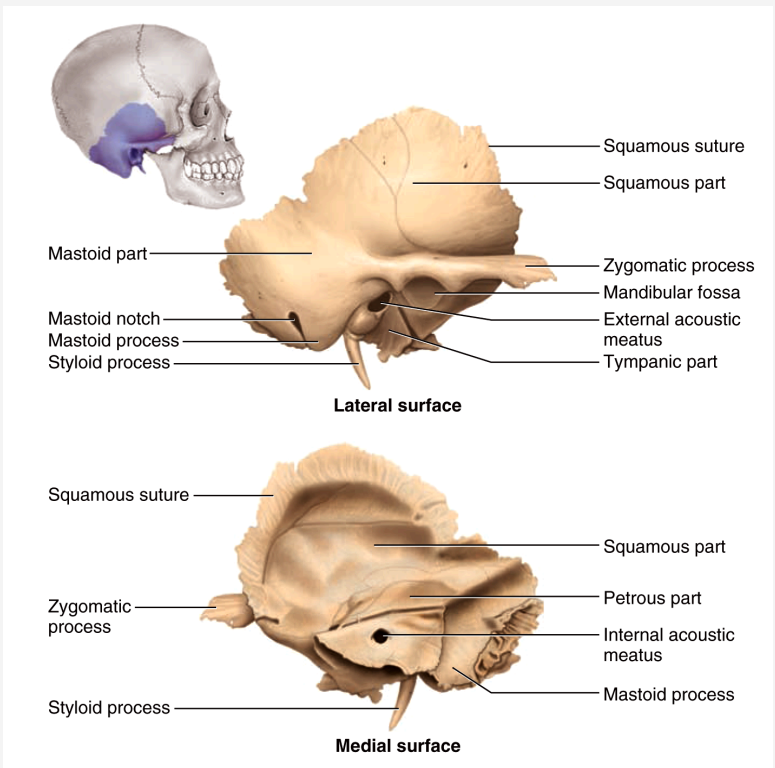
OTOLITH ORGANS: One horizontal and one vertical; filled with "rocks" or weights that detect how human body is moving

*NOTE: If vestibular system is weak, things like eyes following head movement is difficult

THE AUDITORY PROCESS CONT. 9

TEMPORAL BONE

TEMPORAL BONE: houses a lot of peripheral auditory system; this is basically the side of the head.



Temporal squama: flat portion on top; connects to other parts of skull

Zygomatic bone: joins to cheek

Styloid process: muscles connecting to articulation

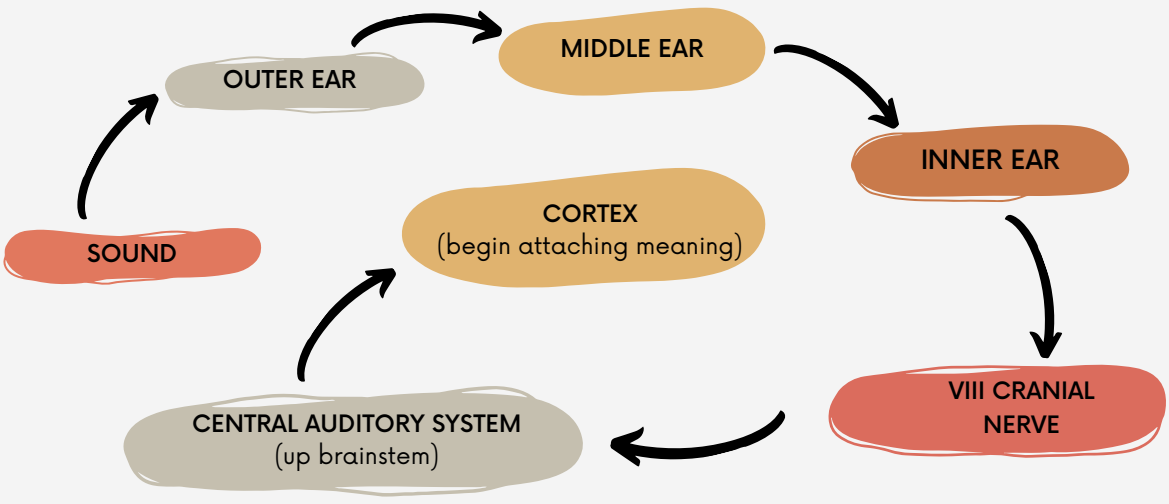
Tympanic part: opening into skull to canal

Mastoid: lots of air cells (pockets) that help with ventilation of area

Petrous part: inner ear lies here; densest part of bone in the body

Pic: https://i.pinimg.com/originals/27/95/a4/2795a41fbf89d3e200b2aaa68be51a5e.png

QUICK SUMMARY



*information taken primarily from SLHS textbook by Kramer and Lectures by C. Ruby. Pictures cited from online and SLHS textbook