Section 5
Audition

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COGS 17 A04
02/14/25

Notice

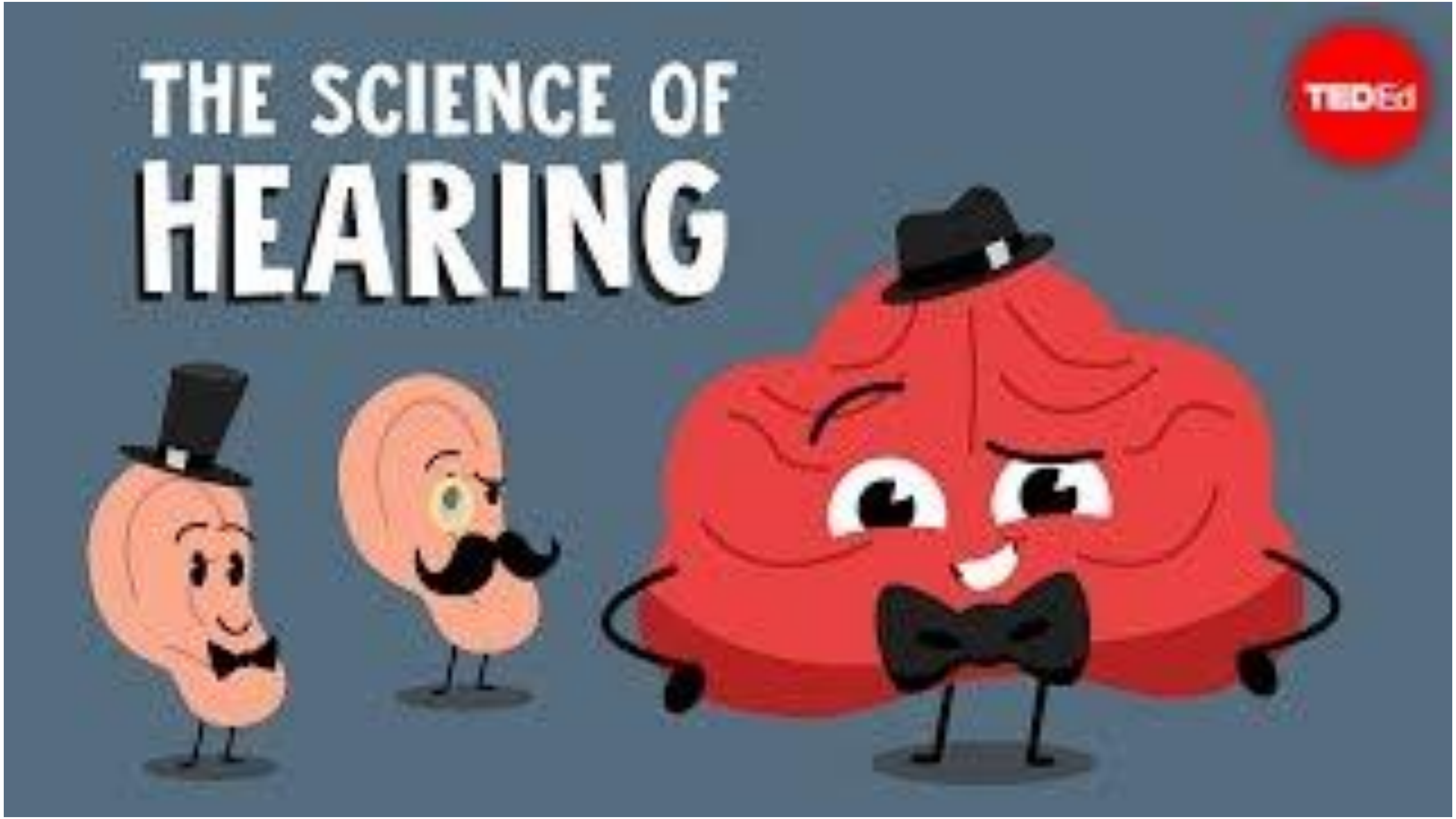
MIDTERM 2

2/20 Thursday

3:30-4:50 pm

NO Discussion Section Next Week

Before we start…

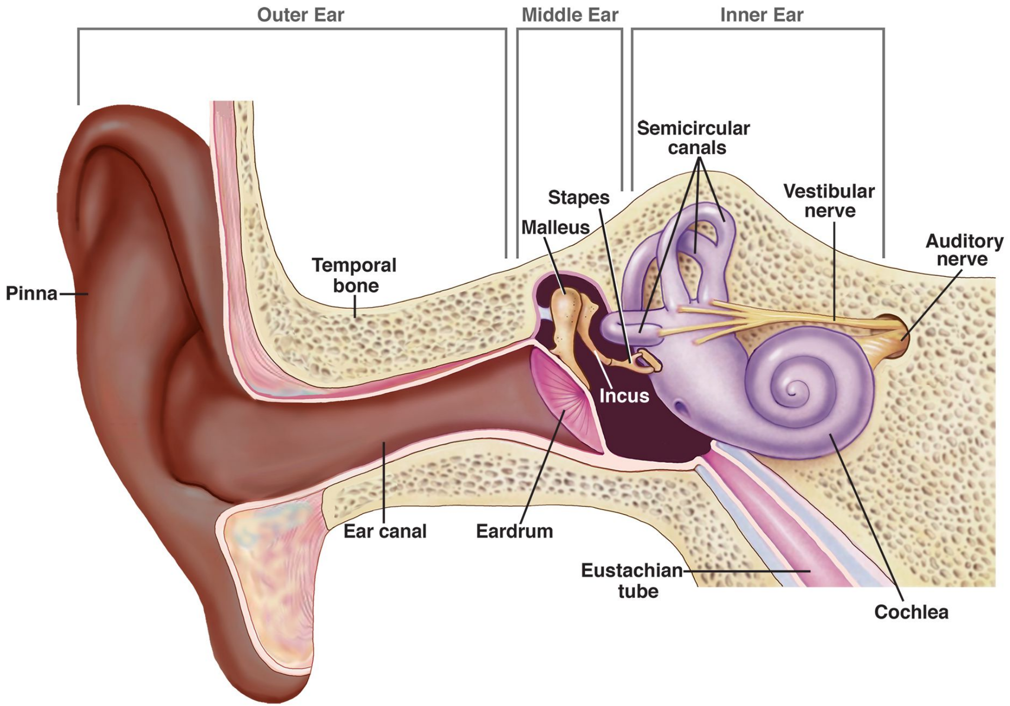


Anatomy of Auditory Reception

Outer Ear

- Pinna
    - The outer ear structure that helps localize sounds

- Auditory Canal
    - Channel that focuses sound waves (air pressure)and connects to the eardrum

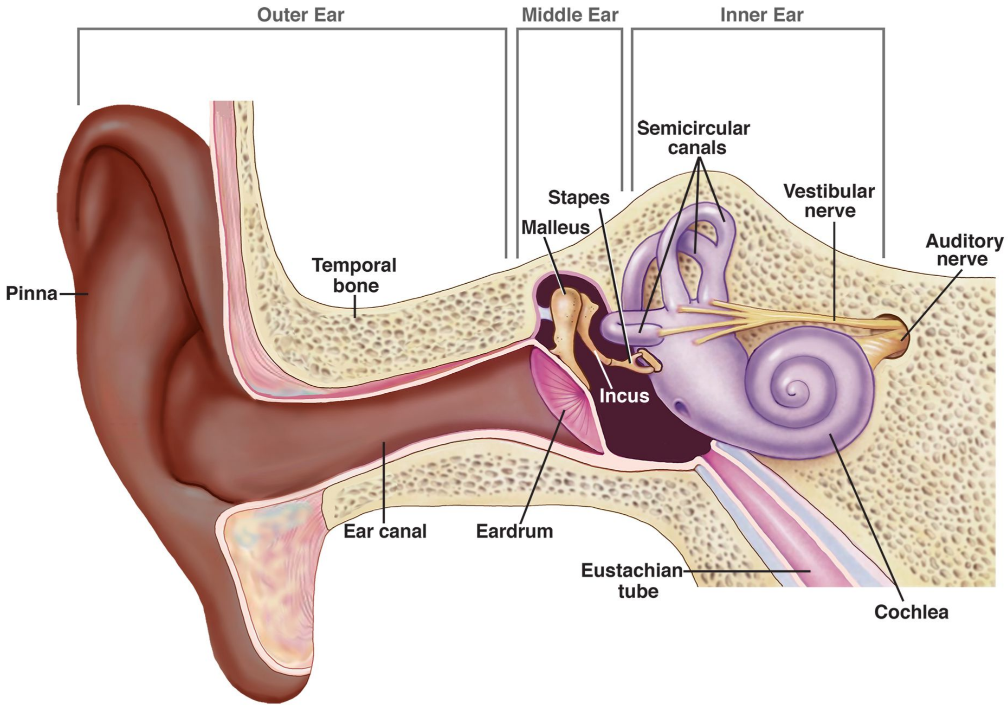


Anatomy of Auditory Reception

Middle Ear

- Eardrum
  - Membrane that helps convert air pressure into kinetic energy via the Ossicles
  - Also called the tympanic membrane

- Ossicles
  - Consists of three small bones: Malleaus, Incus, and Stapes
  - Together they form a lever system that converts and amplifies the vibrations of the eardrum



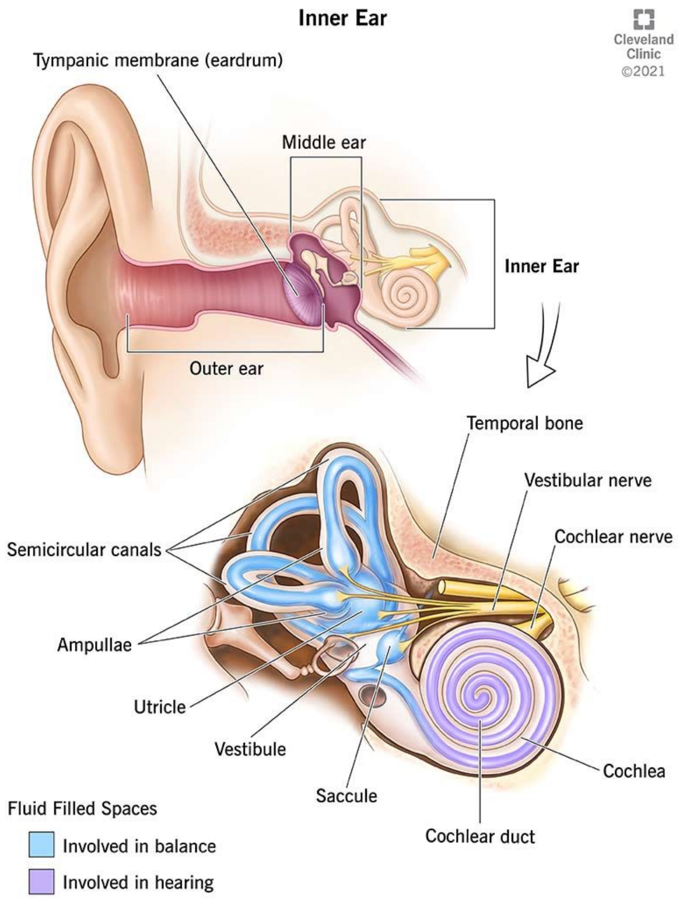
Anatomy of Auditory Reception

Inner Ear

- Oval Window
  - entrance point of sound waves in cochlea
  - A membrane at the Base of the upper chamber of the Cochlea
  - Ossicles act like an amplifying connection from the Eardrum to the Oval window

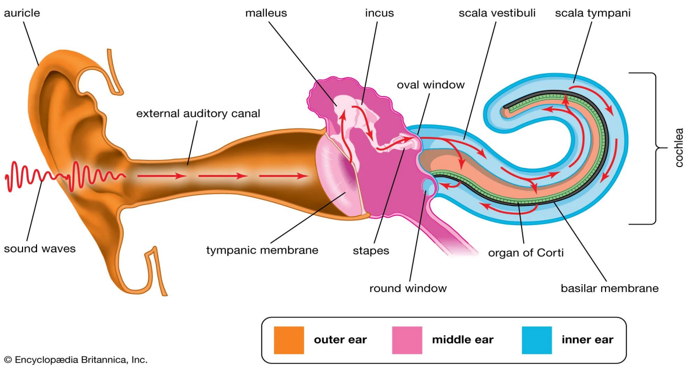
- Cochlea (hearing)
  - A snail-shaped coiled tube with 3 fluid-filled chambers

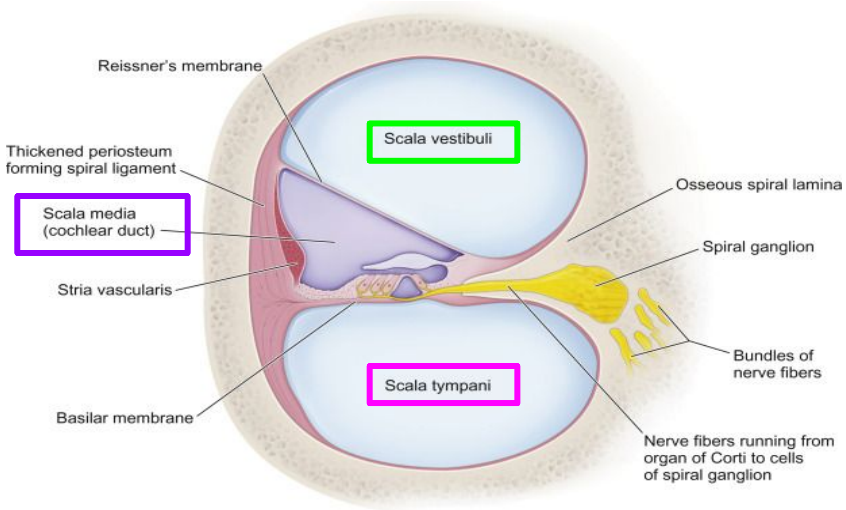
- Vestibule & Semicircular canal (balance)



Cochlea

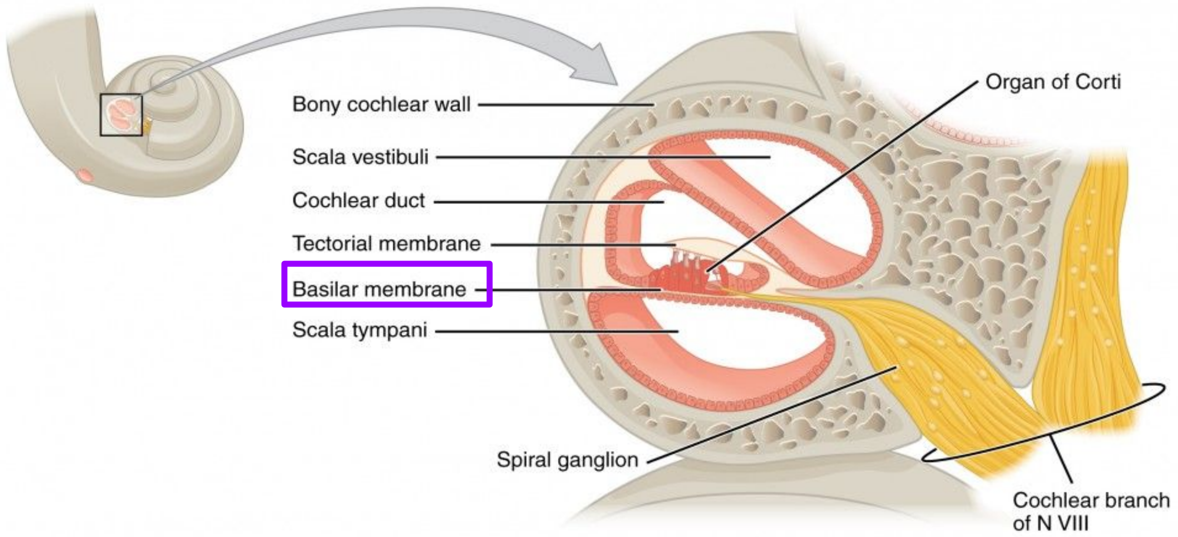
- Converting sound waves → neural signals
- Consists of 3 chambers:
  - **Scala Vestibuli** (Upper)
  - **Scala Media** (Middle)
  - **Scala Tympani** (Lower)
- Vibrations from the **Oval Window** travel up from the base of the top chamber, to the **Apex**, then circle back to the base of the bottom chamber ending at the **Round Window**
- As the vibrations travel, they also vibrate the middle chamber S. Media





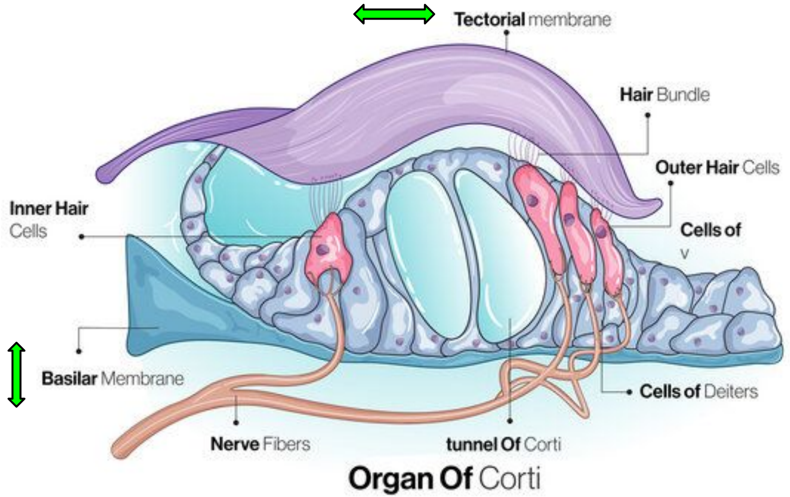
Cochlea

- Basilar Membrane – The floor of Scala Media
- Organ of Corti
  - Located on top of the Basilar Membrane
  - Contains specialized Neurons called **Hair Cells (sensory receptors for hearing)**
  - Covered by the Tectorial Membrane like a blanket



Organ of Corti

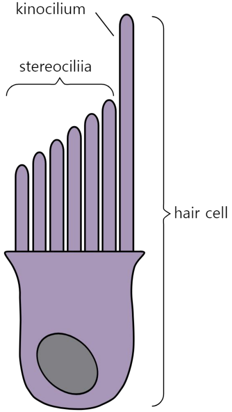
- Chambers are filled with a viscous, non-compressible K+ rich fluid called **Endolymph**
- Vibrations causes the Basilar Membrane to move **up and down** and the Tectorial Membrane to move **left and right**
- Cilia of Hair Cells are bent between these two membranes which triggers a cascade of downstream effects

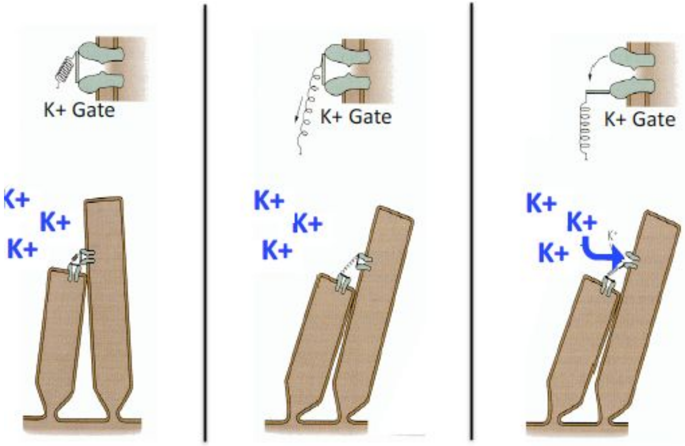


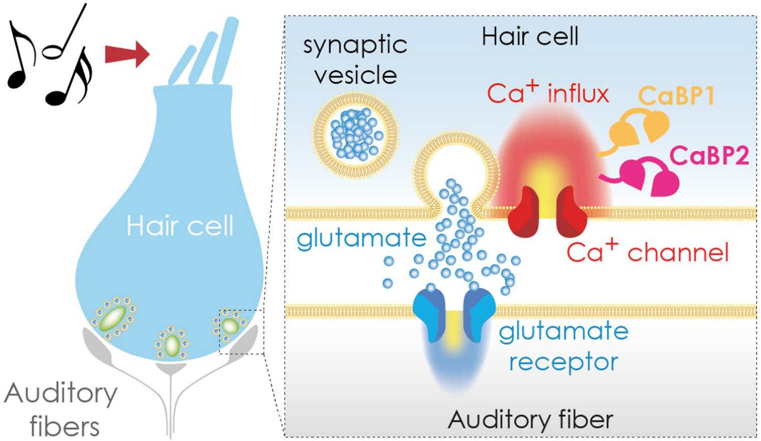
Hair Cell

- If bending towards the **longest cilium**: K+ Gates open to allow an influx of K+, resulting in depolarization. Chain rxn involves secondary messengers which allow Ca++ to enter the cell which triggers the release of Glutamate

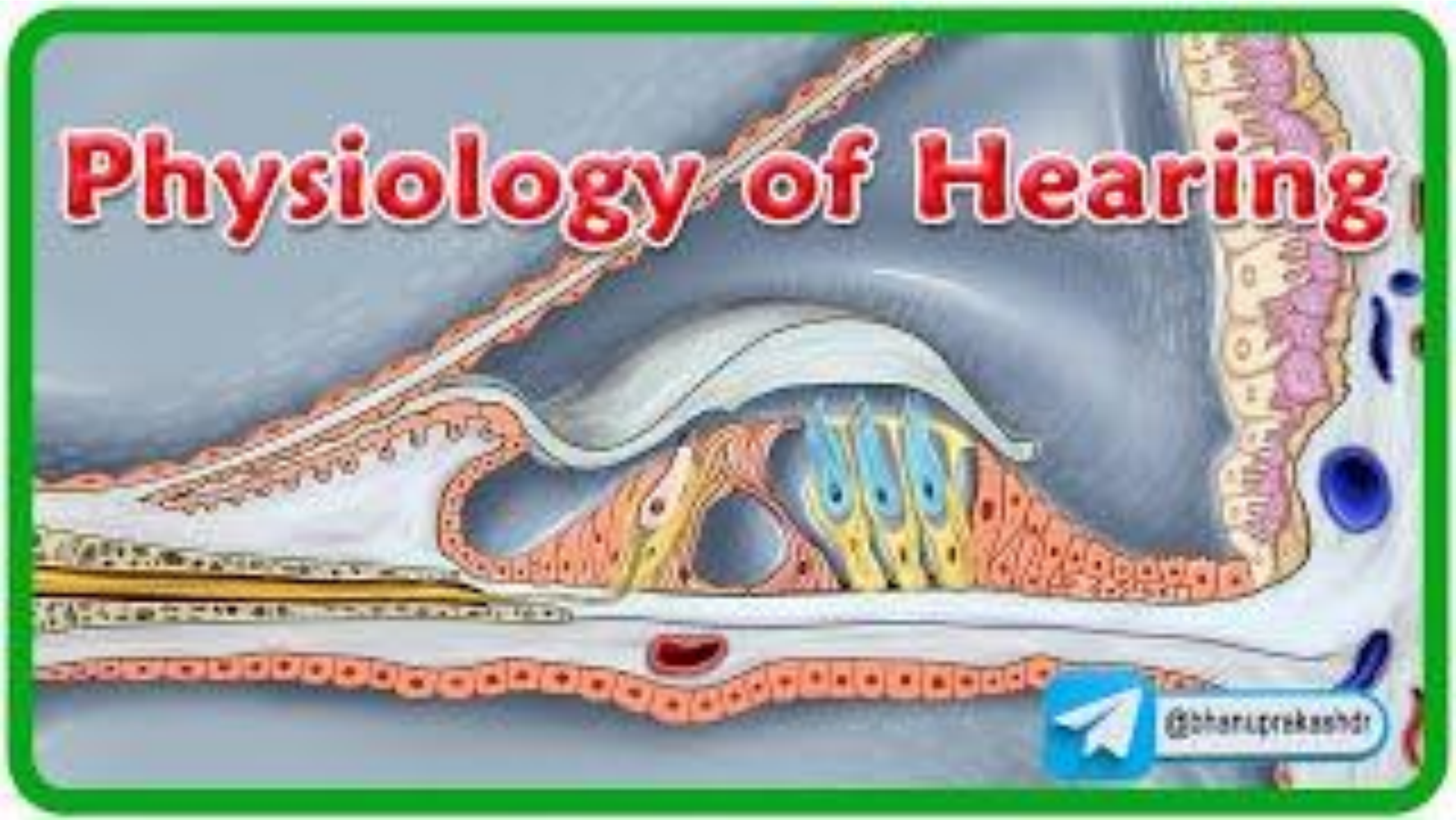
- If bending towards the **shortest cilium**: K+ Gates remain closed and K+ leaves the cell while Ca++ is actively pumped out, restoring polarity.







Hair Cell



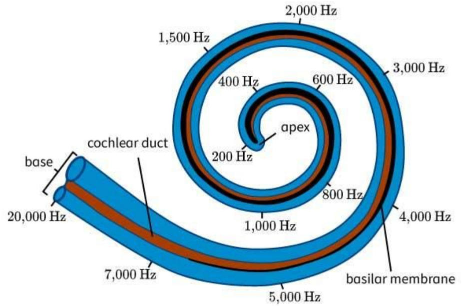
1. Place Coding

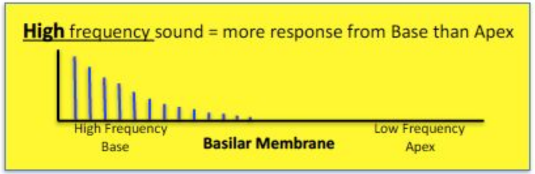
- The concept that certain frequencies are coded to physical locations

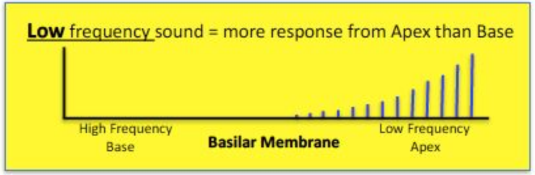
- Base of the basilar membrane
  - Closest to oval window
  - Narrow and Stiff
  - Most responsive to high frequencies
- Apex of the basilar membrane
  - Far end of the Cochlea
  - Wide and Floppy
  - Most displaced by low frequencies

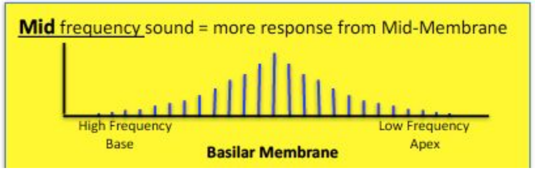
- **Graded** response: The more the basilar membrane resonates, the farther it moves & the more the cilia of HCs are bent → more NT is released

- The **distribution** of NT response along the basilar membrane encodes frequency information









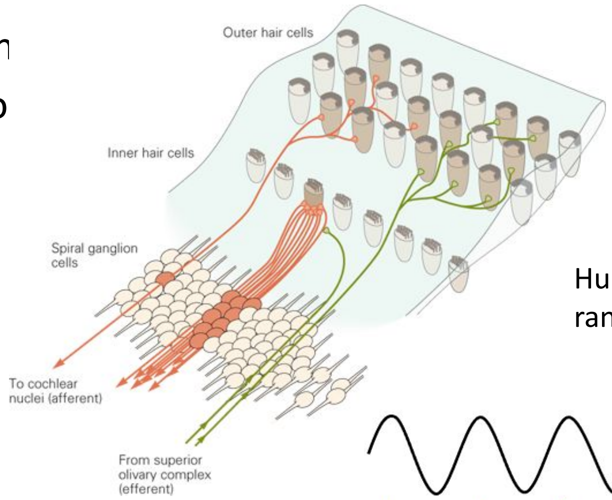
2. Temporal Coding (Rate/Frequency coding)

- Different “places” along the Basilar Membran resonate at the input frequency but may also vary in the **amplitude** of the vibration

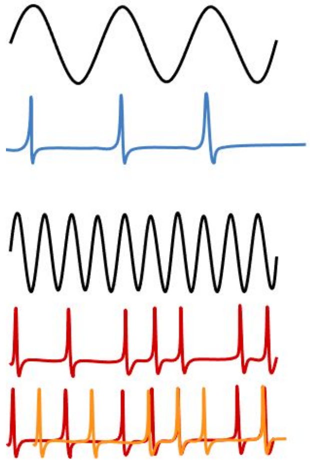
- Hair Cells communicate to **Spiral Ganglions** (whose axons make up the Auditory nerve) which fire action potentials

- Due to their refractory periods, SGs can only fire a max of 1000 times per second (1kHz)

- **Volley Principle (Across Fiber Coding)**
  - Summation of multiple “volleys” of neurons firing → can encode > 1kHz sound waves
  - SGs are **Phase-locked**



Humans can have a hearing range of 31 Hz to 19kHz!



Problem Set

1) Fill in the blanks to complete the statements about <u>Temporal (Rate) Coding</u> for frequency in audition

A) Rate coding depends on the physical structure of the _____________.

B) Hair Cells release neurotransmitters, but their rate of firing is limited by their _____________, where they cannot fire.

C) The _____________(which part) overcome this Refractory Period limitation by taking turns, together producing an output along the _____________ that matches the incoming frequency.

D) The _____________ argues that only if the ganglions are "phase locked" will they produce volleys of activity at a rate that matches the incoming frequency.

Problem Set

1) Fill in the blanks to complete the statements about <u>Temporal (Rate) Coding</u> for frequency in audition

A) Rate coding depends on the physical structure of the __basilar membrane__.

B) Hair Cells release neurotransmitters, but their rate of firing is limited by their _refractory period_, where they cannot fire.

C) The __Spiral Ganglions__(which part) overcome this Refractory Period limitation by taking turns, together producing an output along the __Auditory Nerve__ that matches the incoming frequency.

D) The __Volley Principle__ argues that only if the ganglions are "phase locked" will they produce volleys of activity at a rate that matches the incoming frequency.

Problem Set

2) Fill in the blanks to complete each statement about <u>Place Coding</u> for frequency in audition

A) The _____________ end of the membrane is narrow and stiff.

B) Apex at the basilar membrane is most displaced by _______________ frequencies.

C) Your nervous system does not only record the place of maximum resonance; it also integrates information across _____________ to code for that frequency.

Problem Set

2) Fill in the blanks to complete each statement about <u>Place Coding</u> for frequency in audition

A) The __base__ end of the membrane is narrow and stiff.

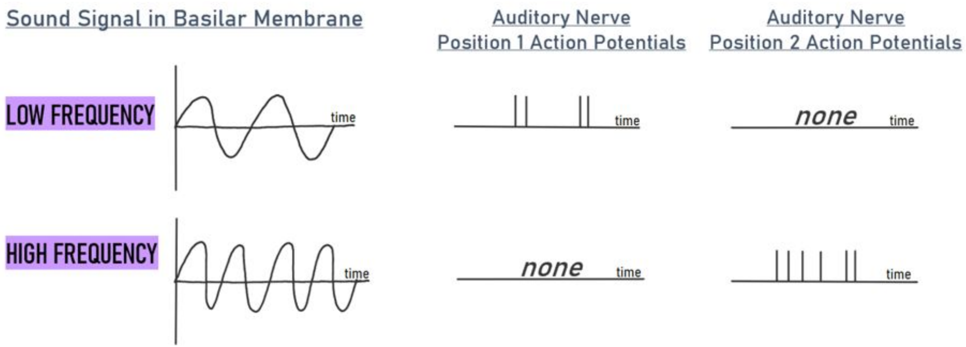
B) Apex at the basilar membrane is most displaced by __low__ frequencies.

C) Your nervous system does not only record the place of maximum resonance; it also integrates information across __multiple locations/distirbution__ to code for that frequency.

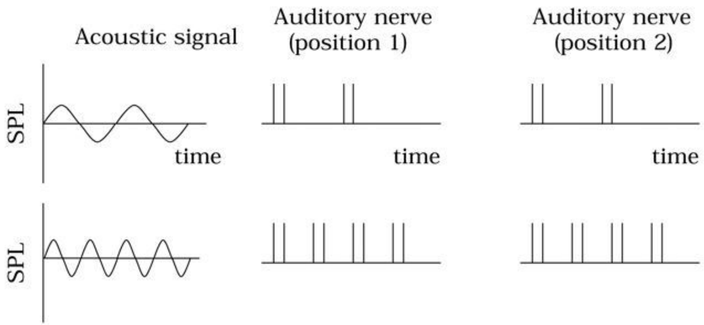
Problem Set

3) Which coding theory is this diagram for? Temporal or Place?

a.



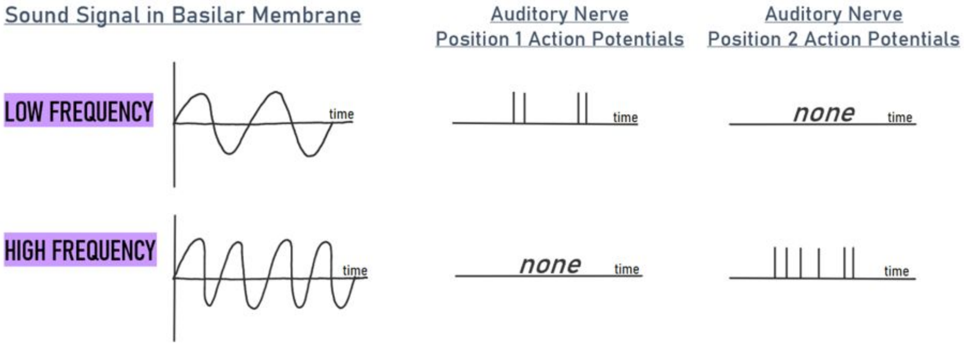
b.



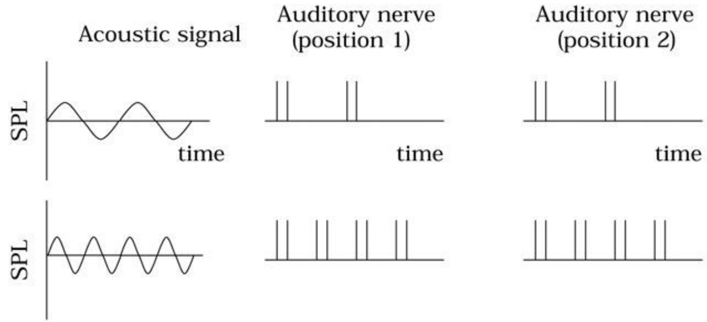
Problem Set

3) Which coding theory is this diagram for? Temporal or Place?

a. Place



b. Temporal

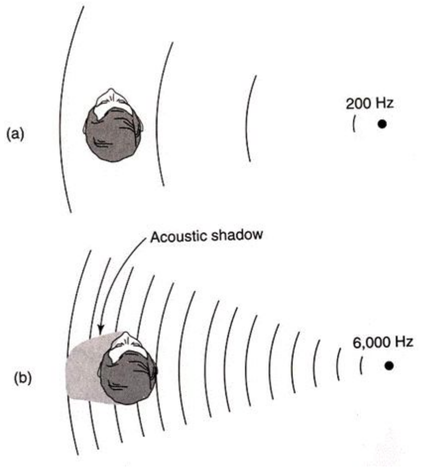


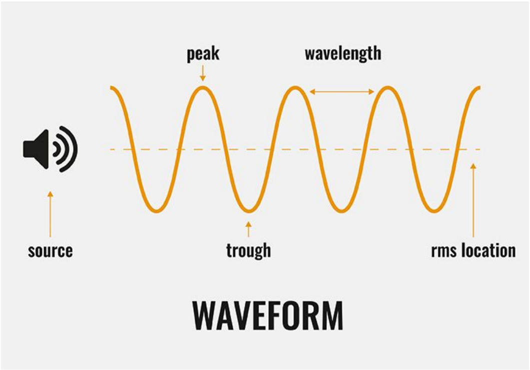
Auditory Localization

- Because sound is a physical pressure wave, binaural hearing allows us to localize the source of a sound based on:

1. **Intensity/Amplitude Differences:**
    - Just as in visual sys, disparity b/w inputs from both ears' receptors is used to perceive depth
    - Sound at ear closer to source is louder/intense than at other ear, because of head shadow
    - works best for **high** frequency sounds (due to short wavelengths)

2. **Phase Differences:**
    - For **lower** frequencies, the auditory system can detect differences in peak vs. trough of waves between the two ears
    - One ear may pick up the peak, while the other picks up the trough, helping to determine the direction of the sound source

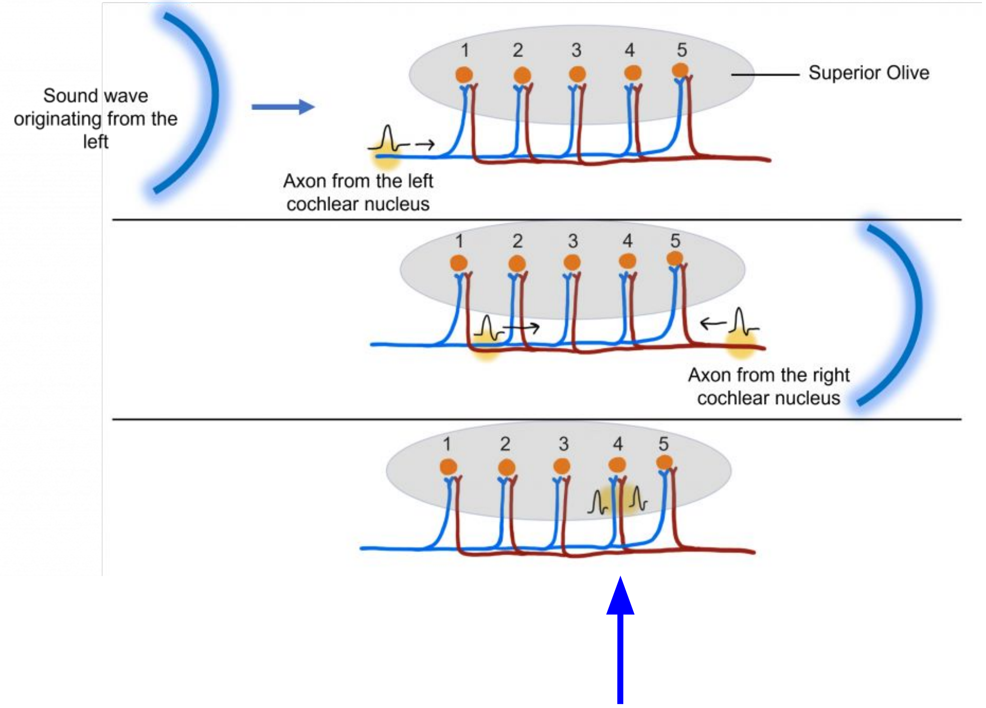




Auditory Localization

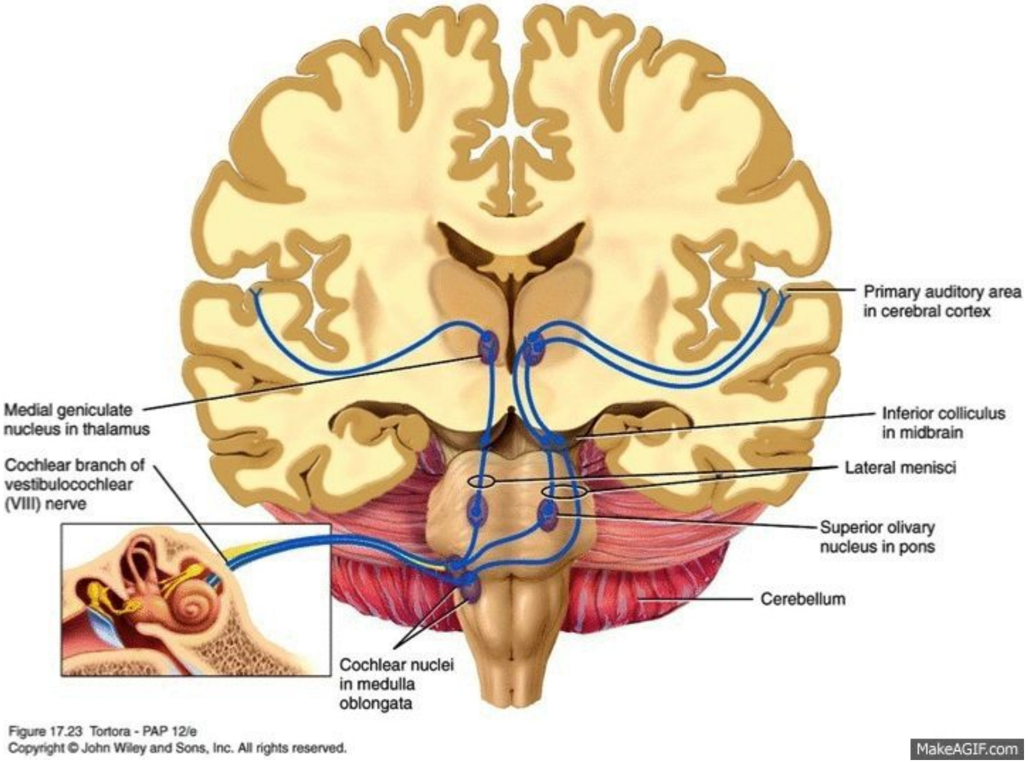
3. Timing Differences:

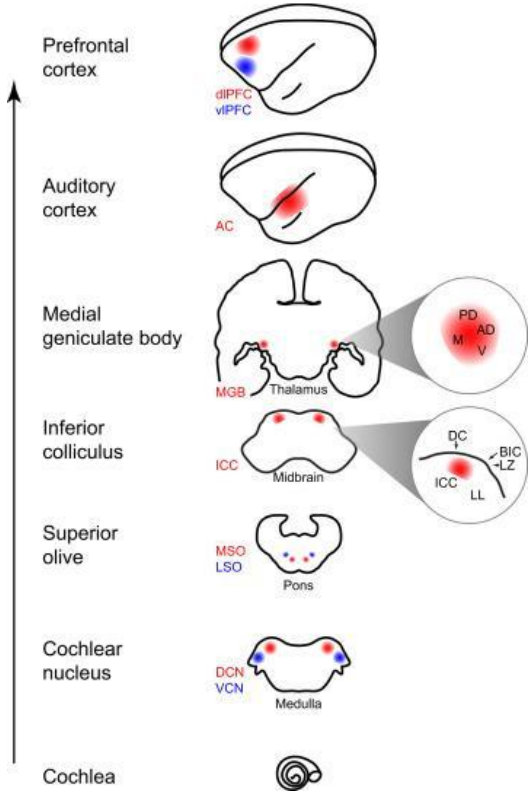
- “Interaural Time-Disparity Detectors” in the **Superior Olive (in medulla)** forms a competitive “racing” circuit
- If a sound is to the left, it reaches the left ear earlier than the right.
- Both ears sends off a signal, but because the left ear is triggered first, the signal travels farther than the right ear signal.
- Only when input from **BOTH** ears **converge** will Superior Olive fire → depend on the location of the convergence



Auditory Pathway

starts at the cochlear nucleus in medulla ⟶ the superior olivary complex in pons ⟶ the inferior colliculus in midbrain ⟶ medial geniculate nucleus (MGN) in thalamus ⟶ eventually the primary auditory cortex (A1)





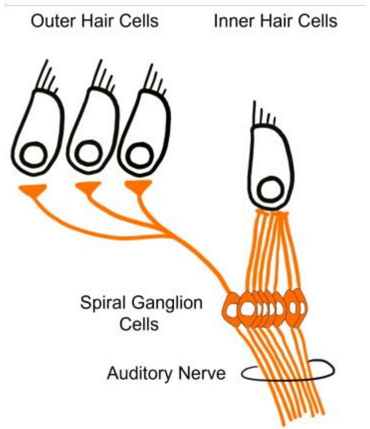
Auditory Pathway

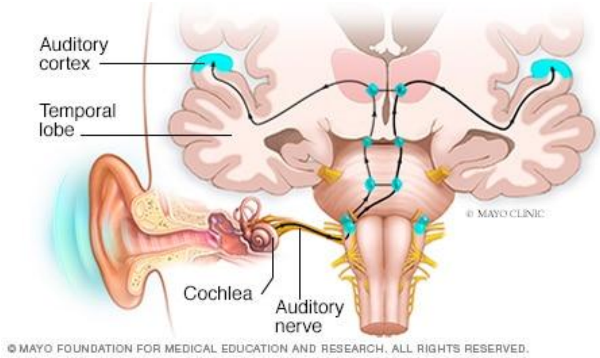
- Starts with 2 types of Hair Cells in Cochlea

- **Inner Hair Cells (IHC)** (like Cones)
  - ~3500 per ear, **Divergent** connectivity 1 IHC to many (8-30) SG
  - Responsible for encoding frequency information
  - High **detailed** with little loss of information

- **Outer Hair Cells (OHC)** (like Rods)
  - ~12000 per ear, **Convergent** connectivity ~20 OHC to 1 SG
  - Cannot encode frequency information, but good for **amplitude** information

- **Spiral Ganglion (SG)**
  - Specialized neurons whose axons form the **Auditory Nerve** (part of the 8th Cranial Nerve)
  - Feeds into Cochlear Nucleus in the Medulla
  - Each nerve connects only to the ipsilateral side

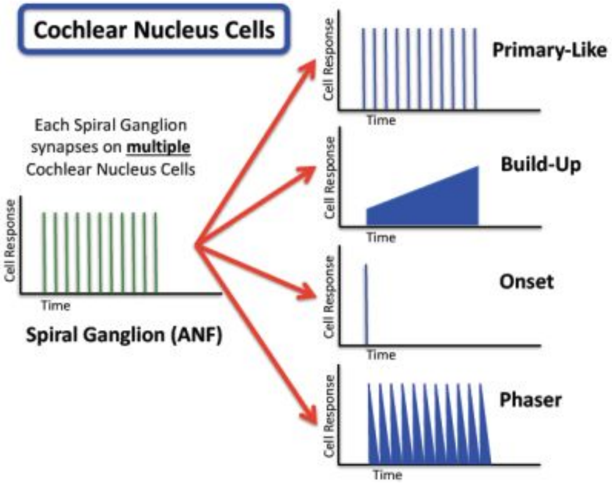




Auditory Pathway

- Each SG synapses on multiple Cochlear Nucleus cells in medulla

- **Cochlear Nucleus:** first brainstem structure that receive input from the auditory nerve
    a. L cochlear nucleus receives from L ear only, R from R only (monaural site)
    b. Cell types: responds to sound in distinct ways
        a. Primary–Like Cells
            i. Reproduces SG firing patterns
            ii. Preserves the tonotopic map
        b. Build–Up Cells
            i. Create continually increasing **graded** responses
        c. Onset Cells
            i. Single onset signal ("Starting Now!")
            ii. Goes to S. Olive to determine which ear received sound first



- Fibers from Cochlear Nucleus go to ipsi- and contra-lateral S. Olive

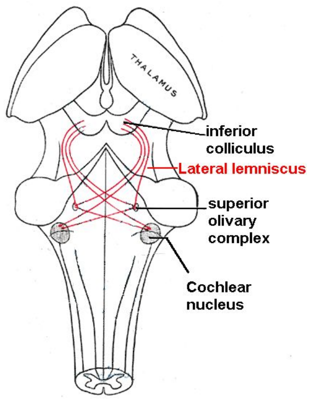
Auditory Pathway

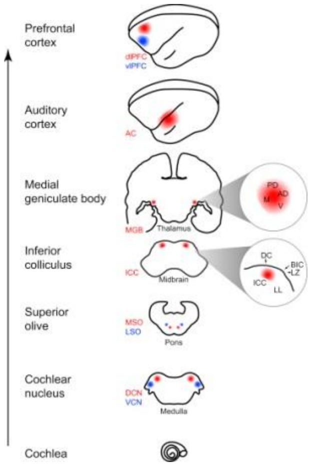
- **Superior Olive** is the first **Binaural** site along the path
  - Localize the source of a sound by integrating signal from both ears

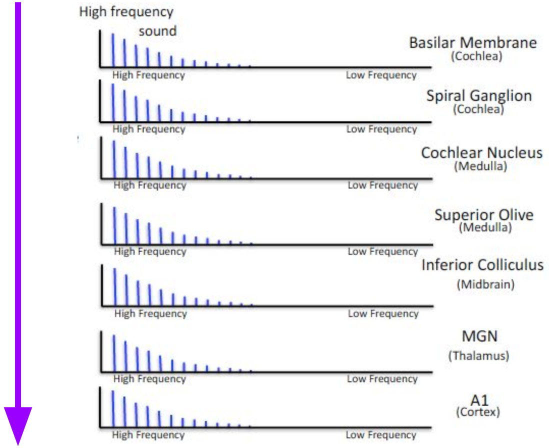
- **Inferior Colliculus** in midbrain receives inputs from contra-lateral CN & ipsi-lateral SO
  - Communicate w/ Superior Colliculi (visual motion maps) and Tegmentum, to direct eyes to source of sound

- Pathway continues up to the **Medial Geniculate Nucleus (MGN)** in the Thalamus which processes tonotopic maps

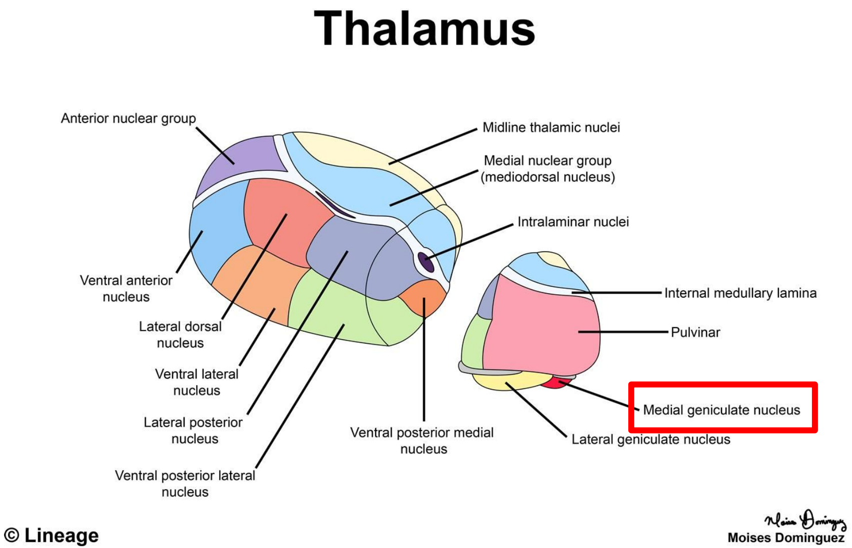
- **Tonotopic** Maps in Auditory System
  - At each point along the pathway, primary-like cells re-represent the same pattern to preserve the topological map created by the distribution of activity across BM (= place coded frequency)







Medial Geniculate Nucleus (MGN)



LGN (Lateral Geniculate Nucleus) • **L** is for Light (Visual)

MGN (Medial Geniculate Nucleus) • **M** is for Music (Auditory)

VPN (Ventral Posterior Nucleus) • **VP** is for Very Personal (Touch)

DMN (Dorsal Medial Nucleus) • **DM** is for Dog Muzzle (Smell)

VLN (Ventro Lateral Nucleus) • **VL** is for Victory Lap (Motor)

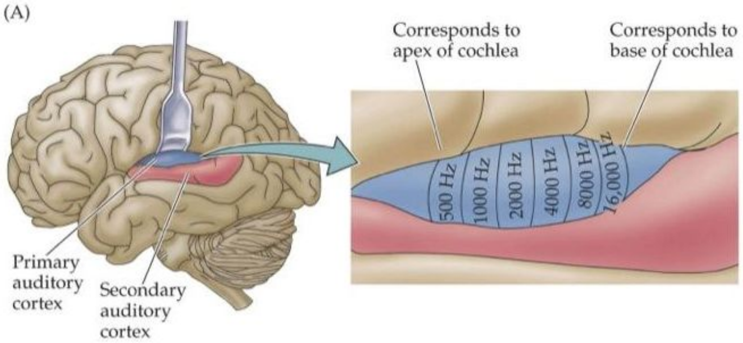
MDN (Medial Dorsal Nucleus) • **MD** is for Memory Doctor

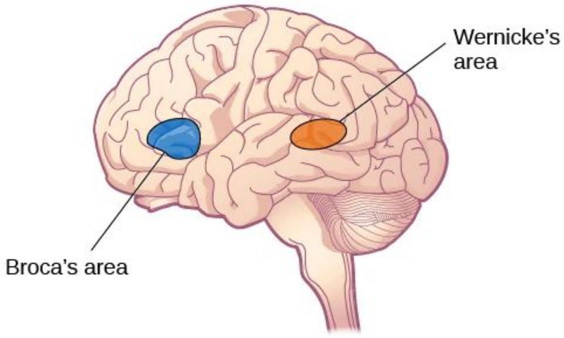
Auditory Cortex

- Fibers from MGN synapse to A1 and A2 Cortices

- **Primary Auditory Cortex (A1)**: primary projection area
  - Tonotopic/Amplitude map is preserved and represented along the lateral axis (High to low frequency: posterior to anterior; High to low amplitude : medial to lateral)
  - Cells within each layer are attuned to various attributes
    - Some cells respond best to **simple** tones
    - Some to more complex sounds
  - Other areas respond to the location of the sound source
- **Secondary Auditory Cortex (A2)**
  - Responds best to **changing/complex** sounds (familiar noises, speech sounds, etc)
  - Damage to A2 not necessarily result in deafness, but Auditory Agnosia (= inability to recognize or identify familiar sounds)

- **Higher Auditory Cortex**: processes complex patterns, integrates auditory input w/ other perceptual & cognitive activities
  - e.g., speech comprehension (Wernicke’s Area in L hem)





Beyond human

You’re almost there!