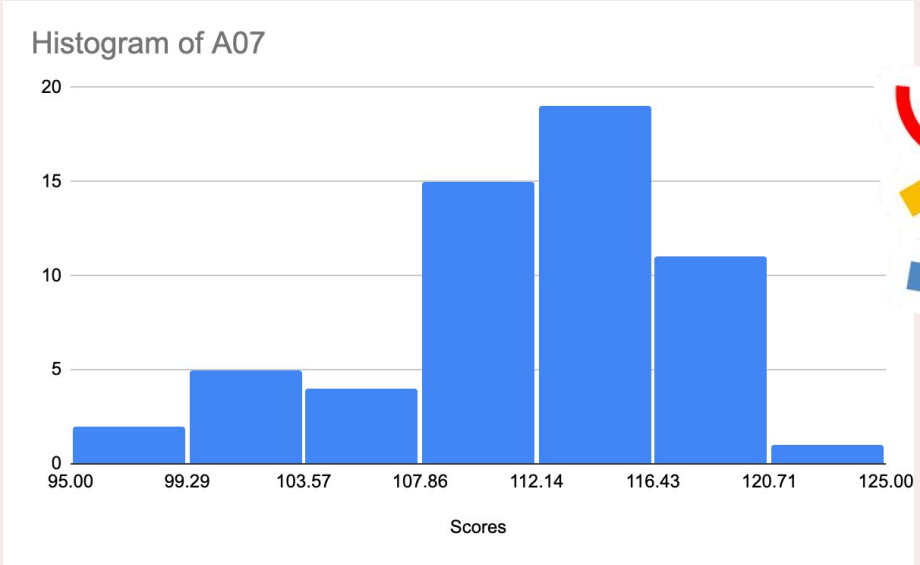
COGS 17

Week 5

Audition

Congrats!!

Our section scored an average of 112, equiv. to 89%!



Reminders!

Homework Problem Sets

- Homework #4 is due WED @ 11:59 PM!
- No late homeworks accepted

Midterm

- Midterm 2 is 5/15 (Th) from 3-30:4:50 PM!
- Can be taken online or in class
- Will be proctored in class

Extra Credit

- SONA
- Mnemonics
- Do all HWs → 4 extra credit points

For Slides + Problem Sets

Link:

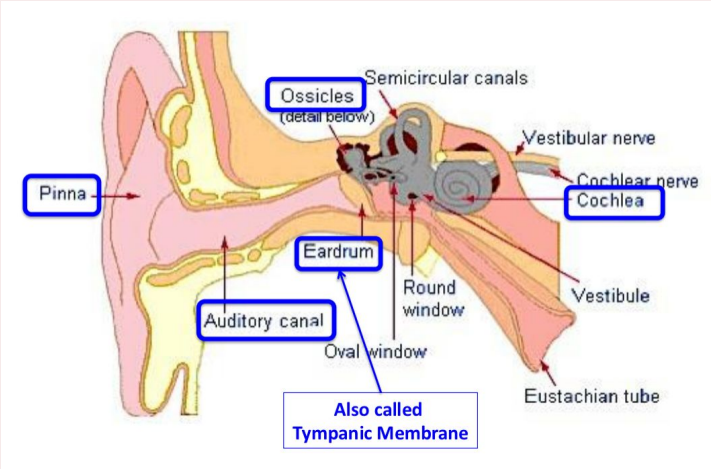
https://drive.google.com/drive/folders/1DlvXFvEKxhF3ykEaK2_jBsNUgGOb8fS3?usp=drive_link

Anatomy of Auditory Reception

Outer Ear

- **Pinna**
  - Outer ear structure that helps localize sounds

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

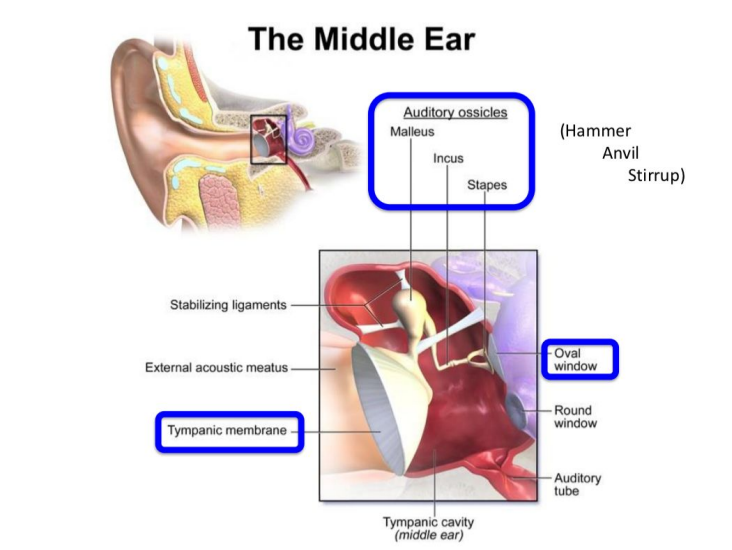


Anatomy of Auditory Reception

Middle Ear

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

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



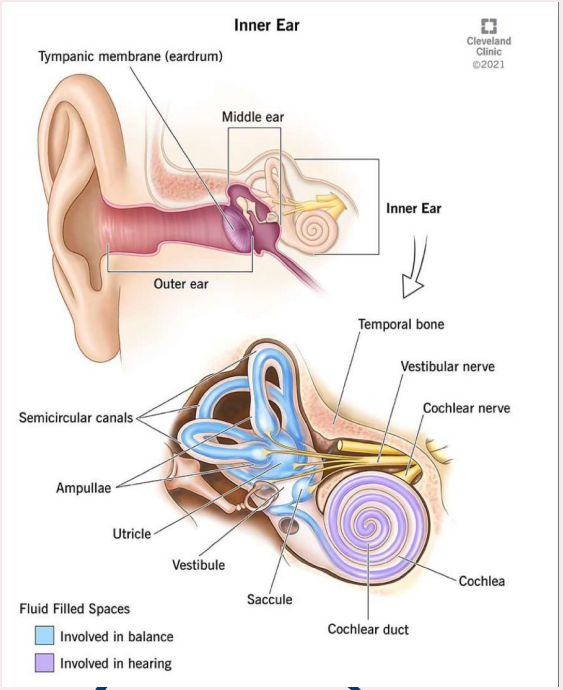
Anatomy of Auditory Reception

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

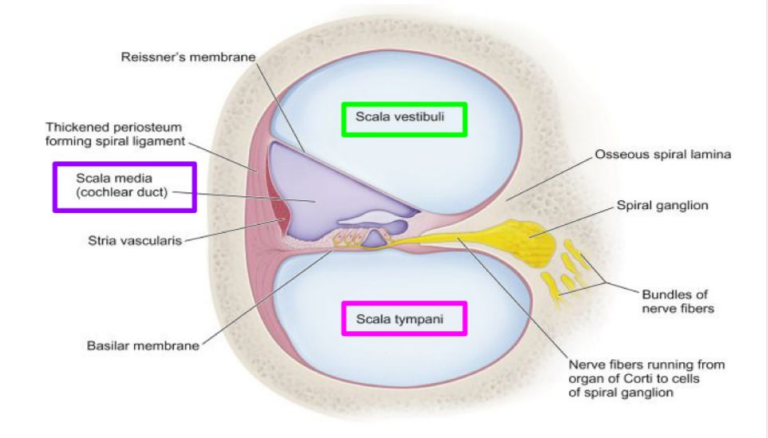
Converts sound waves → neural signals

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 **Scala Media**

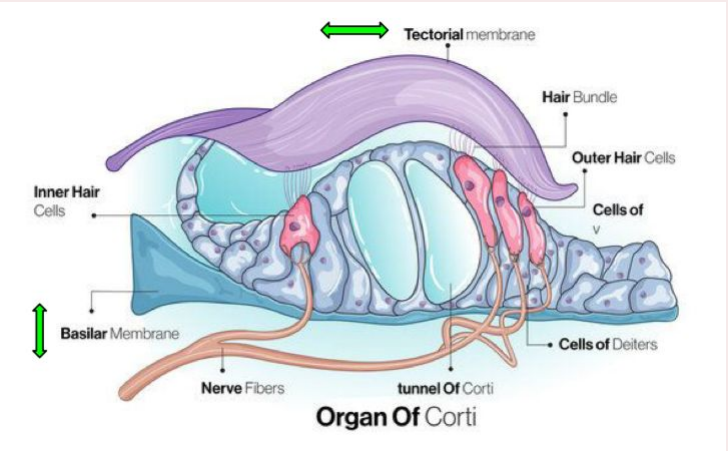


Cochlea

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

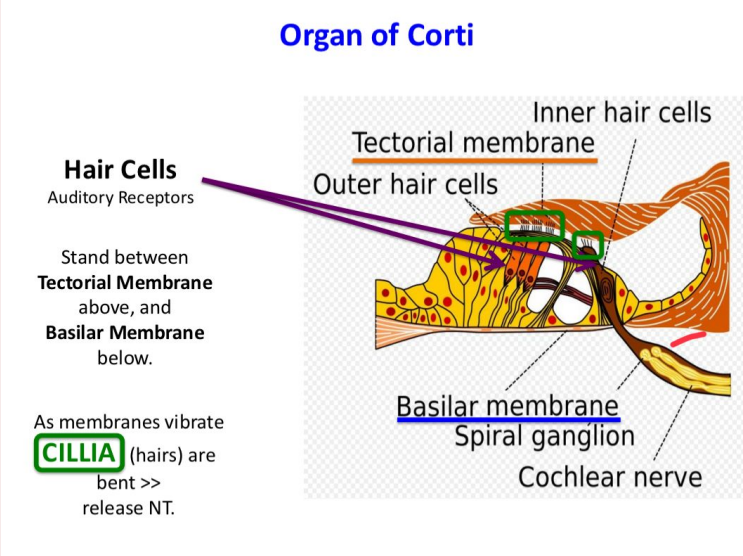


Organ of Corti

Chambers are filled with a viscous, non-compressible K+ rich fluid called **Endolymph**

Vibrations cause 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 events



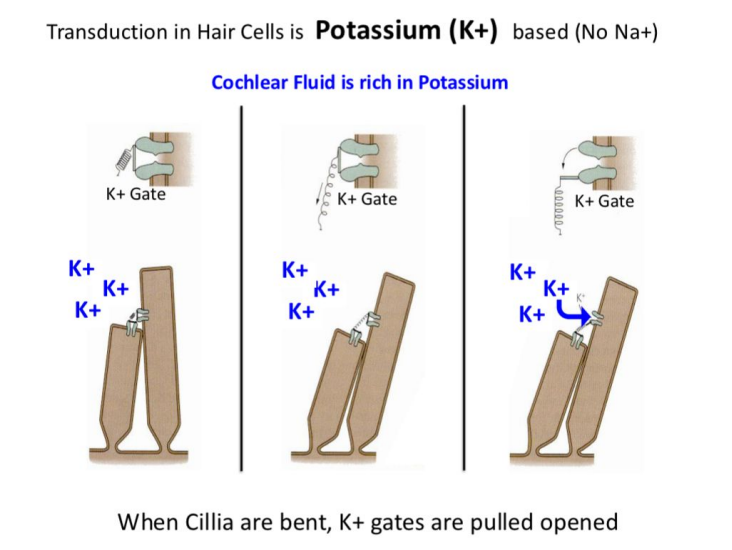
Hair Cell

If bending towards the **longest cilium**:

- K+ gates open to allow an influx of K+, resulting in depolarization
- Chain reaction 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
- K+ leaves the cell while Ca++ is actively pumped out, restoring polarity

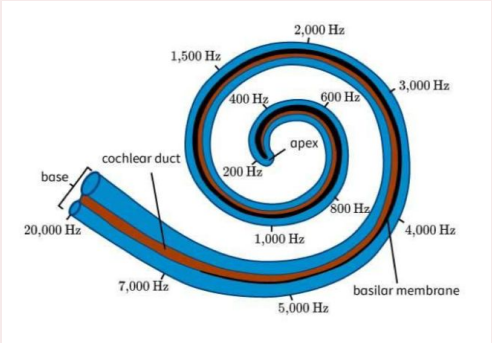


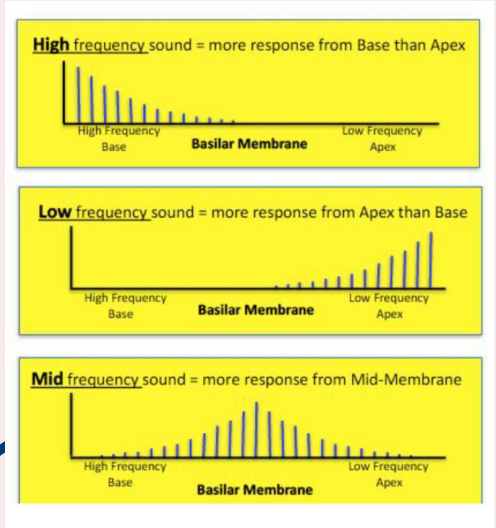
Place Coding

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**





Place Coding

Graded response: The more the basilar membrane resonates, the farther it moves and the more the cilia of hair cells are bent → more NT is released

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

Temporal (Rate) Coding

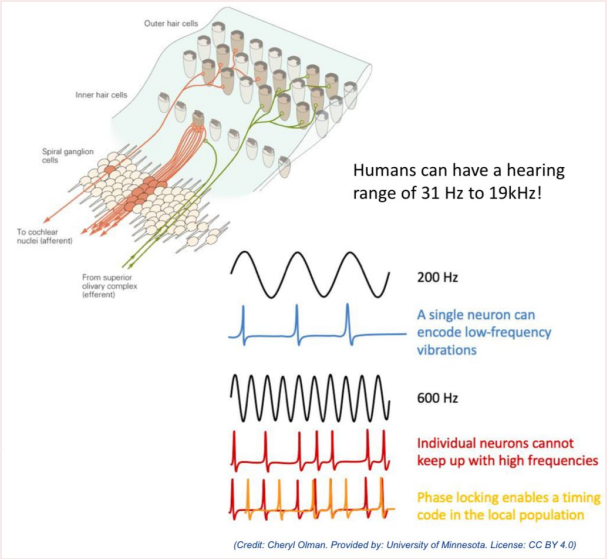
Different “places” along the Basilar Membrane resonate at the input frequency but may also vary in the **amplitude** of the vibration

Hair cells communicate to **Spiral Ganglions** (whose axons make up the **Auditory nerve**) which fire APs

Due to their refractory periods, Spiral Ganglions 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
- Spiral Ganglions are **Phase-locked**



Auditory Localization

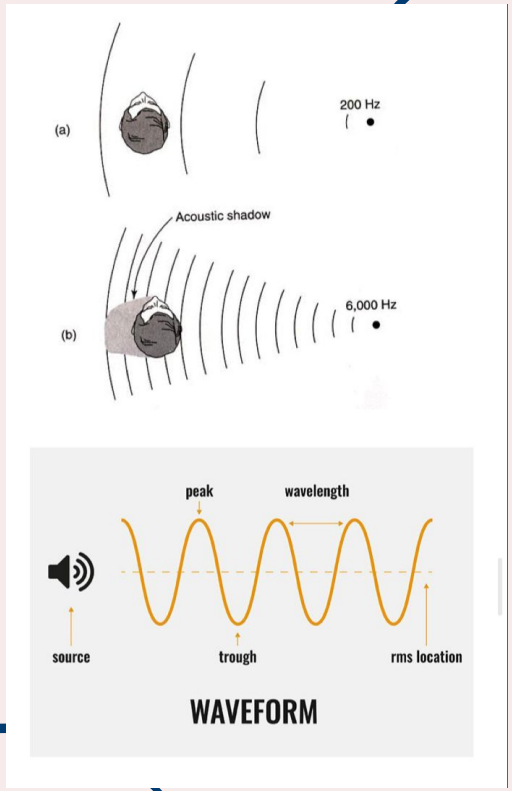
Because sound is a physical pressure wave, **binaural** hearing allows us to localize the source of a sound based on:

1. Intensity/Amplitude Differences:

- Disparity between 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

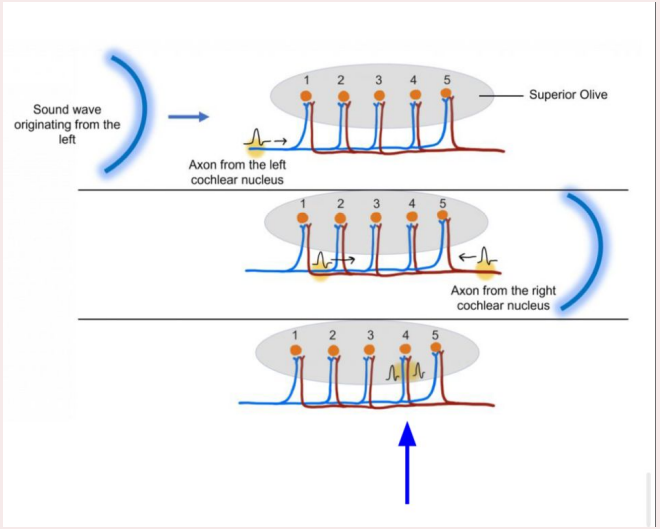
- For **lower frequencies**, the auditory system can detect differences in peak vs. trough of waves between the two ears
- One ear may pick up the peak, while the other picks up the trough, helping to determine the direction of the sound source



Auditory Localization

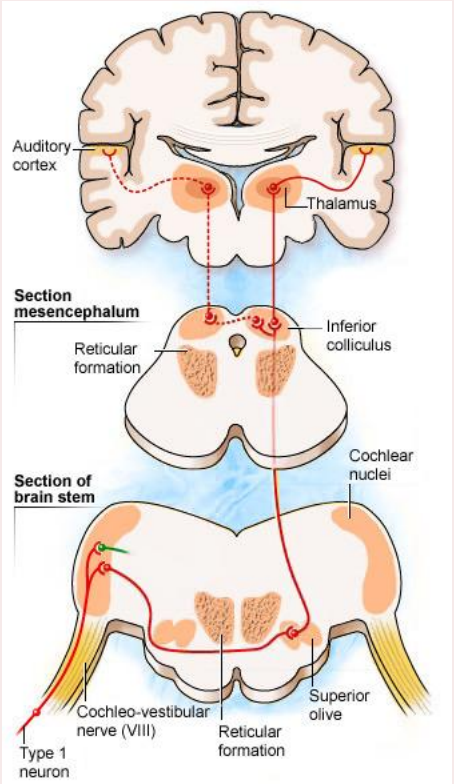
3. Timing Differences:

- "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 send 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 the Superior Olive fire → dependent on location of convergence



Auditory Pathway

1. Starts at the cochlear nucleus in medulla
2. Superior olivary complex in pons
3. The inferior colliculus in midbrain
4. Medial geniculate nucleus (MGN) in thalamus
5. Eventually sent to primary auditory cortex (A1)



Auditory Pathway

Starts with 2 types of Hair Cells in Cochlea

Inner Hair Cells (IHC)

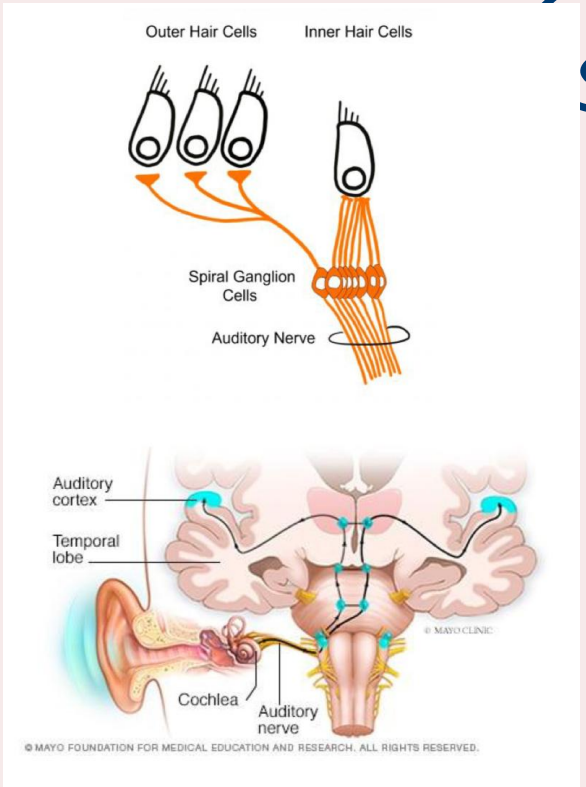
- ~3500 per ear, Divergent connectivity IHC to many SG
- Responsible for encoding frequency info
- High detail with little loss of info

Outer Hair Cells (OHC)

- ~12000 per ear, Convergent connectivity ~20 OHC to 1 SG
- Cannot encode frequency info, but good for amplitude info

Spiral Ganglion (SG)

- Specialized neurons whose axons form the Auditory Nerve
- Feeds into Cochlear Nucleus in the medulla
- Each nerve connects only to the ipsilateral side

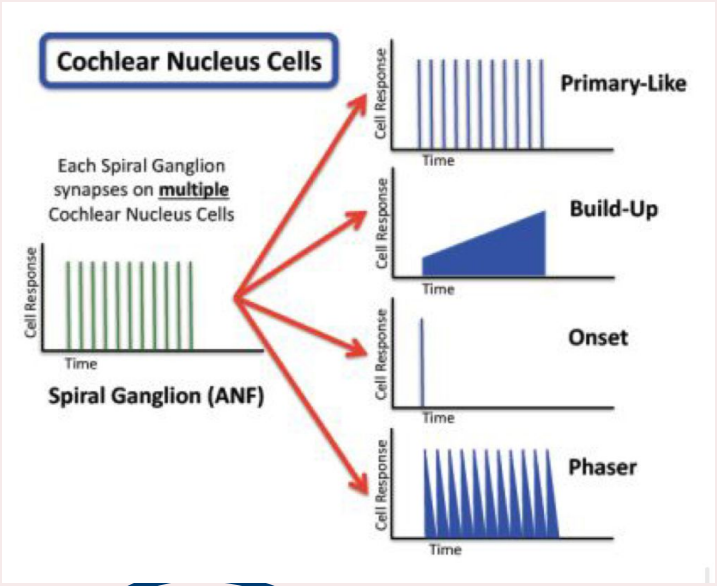


Auditory Pathway

Each SG synapses on multiple Cochlear Nucleus cells in medulla

Cochlear Nucleus (CN): first brainstem structure that receives input from the auditory nerve

a. Left cochlear nucleus receives from left ear only, vice versa
b. Cell types: responds to sound in distinct ways
    i. **Primary-Like Cells**
        1. Reproduces SG firing patterns
        2. Preserves tonotopic map
    ii. **Build-Up Cells**
        1. Creates continually increasing graded responses
    iii. **Onset Cells** → single onset signal (“Start!”)
        1. Goes to Superior Olive to determine which ear received sound first



Auditory Pathway

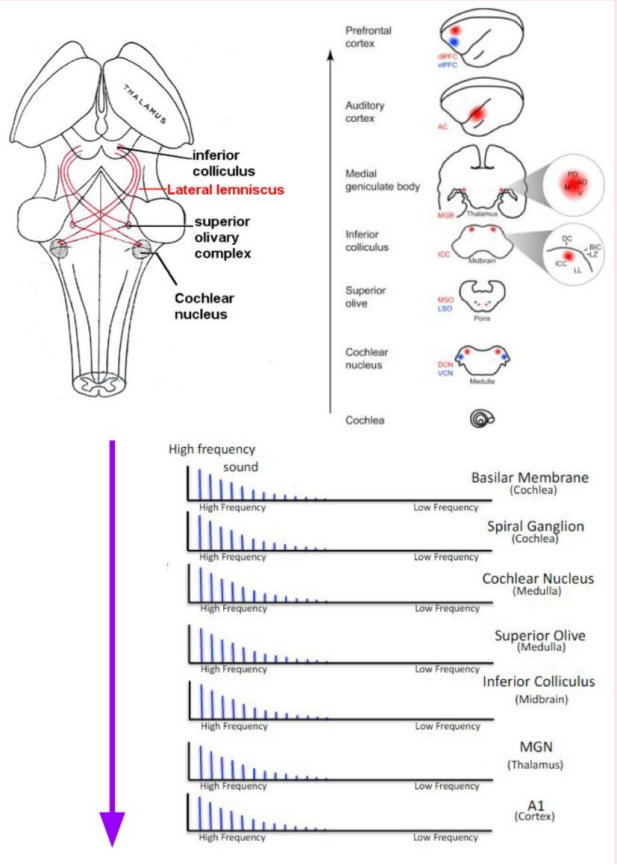
Fibers from Cochlear Nucleus go to ipsi- and contralateral Superior Olive

Superior Olive is the first Binaural sites along the path

- Localize the source of sound by integrating signal from both ears

Inferior Colliculus in midbrain receives input from contralateral CN and ipsilateral Superior Olive

- Communicate with **Superior Colliculi** (visual motion maps) and **Tegmentum** to direct eyes to source of sound

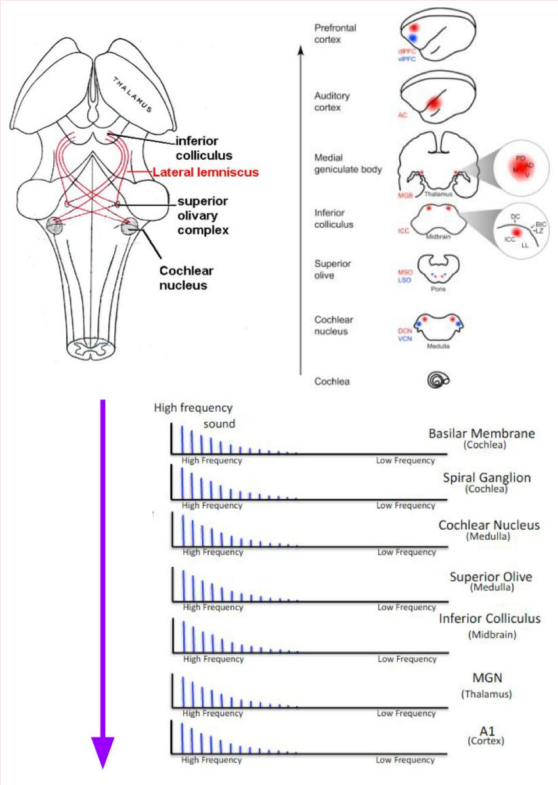


Auditory Pathway

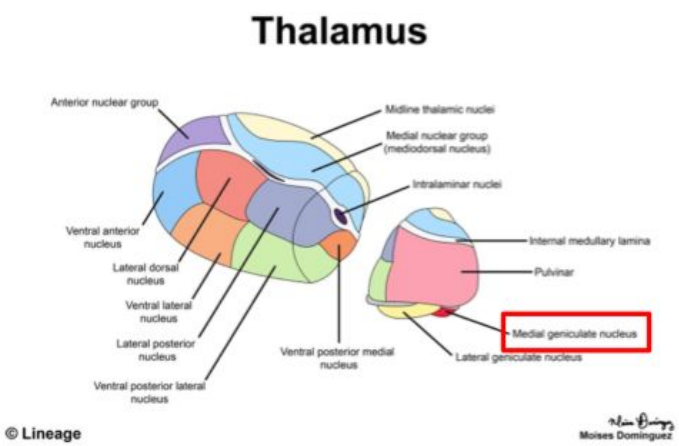
Pathway continues up to the **Medial Geniculate Nucleus (MGN)** in the thalamus which processes tonotopic maps

Tonotopic maps in the 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)

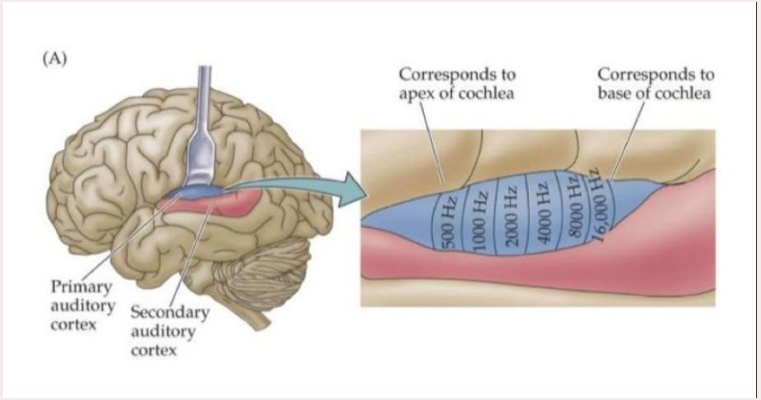
MDN (Medial Dorsal Nucleus) • **MD** is for Memory Doctor

Auditory Cortex

Fibers from MGN synapse to A1 and A2 Cortices

Primary Auditory Cortex (A1): primary projection area

- Tonotopic map is preserved and represented along the lateral axis (High → low frequency: posterior to anterior; High → low amplitude: medial to lateral)
- Cells within each layer are attuned to various attributes
    - Some cells respond best to simple tones, others more complex



Auditory Cortex

Secondary Auditory Cortex (A2)

- Responds best to changing/complex sounds (familiar noises, speech sounds, etc.)
- Damage to A2 not necessarily results in deafness, but Auditory Agnosia (= inability to recognize or identify familiar sounds)

Higher Auditory Cortex: processes complex patterns, integrates auditory input with other perceptual and cognitive activities

- E.g., speech comprehension (Wernicke's Area in left hemisphere)