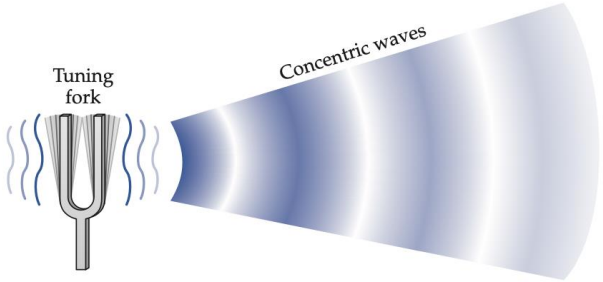
BIO-311 Neuroscience

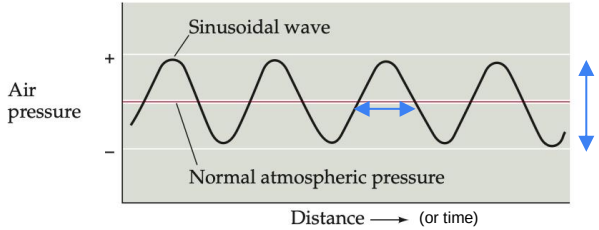
Audition

Summary

- What is sound:
  - Complex sound = superposition of pure tones
- Anatomy of the ear and functional interpretation:
  - Outer, middle, and inner ear
  - Inner ear cochlea: mechanical signal → neural signal
  - Ionic basis of audio sensors (inner hair cells)
  - Outer hair cells: cochlear amplifiers
- The auditory pathway & auditory encoding:
  - Tonotopy preserved from cochlea to primary auditory cortex
  - Bilateral projections & parallel pathways
  - Strategy for localization: ITD & IID

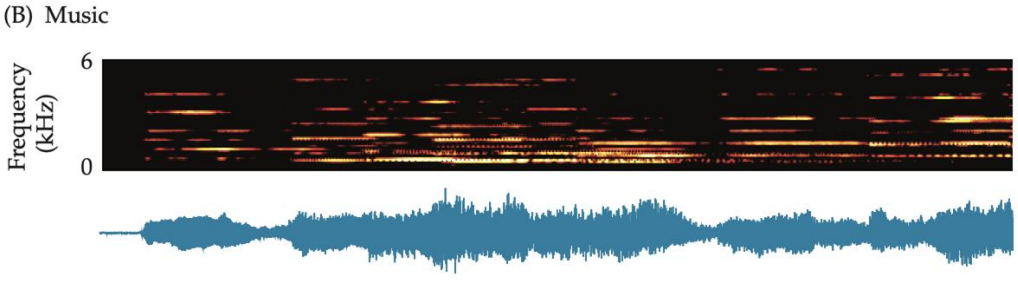
What is sound?





A pure tone is a periodic oscillation of air pressure at a single frequency

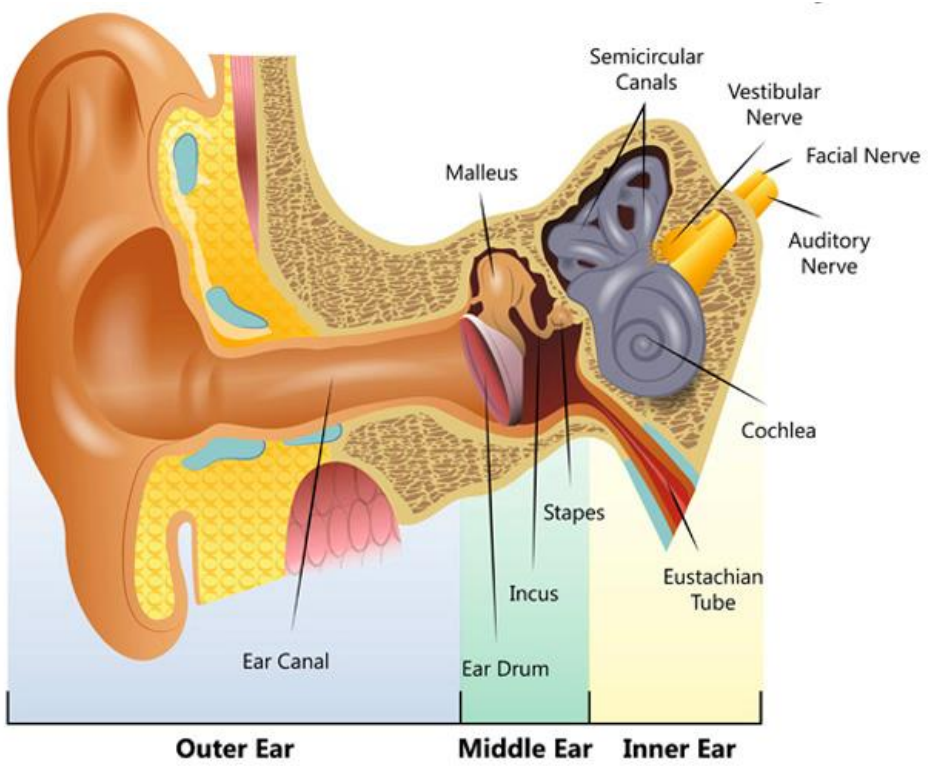
A pure tone is characterized by amplitude (dB) and frequency (Hz) ⟷ (time)



Linear superposition of many pure tones makes up complex sounds (speech, music, …) – Fourier!

This can be decomposed by the inner ear

Anatomy: the outer, middle, and inner ear

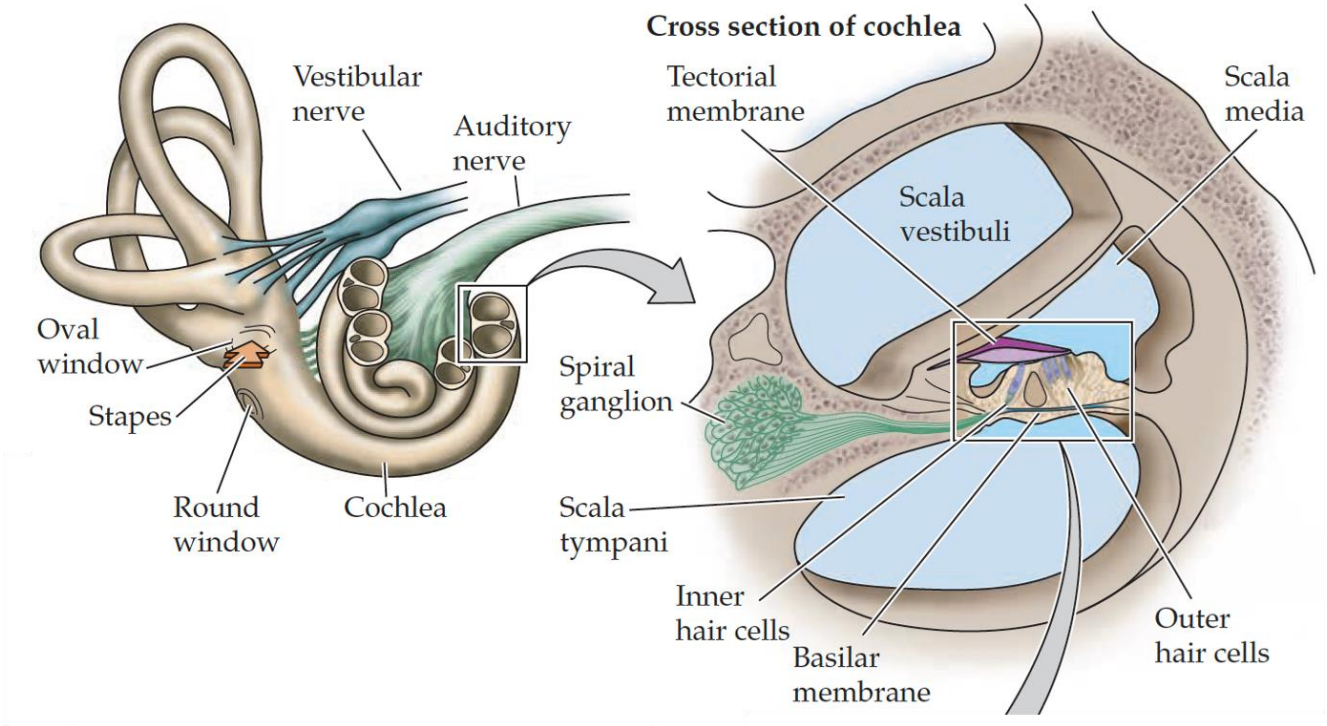


Outer ear:
Focuses acoustic energy (sound)

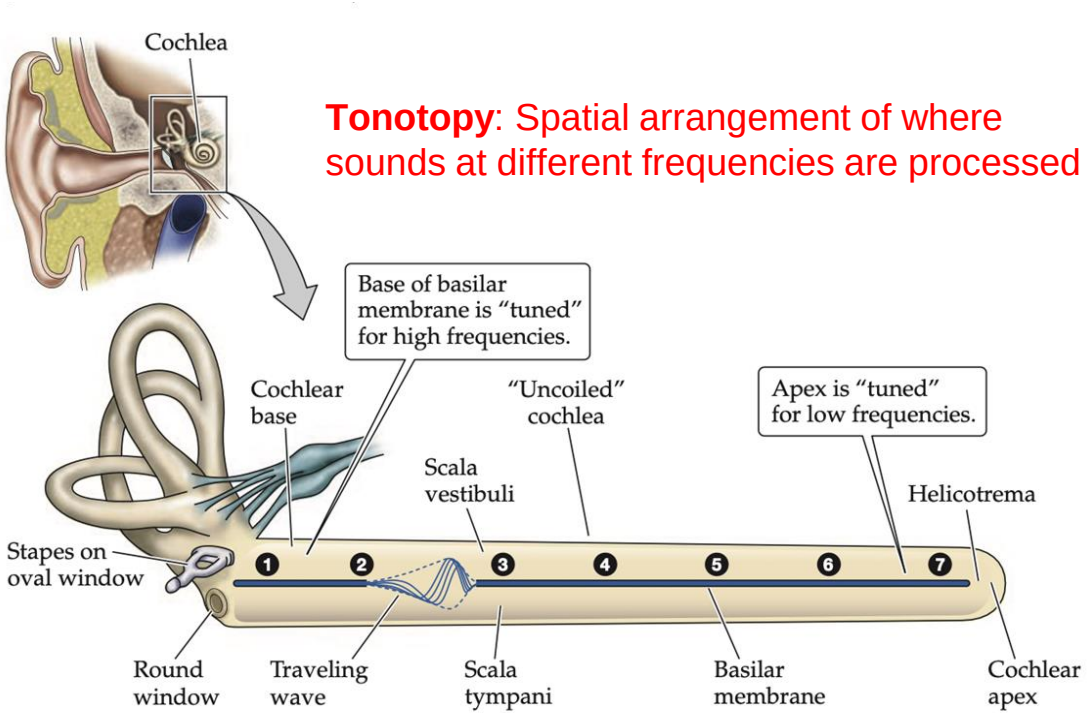
Middle ear:
Pressure boost — from low-impedance medium (air) to high-impedance medium in the inner ear (fluid)

Inner ear:
Transforms pressure waves to neural impulses.

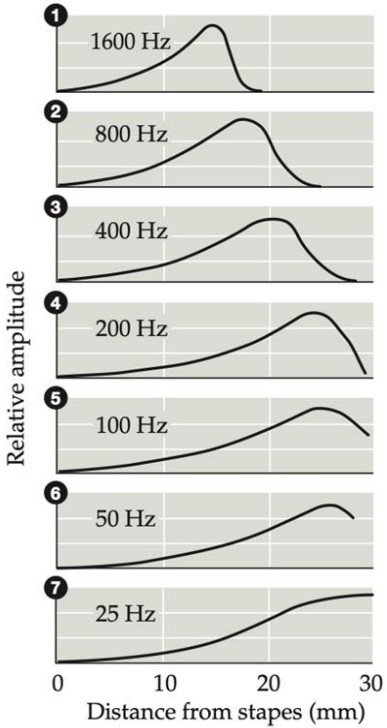
The inner ear's cochlea



Anatomical functionalization: frequency encoding



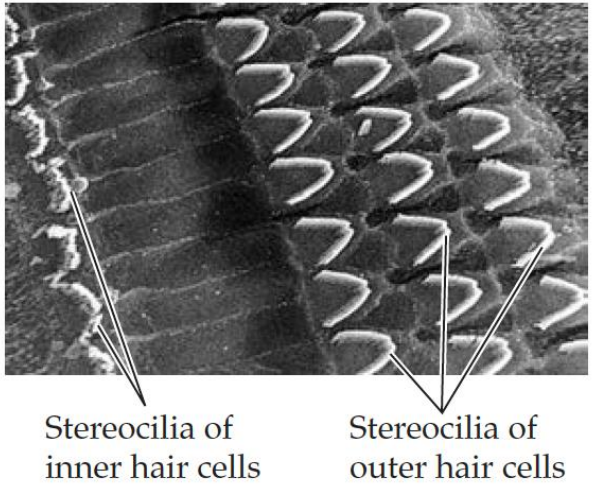
Tonotopy: Spatial arrangement of where sounds at different frequencies are processed

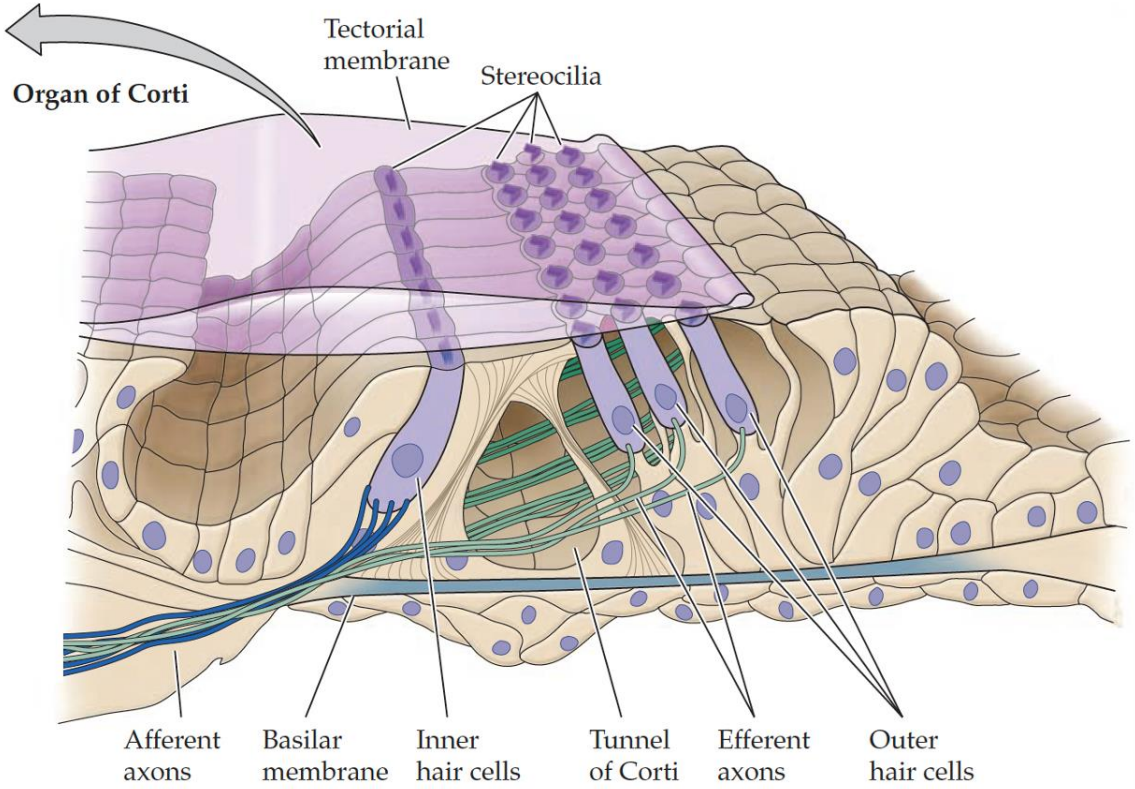


Base
= High-frequency

Apex
= Low-frequency

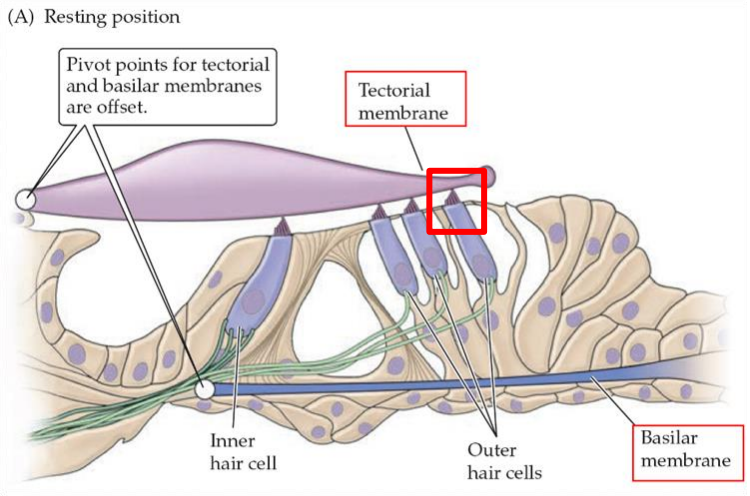
Organ of Corti

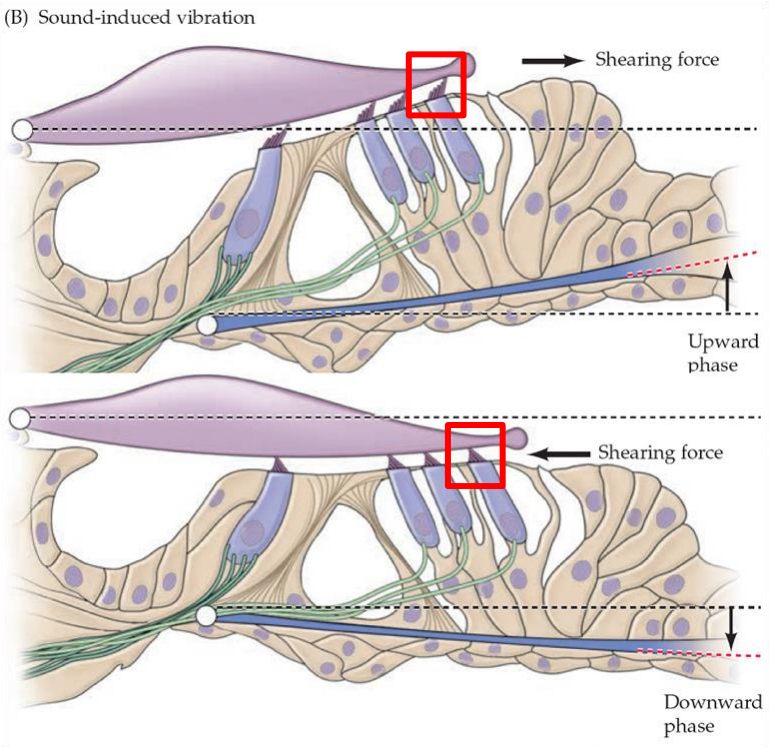




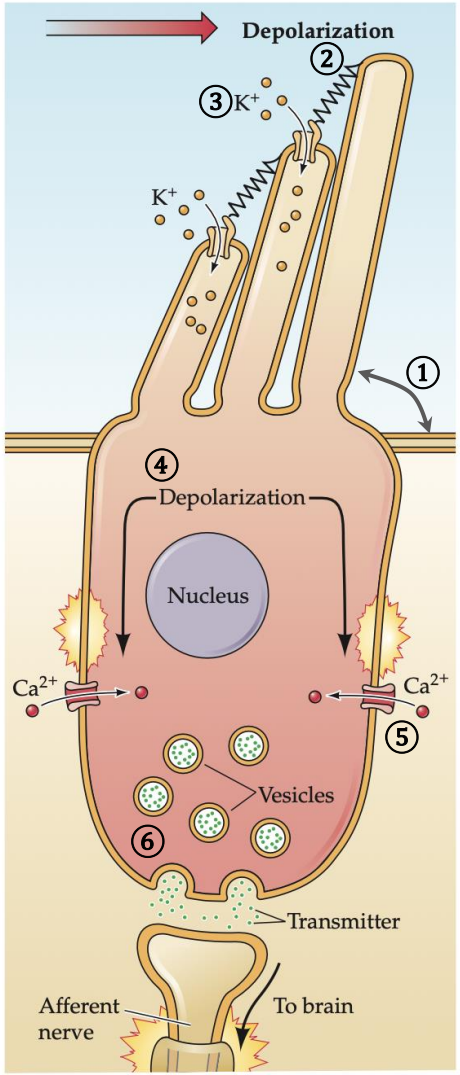
Hair cells are located within the Organ of Corti, between the Basilar and Tectorial membranes

From mechanical waves to electrical potentials





Membrane vibration → shearing force
→ deflection of hair cell stereocilia

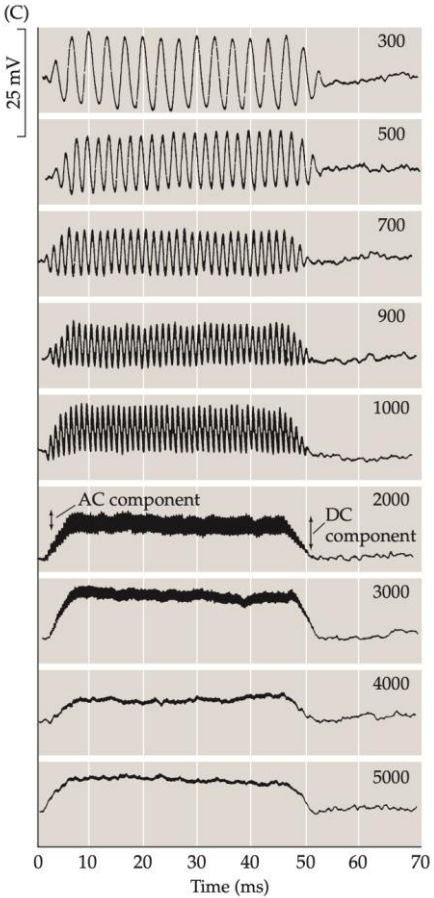


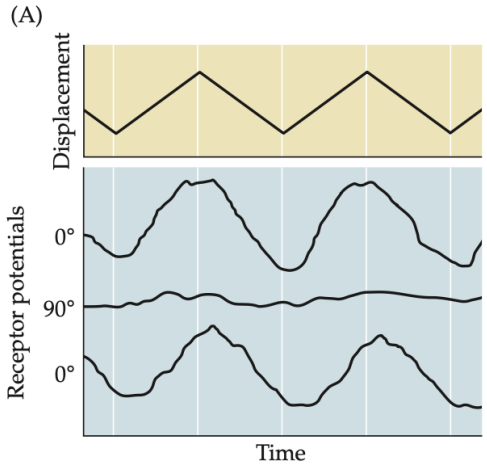
Primary sensory transduction (IHCs)

The ionic basis

Mechanical wave leads to shearing force
→ ① Stereocilia bend
→ ② Tip links stretch
→ ③ Transduction channel opens
→ ④ Depolarization of IHC
→ ⑤ Ca^{2+} channel opening at the base of the IHC, local Ca^{2+} influx
→ ⑥ Transmitter (glutamate) release at the base

Receptor potentials generated by a single IHC in response to pure tones

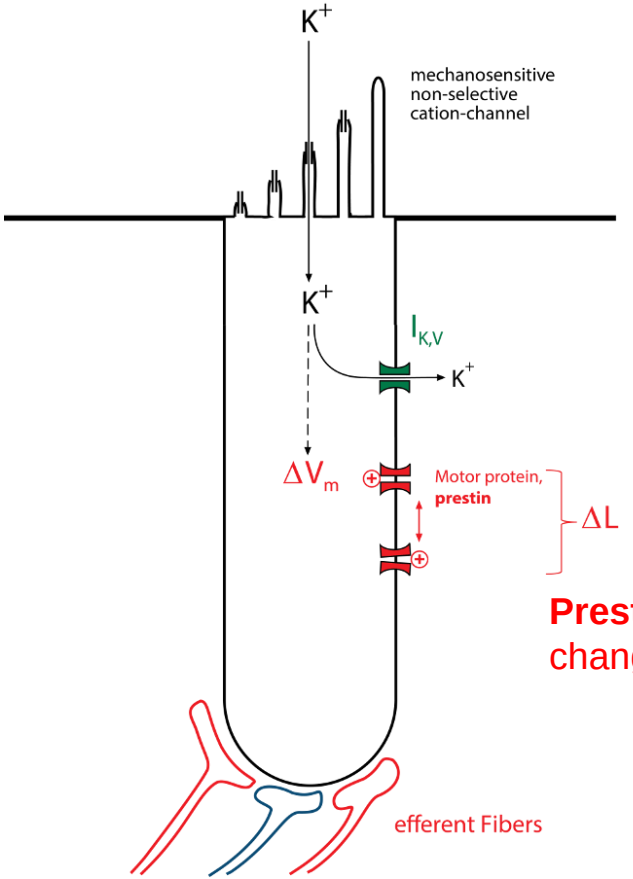




Up to ~2kHz: Mechanical and electrical signals are phase locked

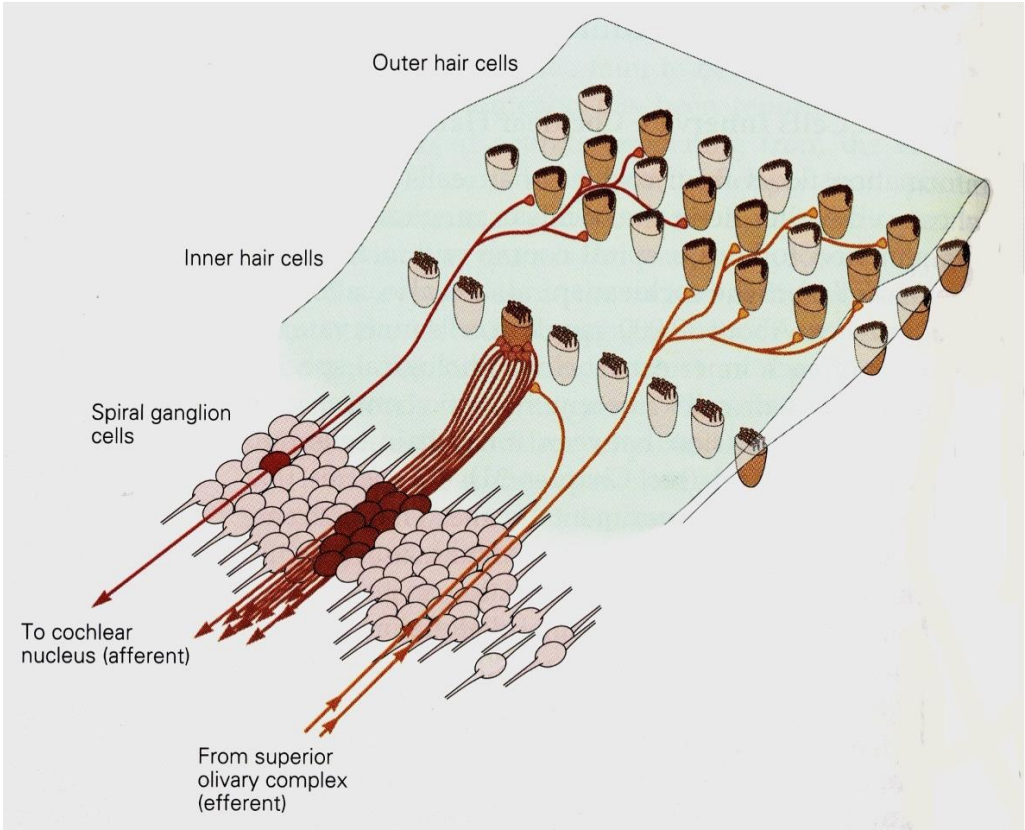
Above ~2kHz: tonotopy, no phase locking

Outer hair cells: “cochlear amplifiers” that actively boost signal

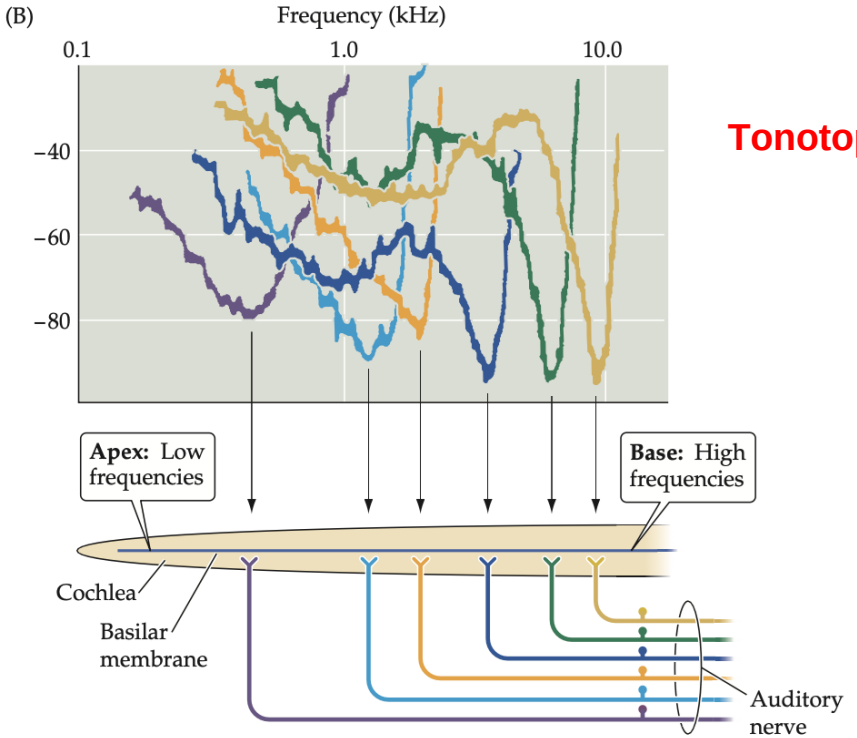


Prestin:
changing length

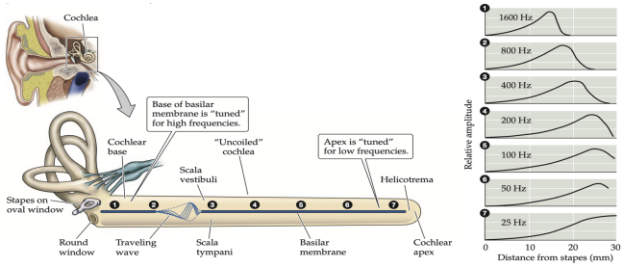
https://youtu.be/pij8a8aNpWQ?si=EEaNCwHP_aPjPAdT
Link to dancing outer hair cell (!)



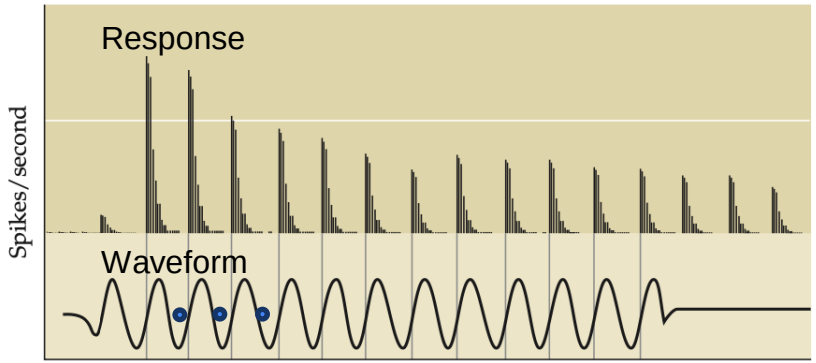
Response properties of auditory nerves

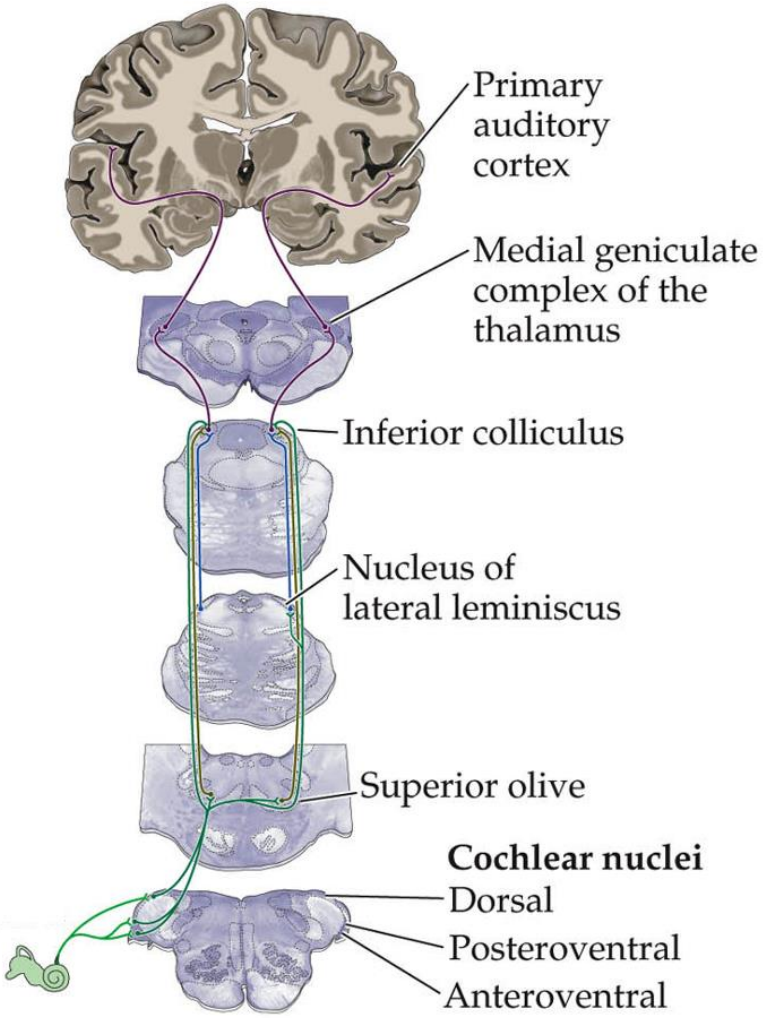


Tonotopy



Phase locking Up to 2 kHz → refractory period



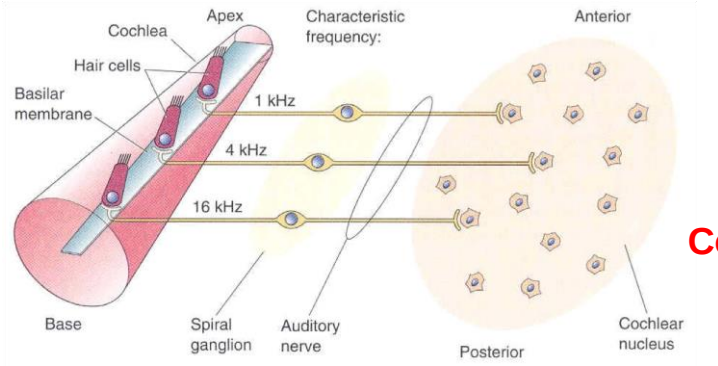


The auditory pathway

Note:

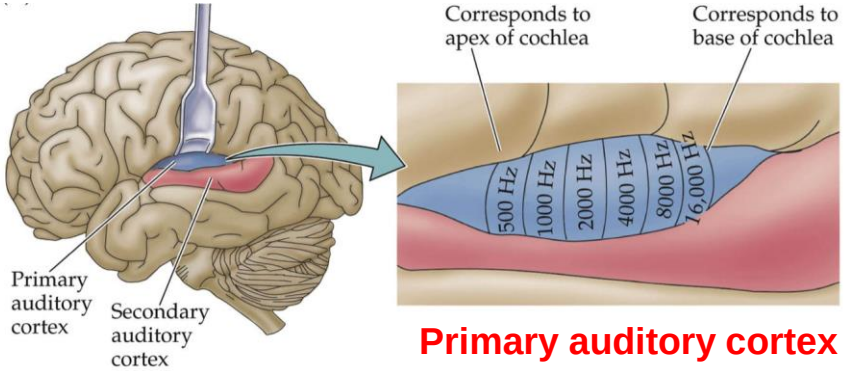
1. Bilateral projection
2. Multiple parallel pathways

Tonotopy preserved throughout the pathway



Cochlea

Cochlear nucleus



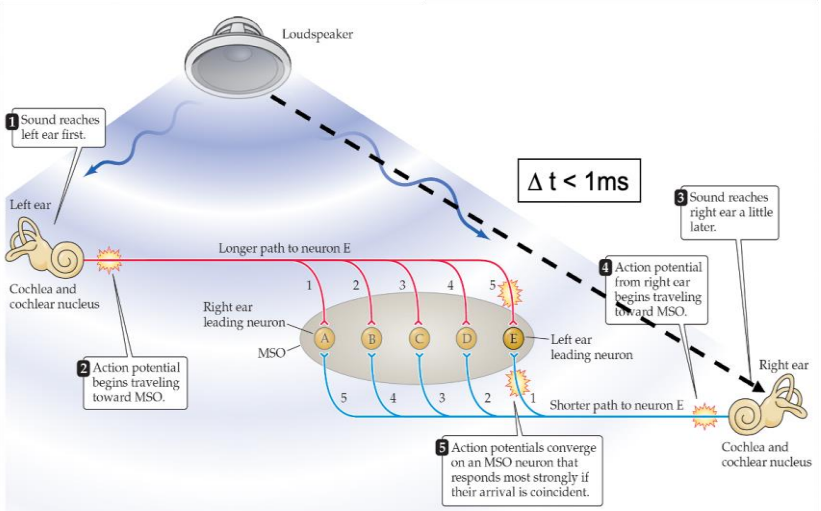
Primary auditory cortex

“Labeled line” coding

Sound source location

Strategy 1: Interaural Time Difference (ITD)

- Computed by Medial Superior Olive (MSO)
- Combines information from both ears
- *Coincidence detection if $\Delta t < 1$ ms*



Strategy 2: Interaural Intensity Difference (IID)

- Computed by Lateral Superior Olive (LSO)
- Inhibitory interneurons in MNTB nuclei