

# **ANATOMY OF HEARING**

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# Human hearing

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The process by which variations in ambient atmospheric pressure (sound waves) are:

1. Captured by the ear
2. Converted into neural signals by the auditory system
3. Interpreted by the brain

→ *Unlike other senses, the ears cannot be 'closed,' making them continuously receptive to sound stimuli.*

# Hearing as remote tactile perception

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Hearing can be described as a 'tactile remote sense' because it involves detecting variations in air pressure through specialized mechanoreceptors in the inner ear.

- Vision: electromagnetic radiation
- Smell: chemical detection
- Hearing: mechanical pressure waves

# Auditory signal processing stages

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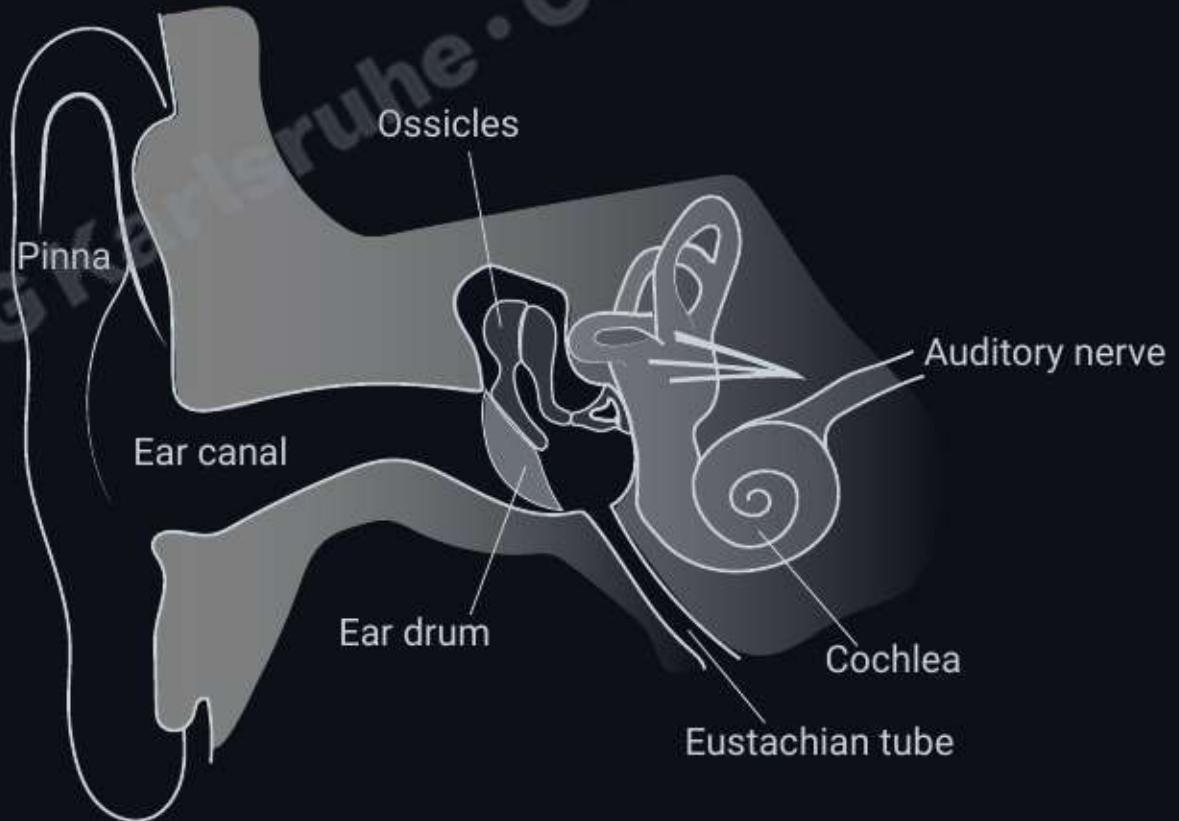
Sound waves → Outer ear (collection) → Middle ear (impedance matching) → Inner ear (transduction) → Auditory nerve → Brain (perception)

**Three main stages:**

1. **Physical:** Sound field characteristics
2. **Mechanical/neural:** Encoded into neural signals by the auditory system
3. **Perceptual:** Processed by the central nervous system and integrated with other sensory information

# Anatomy of the ear

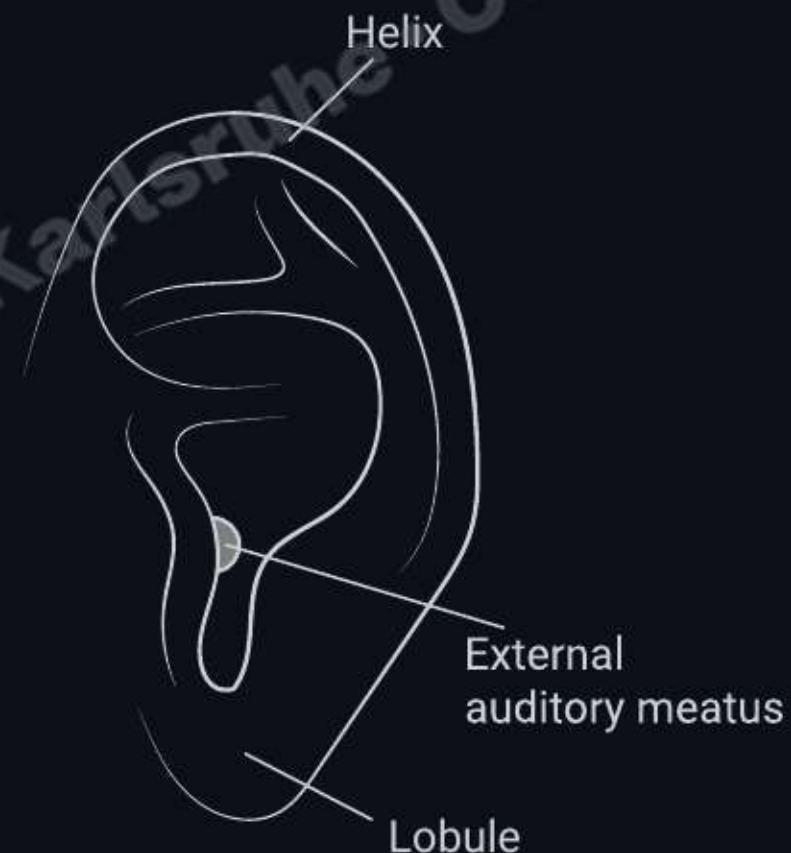
- **Outer ear:** Pinna and ear canal; collects and funnels sound
- **Middle ear:** Eardrum and ossicles; impedance matching
- **Inner ear:** Cochlea (hearing) and vestibular system (balance); transduction
- **Auditory nerve:** Transmits neural signals to brain



# Outer ear

The auricle (pinna) is the visible, irregularly shaped part of the outer ear that encloses the ear canal.

- Directional filtering for sound localization (HRTF)
  - Amplifies 2-4 kHz by ~10-15 dB (speech range)
  - Protects the eardrum
- *The unique shape of each person's pinna creates personalized spatial audio cues.*



# Middle ear

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The eardrum (tympanic membrane) vibrates in response to sound pressure. Three small bones (ossicles) transmit vibrations:

1. Malleus (hammer)
2. Incus (anvil)
3. Stapes (stirrup)

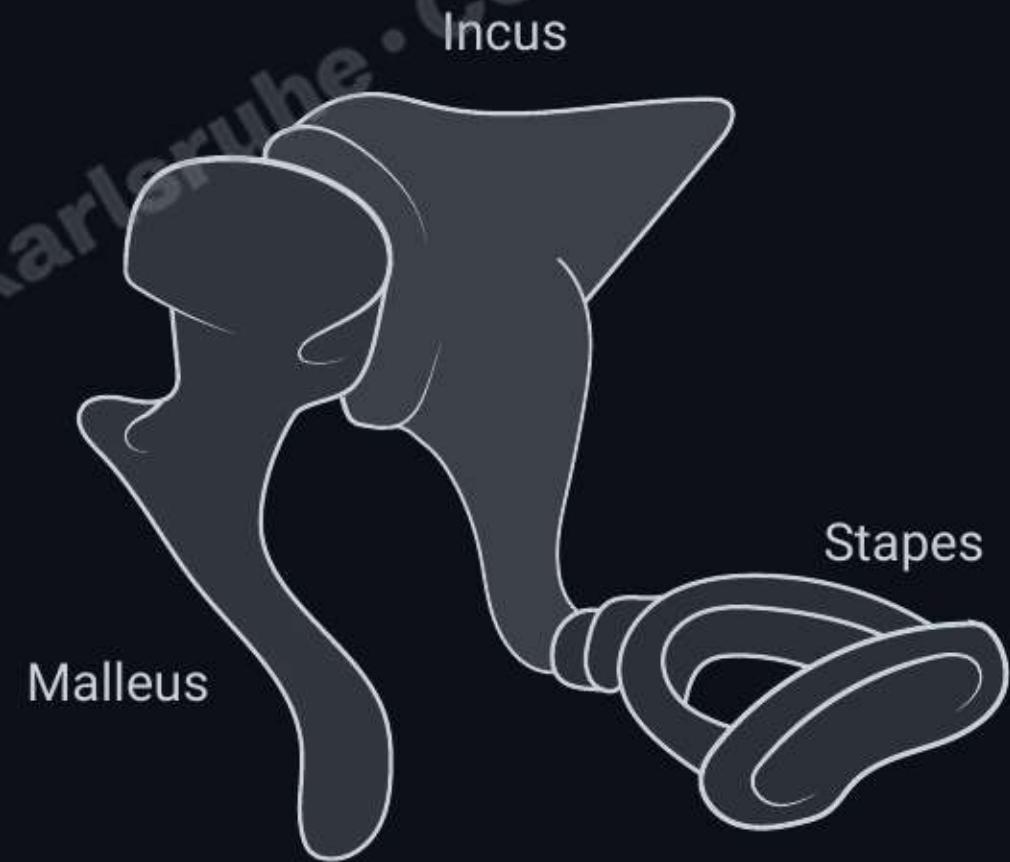
→ *The middle ear enables impedance matching between air and fluid-filled inner ear.*

# Auditory ossicles

The ossicles mechanically amplify sound vibrations:

- **Area ratio:** Eardrum ( $\sim 55 \text{ mm}^2$ ) is  $\sim 17\times$  larger than oval window ( $\sim 3.2 \text{ mm}^2$ )
- **Lever action:** Ossicles act as a lever system

The stapes footplate connects to the oval window, transmitting vibrations into the fluid-filled cochlea.

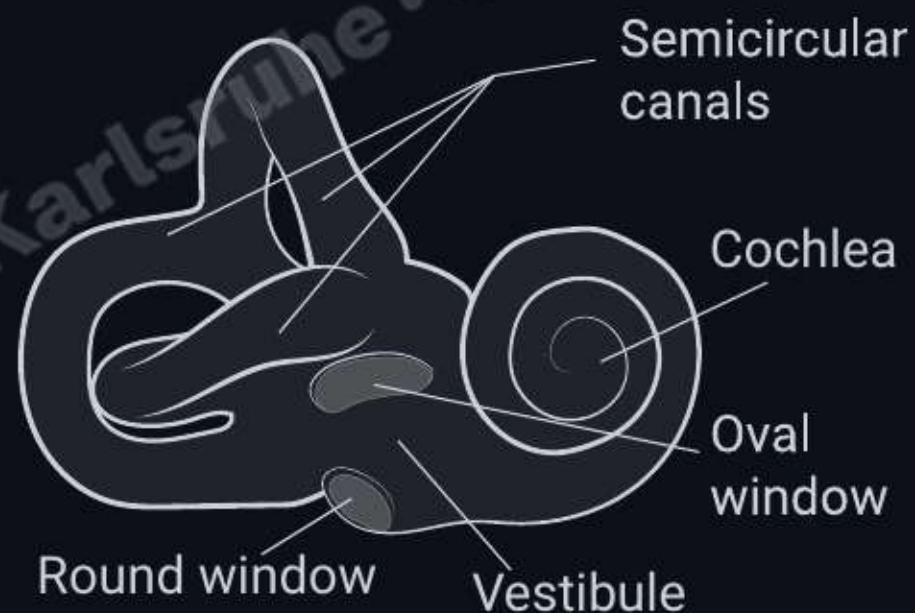


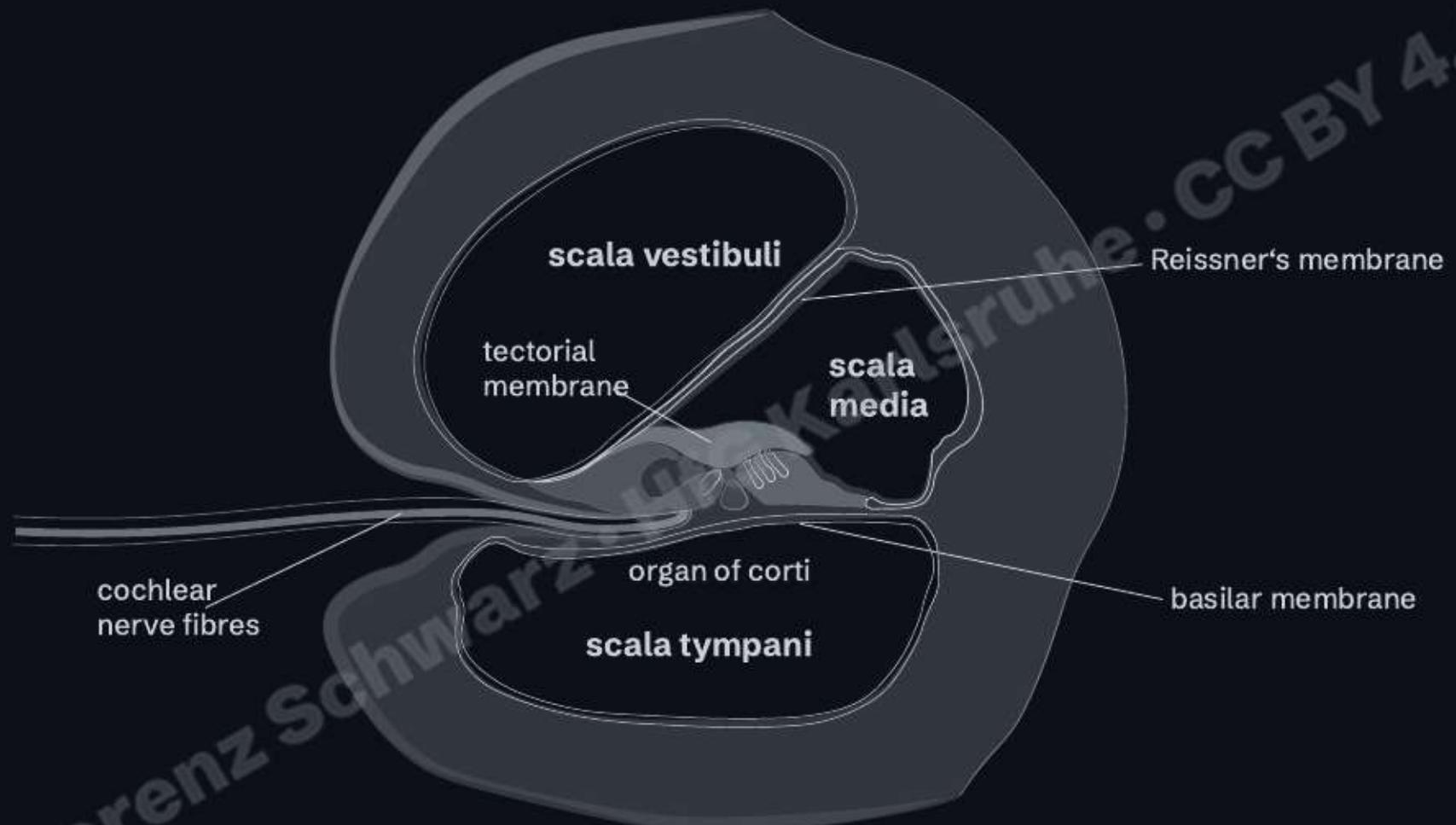
# Inner ear and the cochlea

The cochlea is a spiral-shaped, fluid-filled structure, consisting of three compartments:

- Scala vestibuli (perilymph)
- Scala media (endolymph)
- Scala tympani (perilymph)

The oval window receives vibrations from stapes, while the round window allows pressure release for fluid displacement.





Cross section of cochlea

# Traveling wave and frequency analysis

Sound creates a traveling wave along the basilar membrane. Different frequencies cause the wave to peak at different locations:

- **High frequencies (20 kHz):** Peak near the base (oval window)
- **Low frequencies (20 Hz):** Peak near the apex (tip of cochlea)

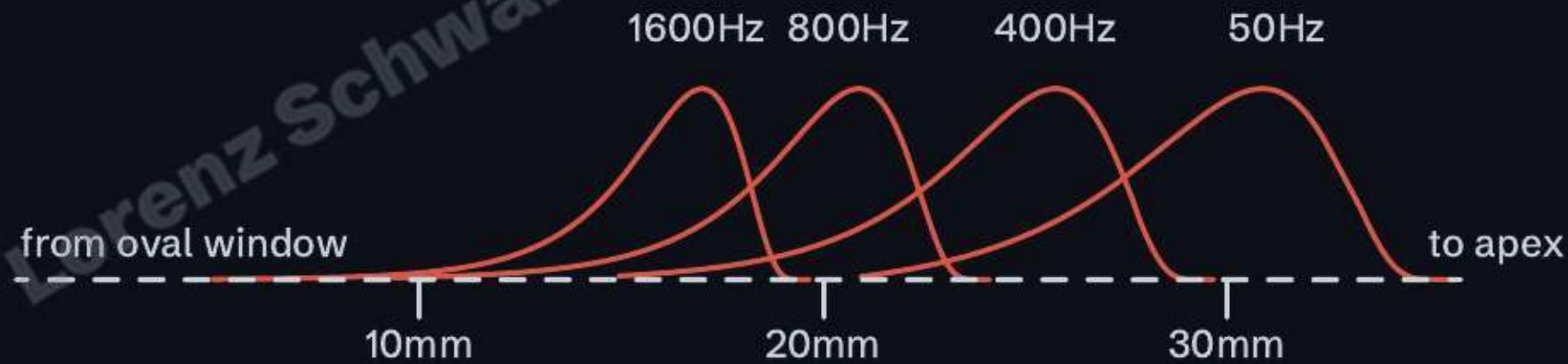
→ *The cochlea performs mechanical frequency analysis through tonotopic organization.*



# Frequency tuning of the basilar membrane

The basilar membrane exhibits a frequency-specific gradient along its length, with each position responding to a specific frequency in an approximately logarithmic mapping.

- **Base:** Narrow and stiff → sensitive to high frequencies
- **Apex:** Wide and flexible → resonates at low frequencies



# Organ of Corti

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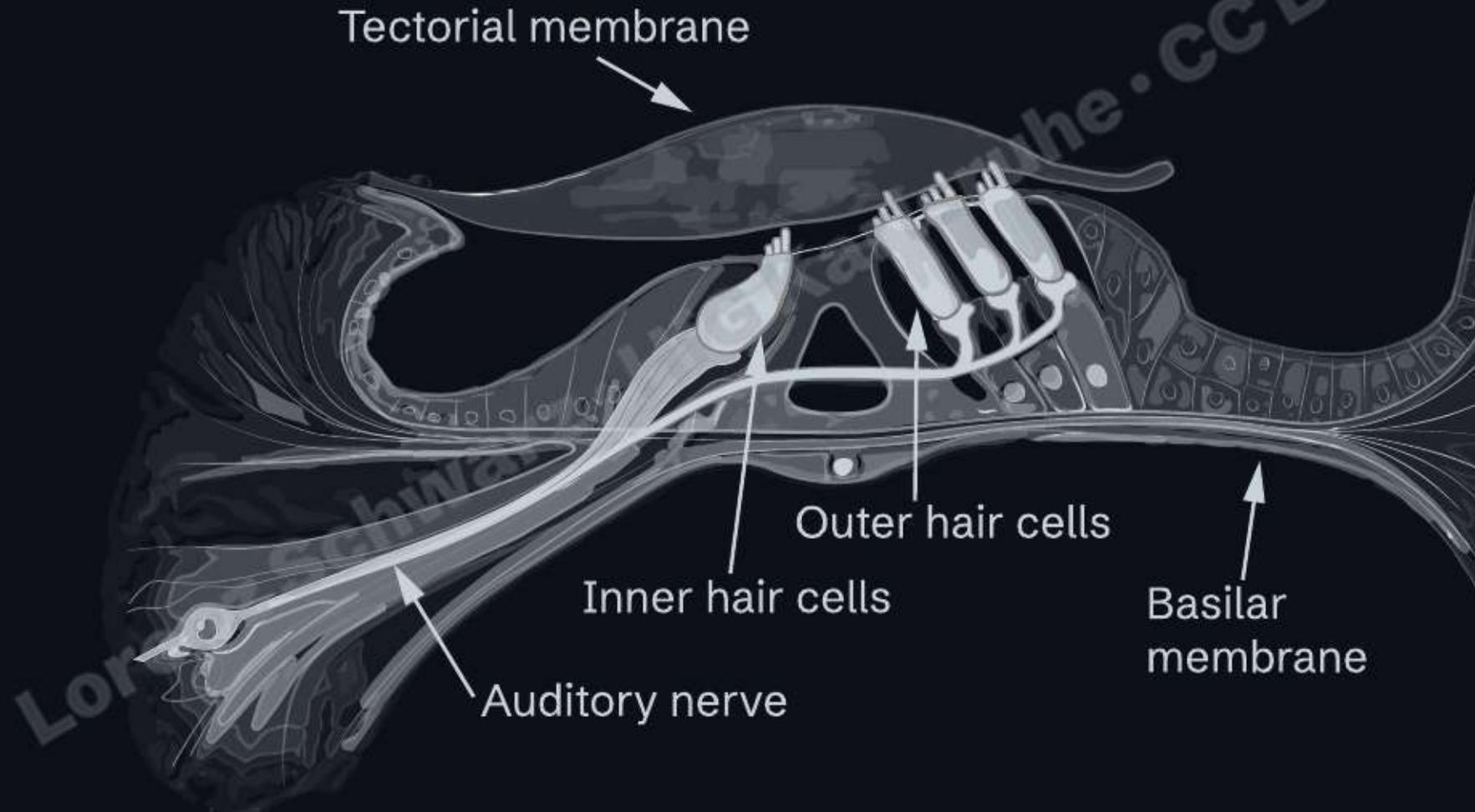
The organ of Corti sits on the basilar membrane and contains the sensory hair cells.

## Four rows of hair cells:

- **Inner hair cells (1 row):** ~3,500 cells; transduce vibrations into neural signals
- **Outer hair cells (3 rows):** ~12,000 cells; amplify vibrations (cochlear amplifier)

**Tectorial membrane:** Overlying structure that bends hair cell stereocilia during basilar membrane motion

# Organ of Corti



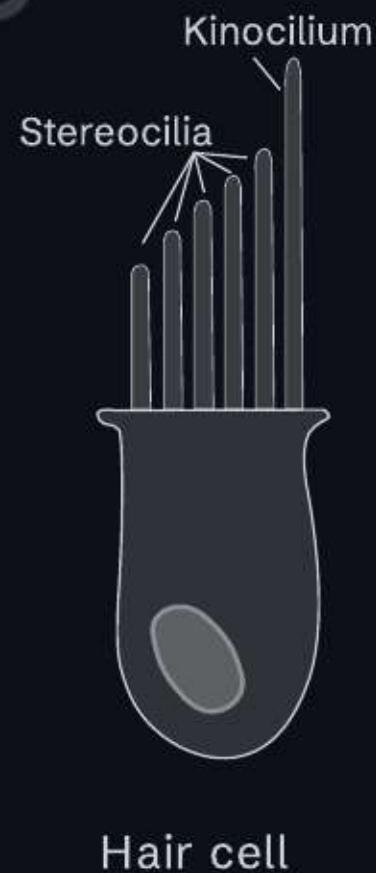
# Hair cell transduction

## Mechanical to neural conversion:

1. Basilar membrane movement bends hair cell stereocilia
2. Bending opens ion channels
3. Ion flow triggers neurotransmitter release
4. Auditory nerve fibers fire action potentials

## Encoding:

- Firing rate encodes sound intensity
- Firing timing encodes frequency information



# Cochlear nerve

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~30,000 **auditory nerve fibers** transmit signals from the cochlea to the brain.

- Each inner hair cell connects to 10–30 nerve fibers
- Different fibers have different thresholds and dynamic ranges
- Collectively encode intensity range of ~120 dB

**Tonotopic organization preserved:** Nerve fibers maintain frequency-specific organization through brainstem to auditory cortex.

# Frequency response of human hearing

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Human hearing is most sensitive to mid-frequencies (2-5 kHz):

- **Ear canal resonance:** Amplifies 2-4 kHz
- **Evolutionary advantage:** Speech intelligibility
- **Sensitivity varies with level:** Low frequencies are less audible at low SPLs

→ *A-weighting for noise measurements approximates this frequency-dependent sensitivity.*

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