ANATOMY OF HEARING

Human hearing

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

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

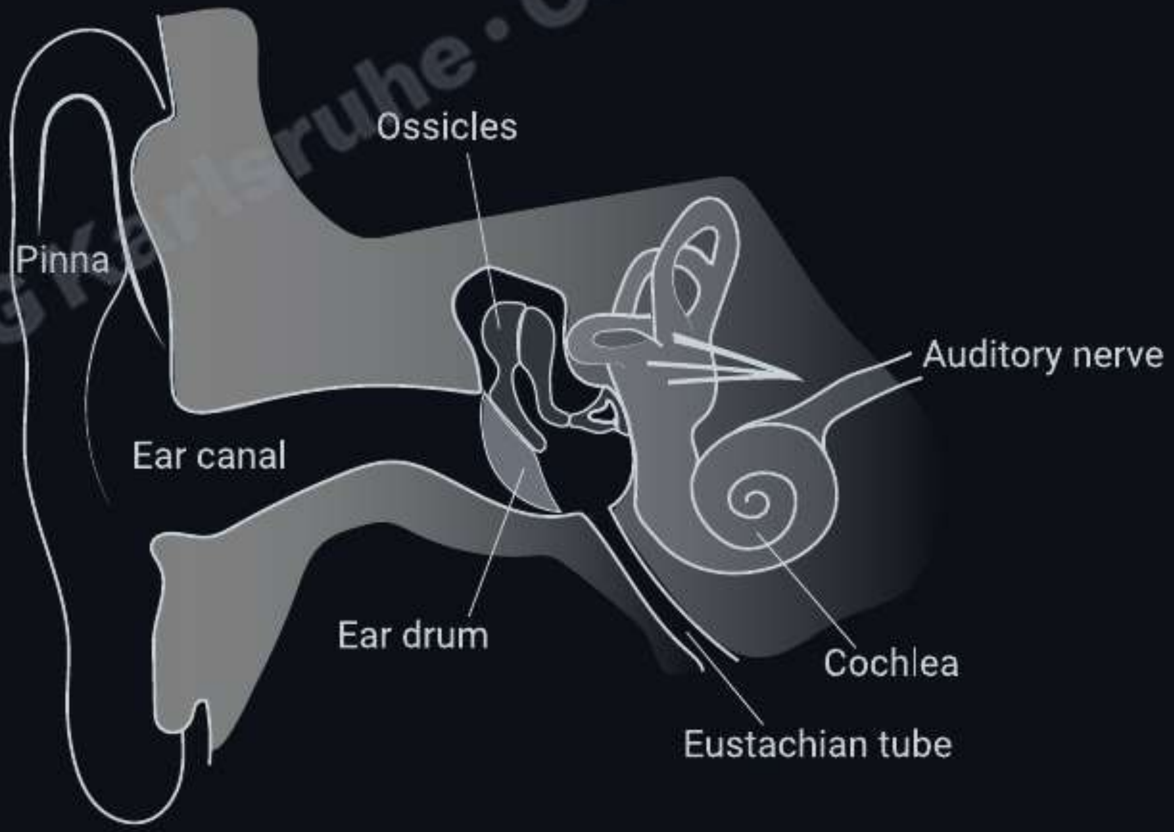
Sound waves → Outer ear (collection) → Middle ear (impedance matching) → Inner ear (transduction) → Auditory nerve → Brain (perception)

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

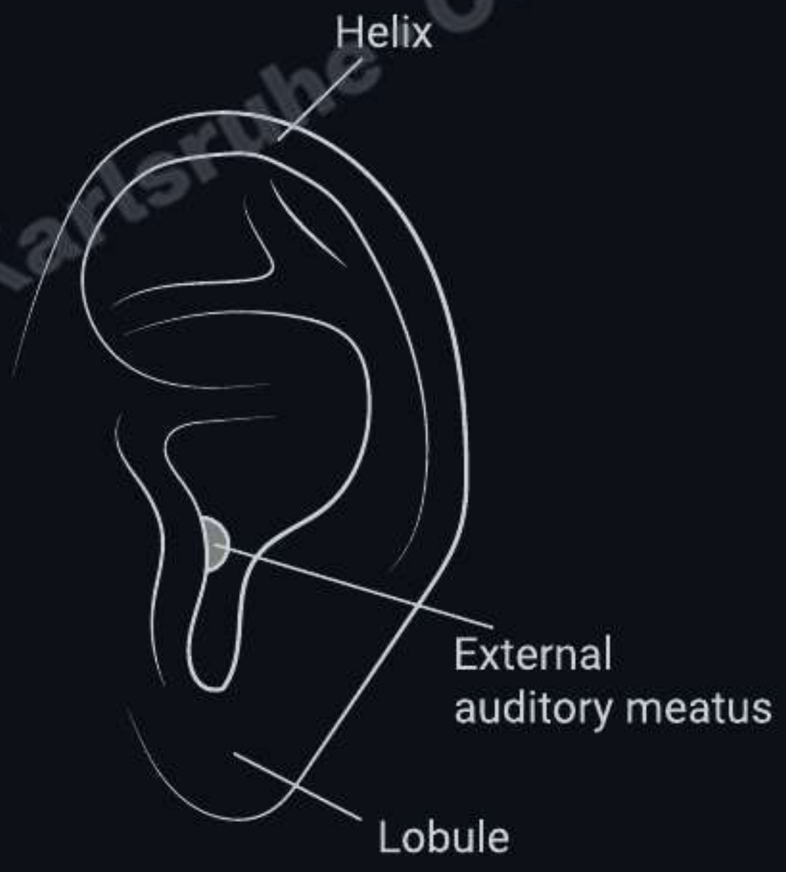


Outer ear

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

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)

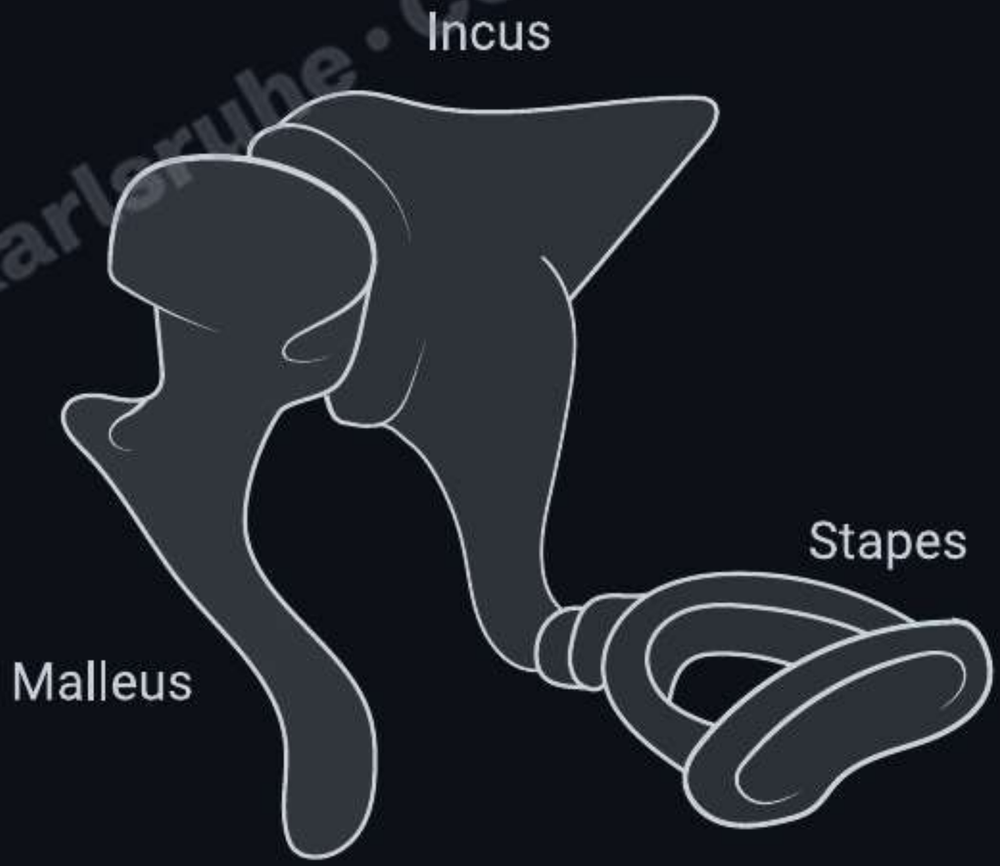
→ *The middle ear enables impedance matching between air and fluid-filled inner ear.*

Auditory ossicles

The ossicles mechanically amplify sound vibrations:

- **Area ratio:** Eardrum (~55 mm²) is ~17× larger than oval window (~3.2 mm²)
- **Lever action:** Ossicles act as a lever system

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

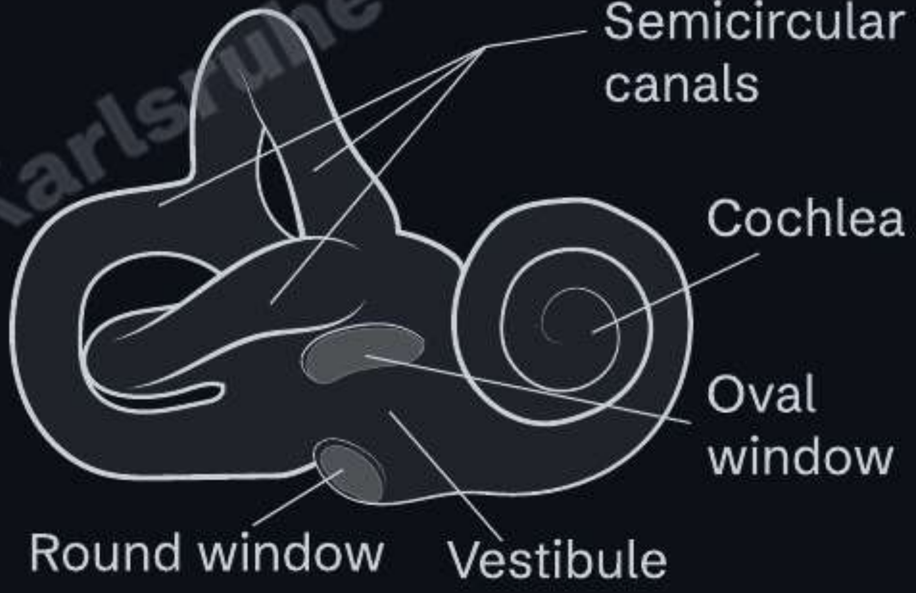


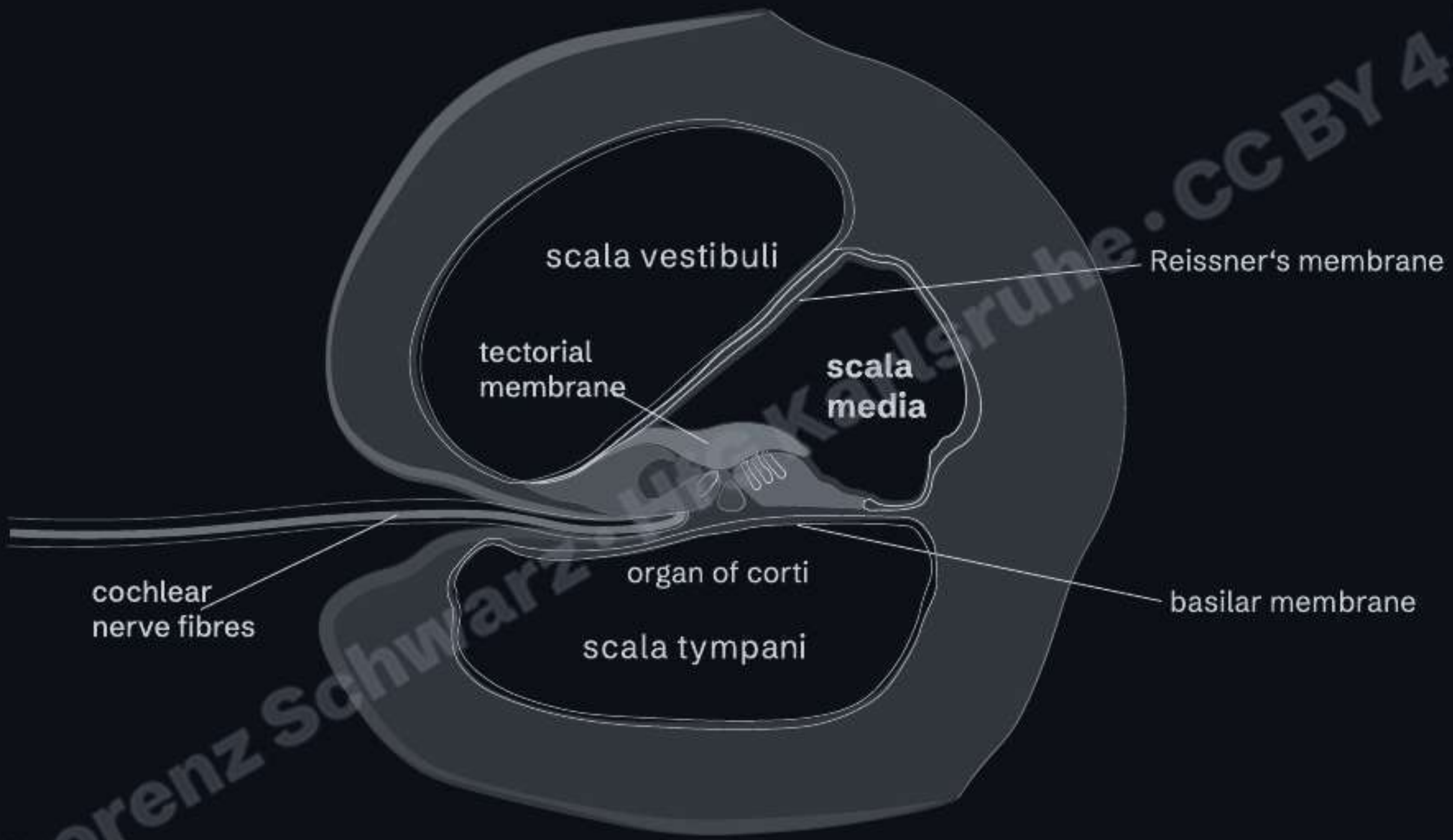
Inner ear and the cochlea

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:

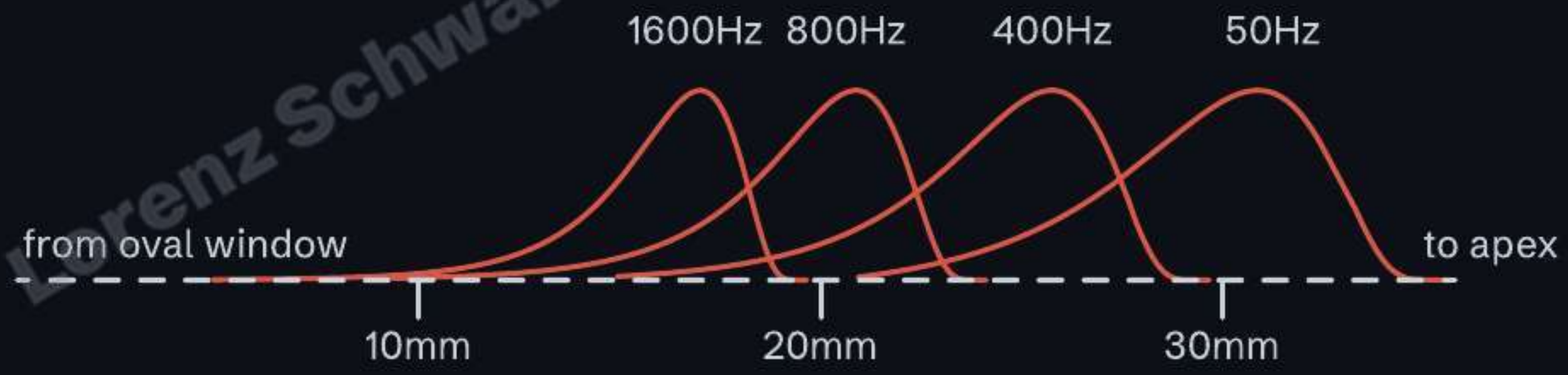
- **High frequencies (20 kHz):** Peak near the base (oval window)
- **Low frequencies (20 Hz):** Peak near the apex (tip of cochlea)

→ *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

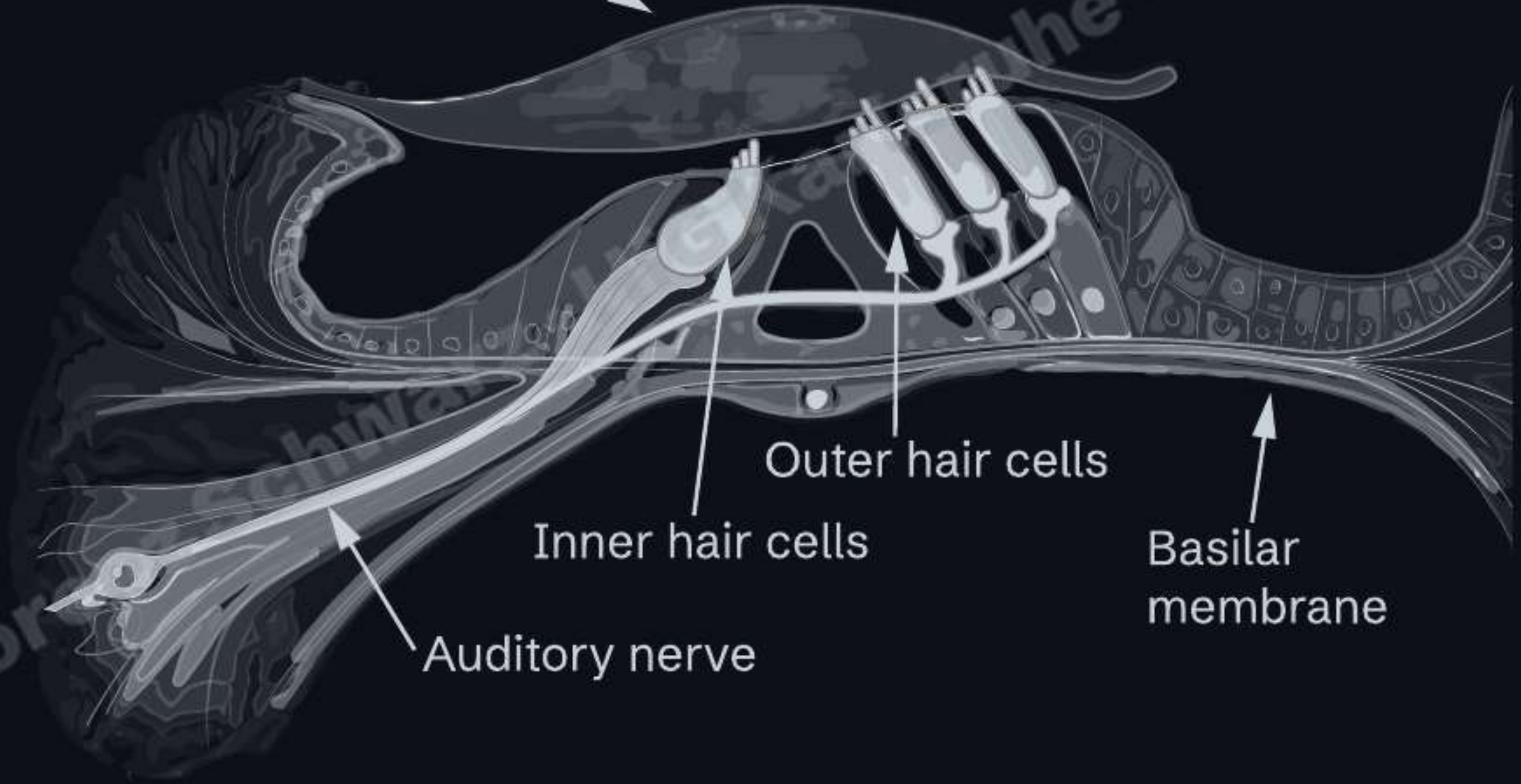
The organ of Corti sits on the basilar membrane and contains the sensory hair cells.

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



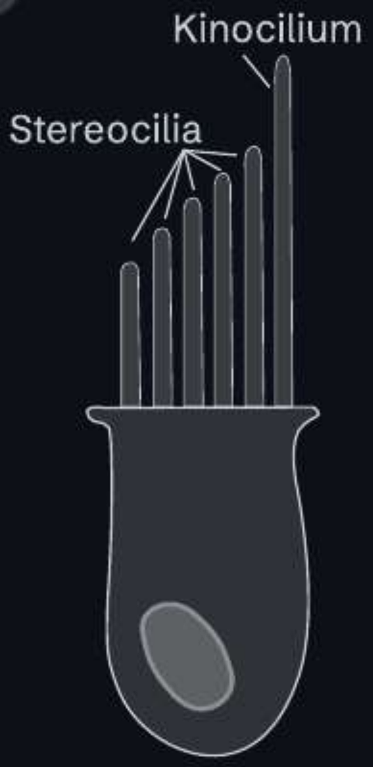
Hair cell transduction

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



Hair cell

Cochlear nerve

~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

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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