PHGY 210,2,4 - Physiology

SENSORY PHYSIOLOGY

Hearing

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SENSORY PHYSIOLOGY

Hearing

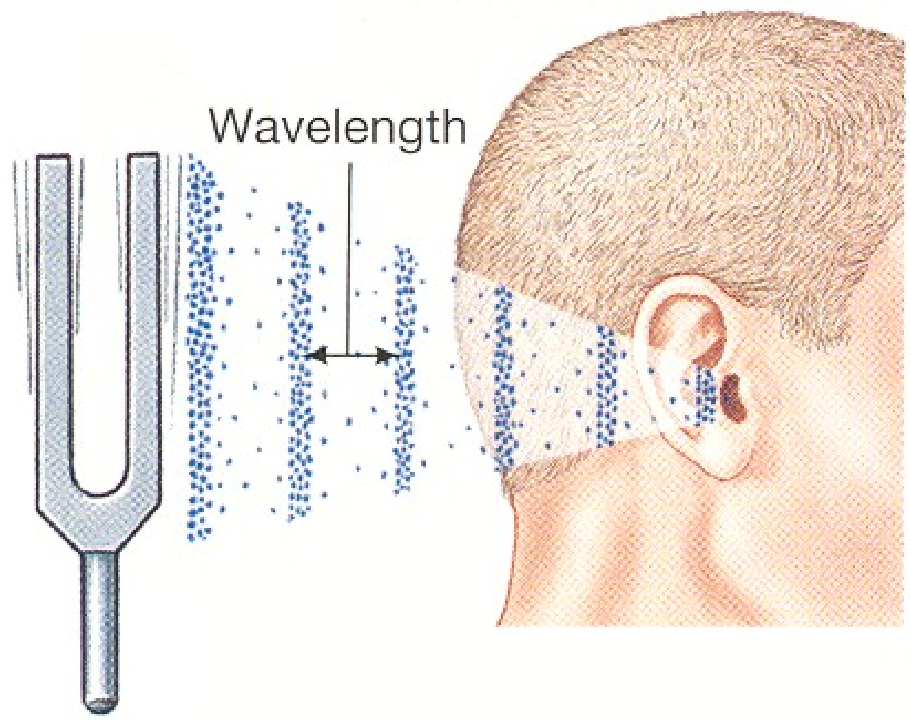
Reading

Rhoades & Pflanzer (4th edition)

Chapter 8: *The Auditory System* (p. 288-297)

Sound Principles

Hearing is our perception of the energy carried by sound waves. Sound waves are alternating waves of air pressure with periods of **compression** and **rarefaction**.

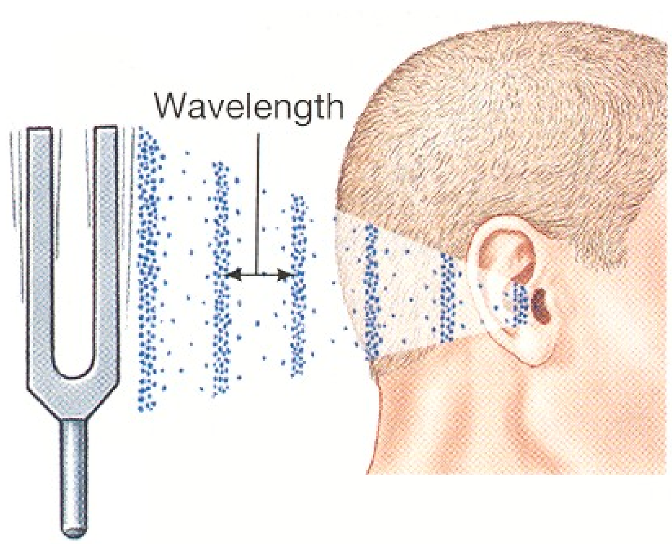


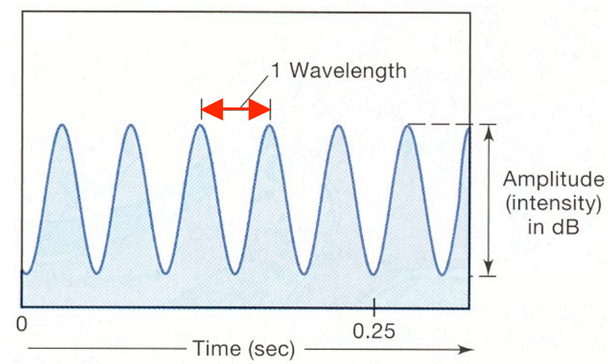
Sound Principles

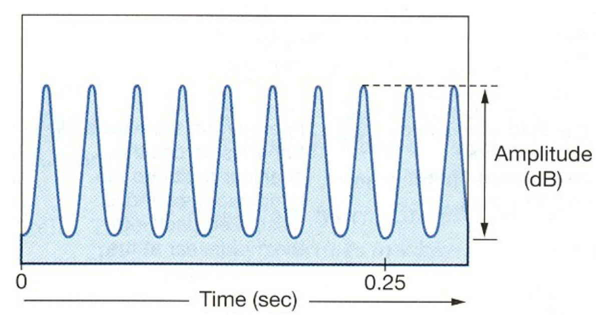
We characterize sound waves by their **pitch** and their **loudness**.

Pitch is a function of the *frequency of sound* waves.
It is measured in cycles per second (*Hertz*).

The range of frequencies audible to humans is 20 to 20kHz.

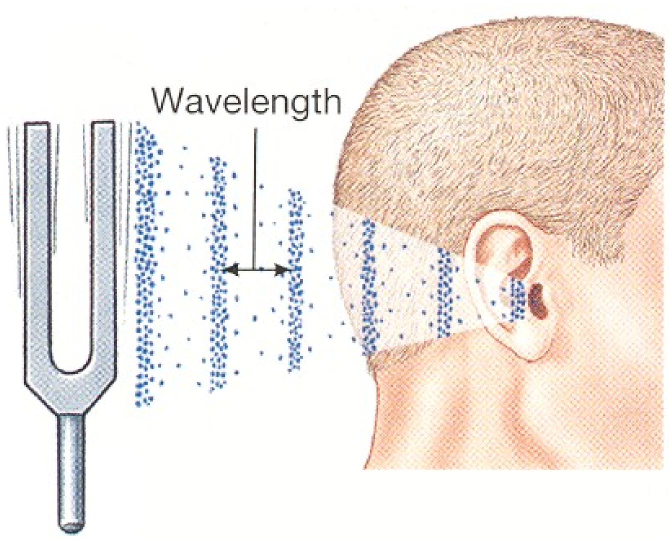


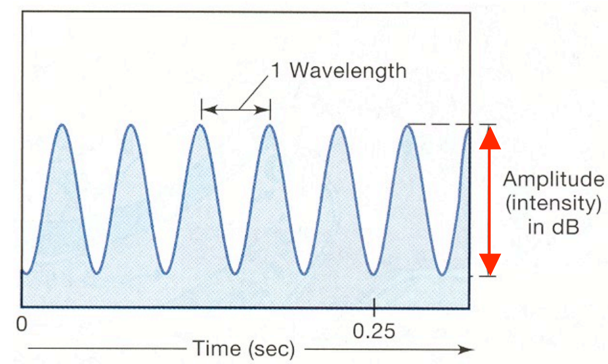




Sound Principles

Loudness is our interpretation of *sound intensity*. It is a function of the wave amplitude, the pressure difference between waves. It is measured with a logarithmic scale [*decibels* (dB)].





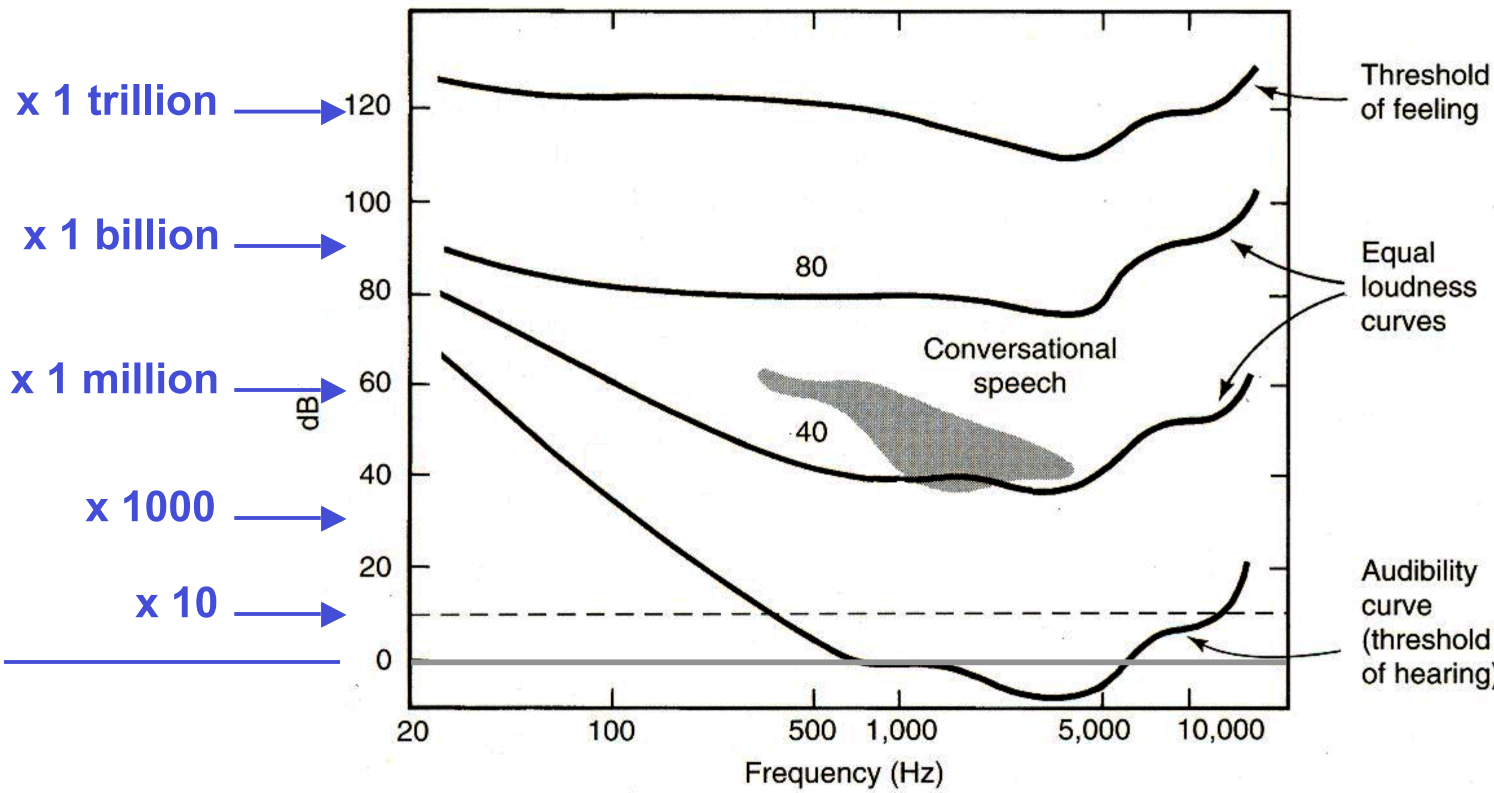
$\Delta dB = 10 \times \log(P2/P1)\ dB$

Sound Principles

The faintest audible sound has ~0 dB loudness.

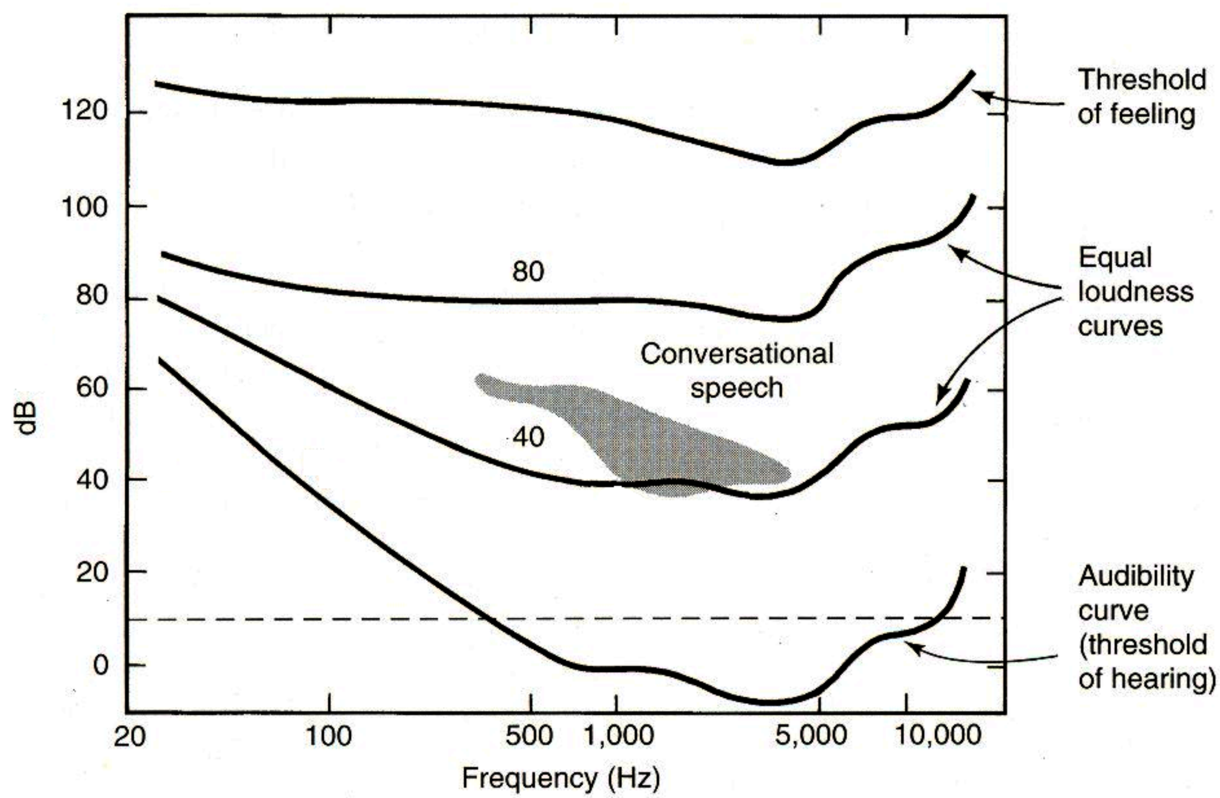
Each 10-dB increase represents a 10-fold increase in loudness.

Loudness in normal conversation is typically 60 dB.



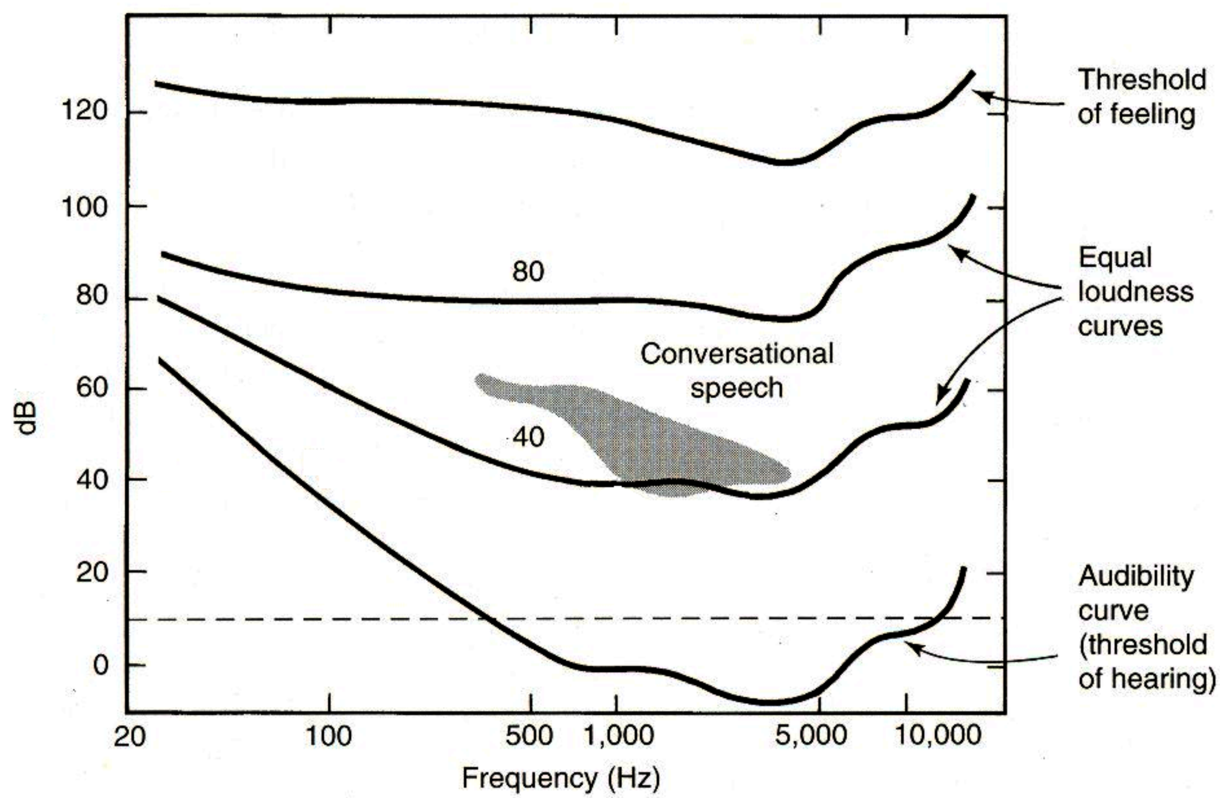
Sound Principles

Prolonged exposure to noise level > 100 dB is usually painful and cause damage resulting in hearing loss.



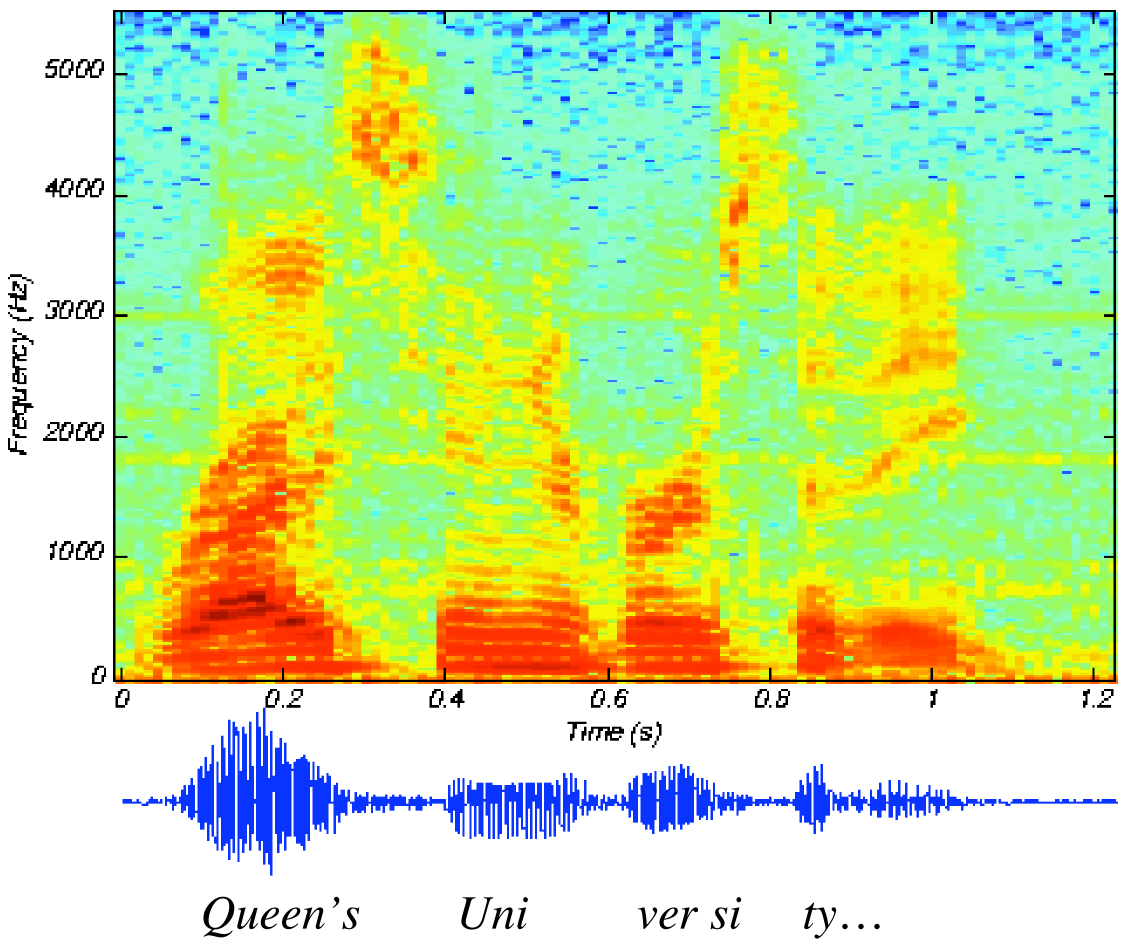
Sound Principles

Speech sounds are composed of multiple frequencies ranging from 100 to 5,000 Hz.



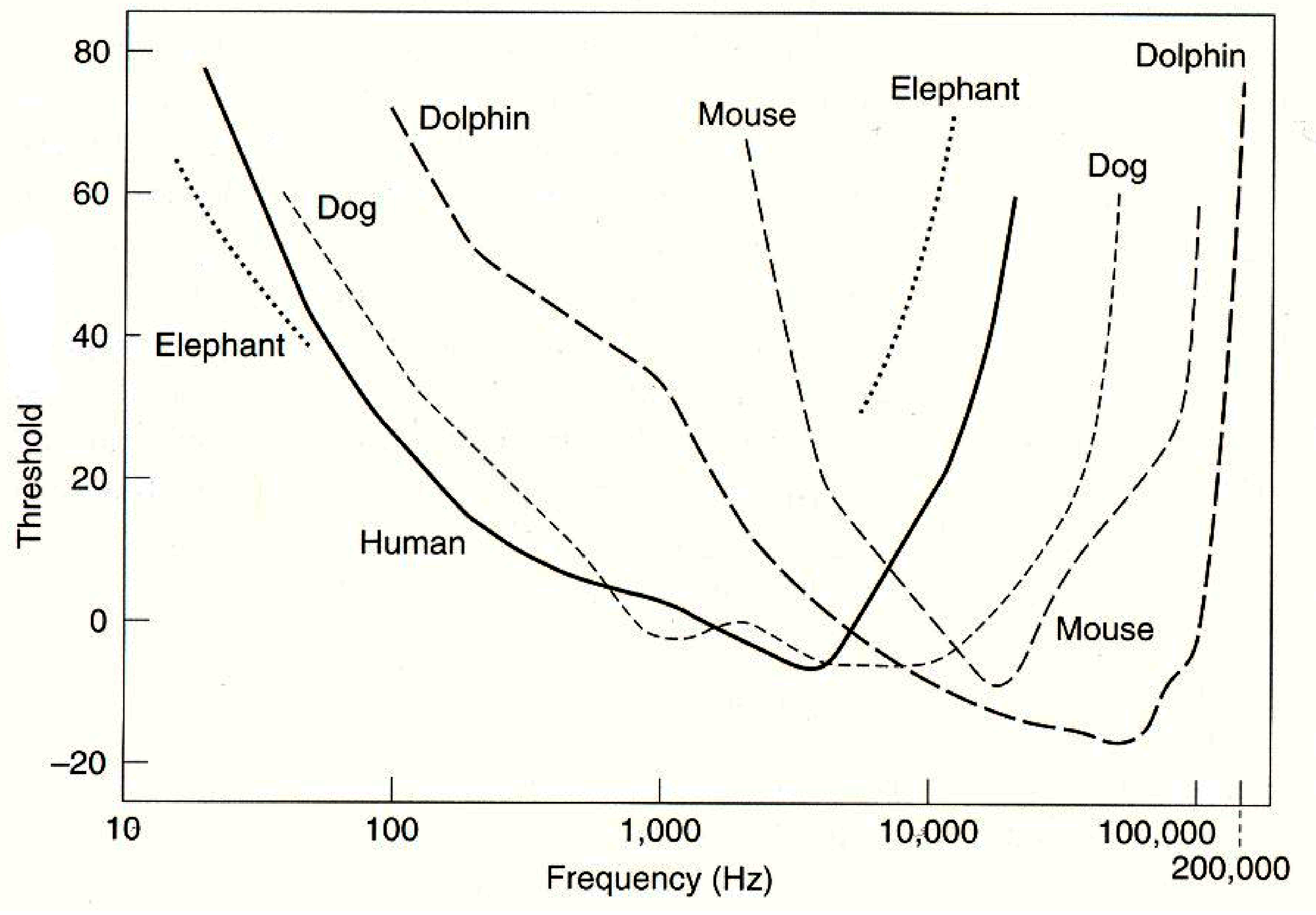
Speech Spectrogram

Speech sounds are composed of multiple frequencies ranging from 100 to 5,000 Hz.



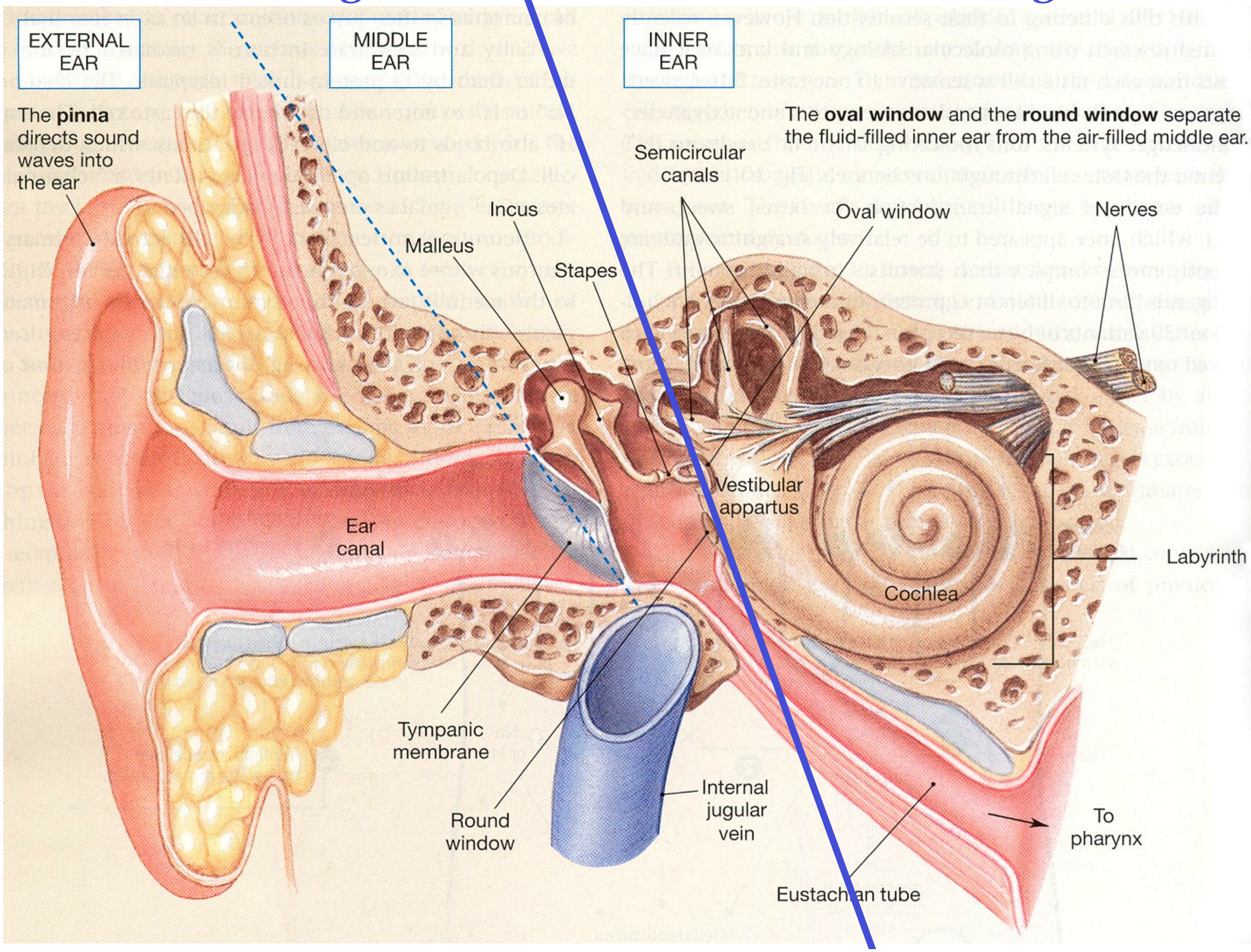
Sound Principles

Sound processing varies among species and their ecologies.



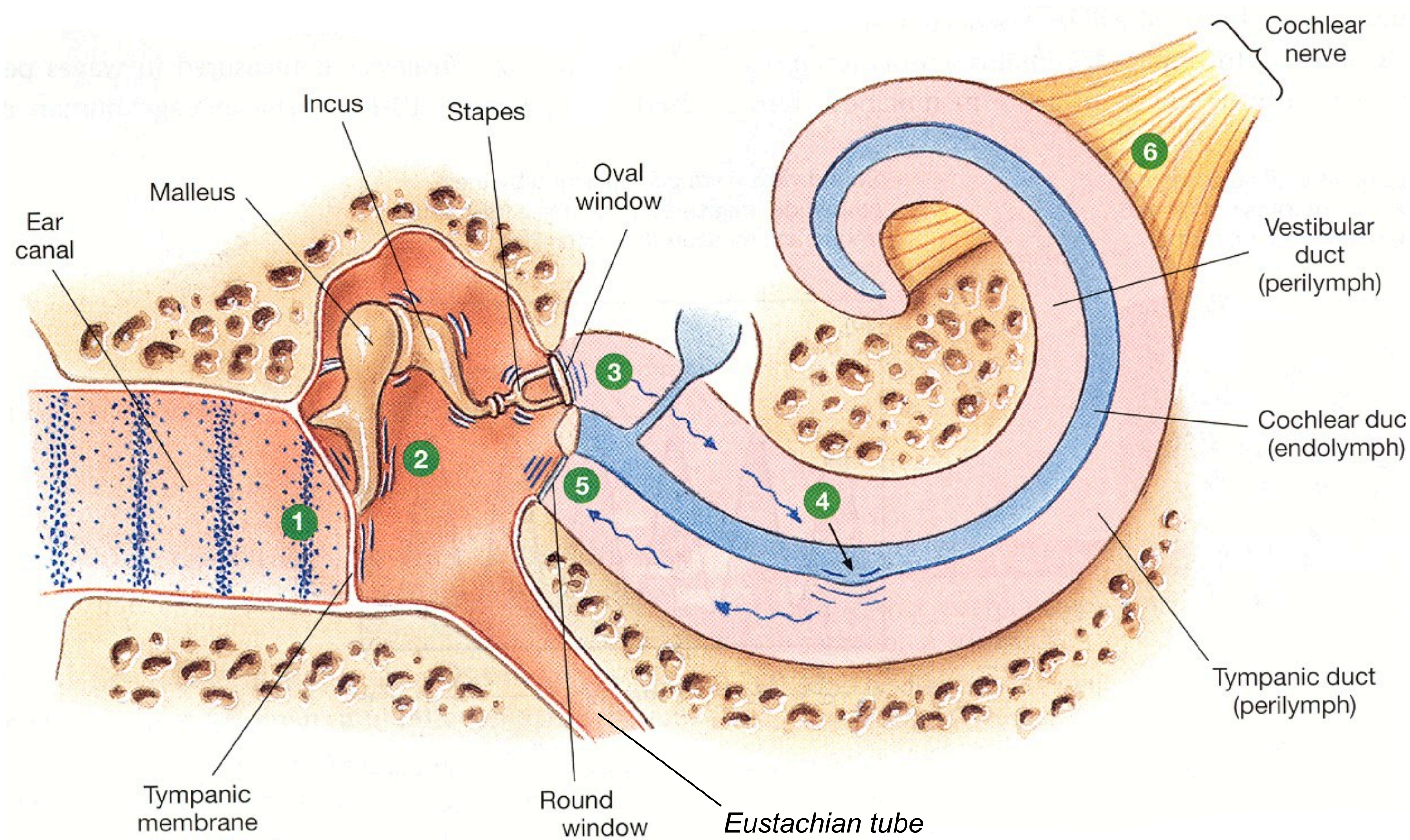
Structure of the Ear

Conductive hearing loss ***Sensorineural hearing loss***



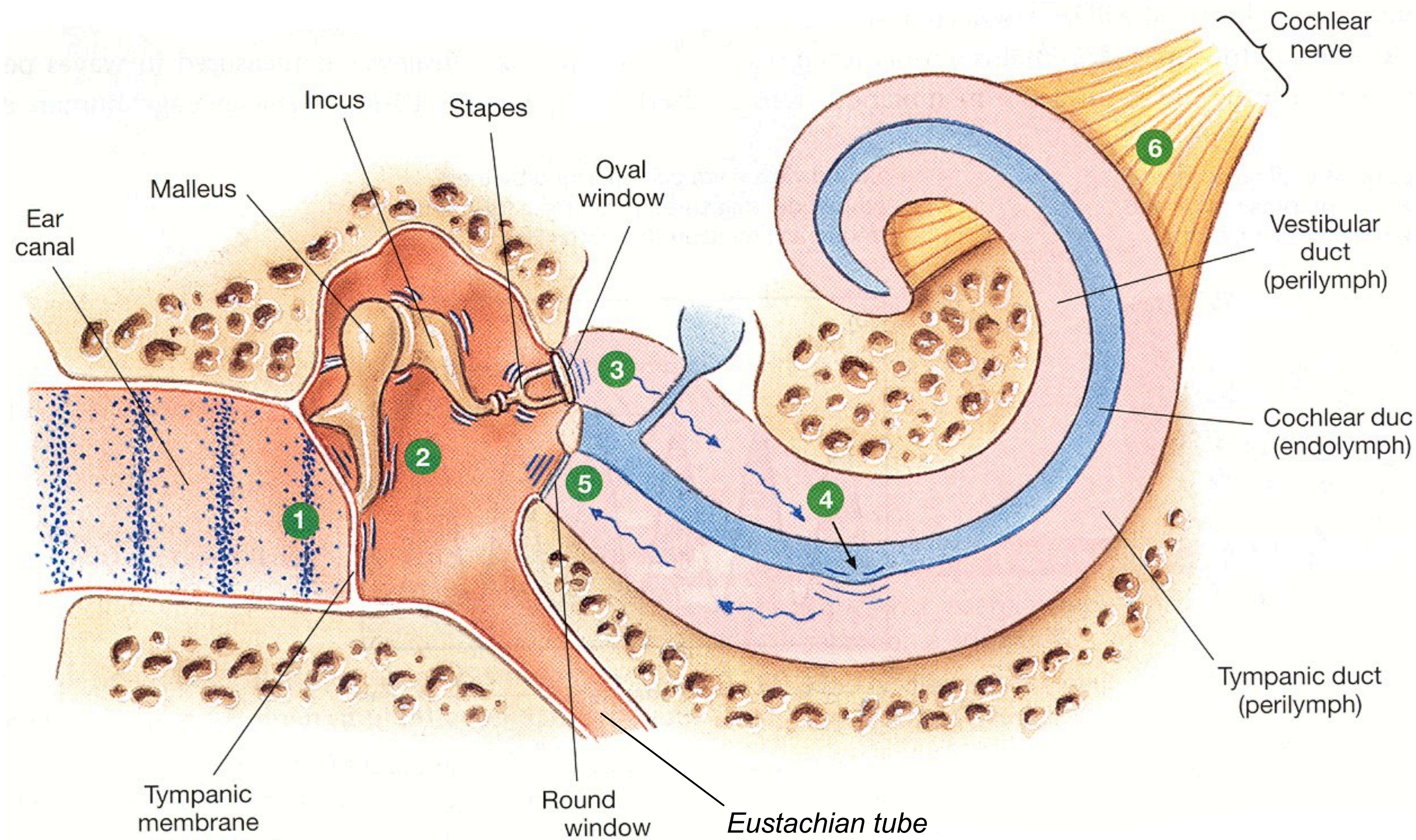
Sound Transmission through the Ear

1) Sound waves in the ear canal strike the tympanic membrane (*eardrum*) and become vibrations.



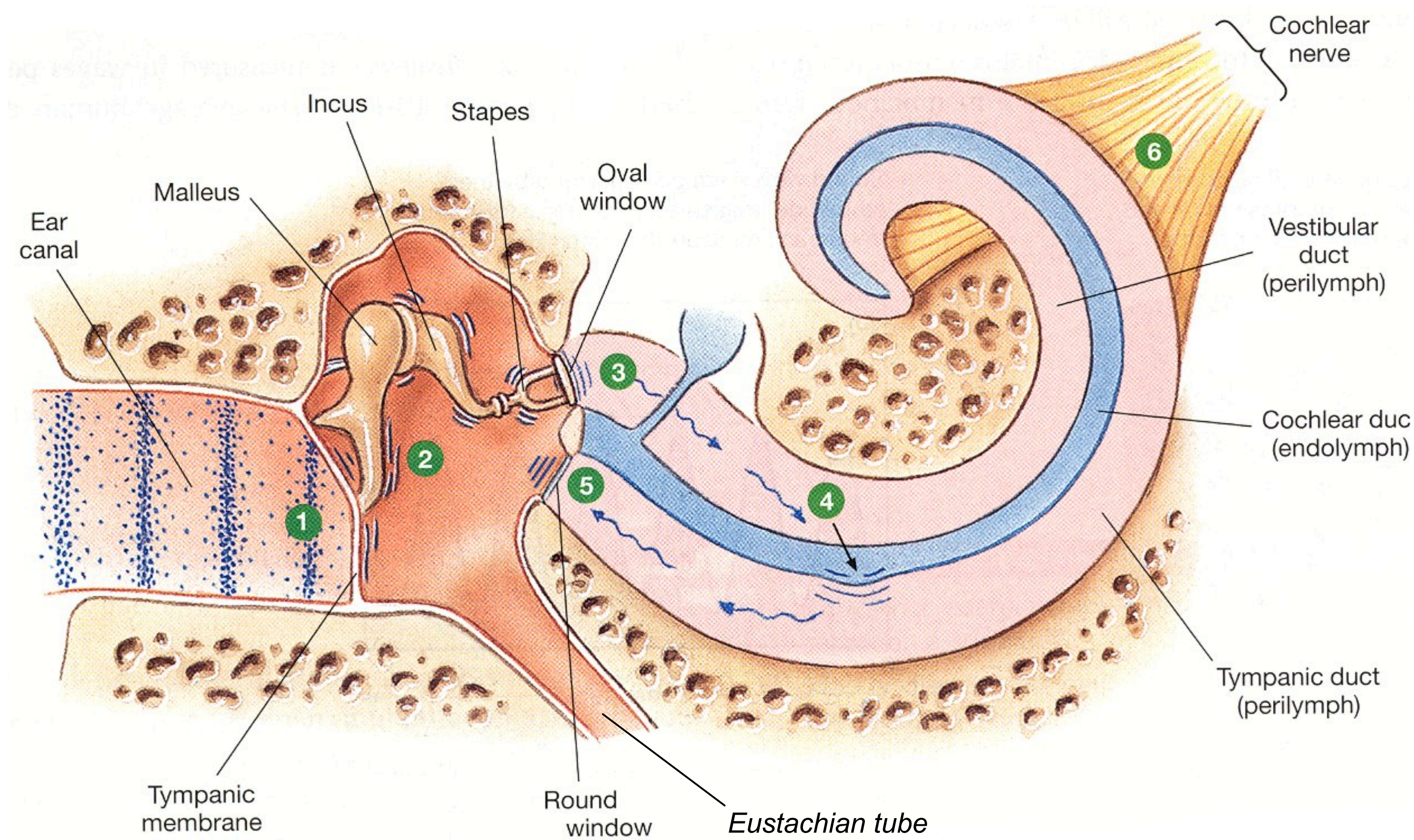
Sound Transmission through the Ear

2) The sound wave energy is transferred to the three bones of the middle ear (*malleus, incus & staples*), which vibrate.



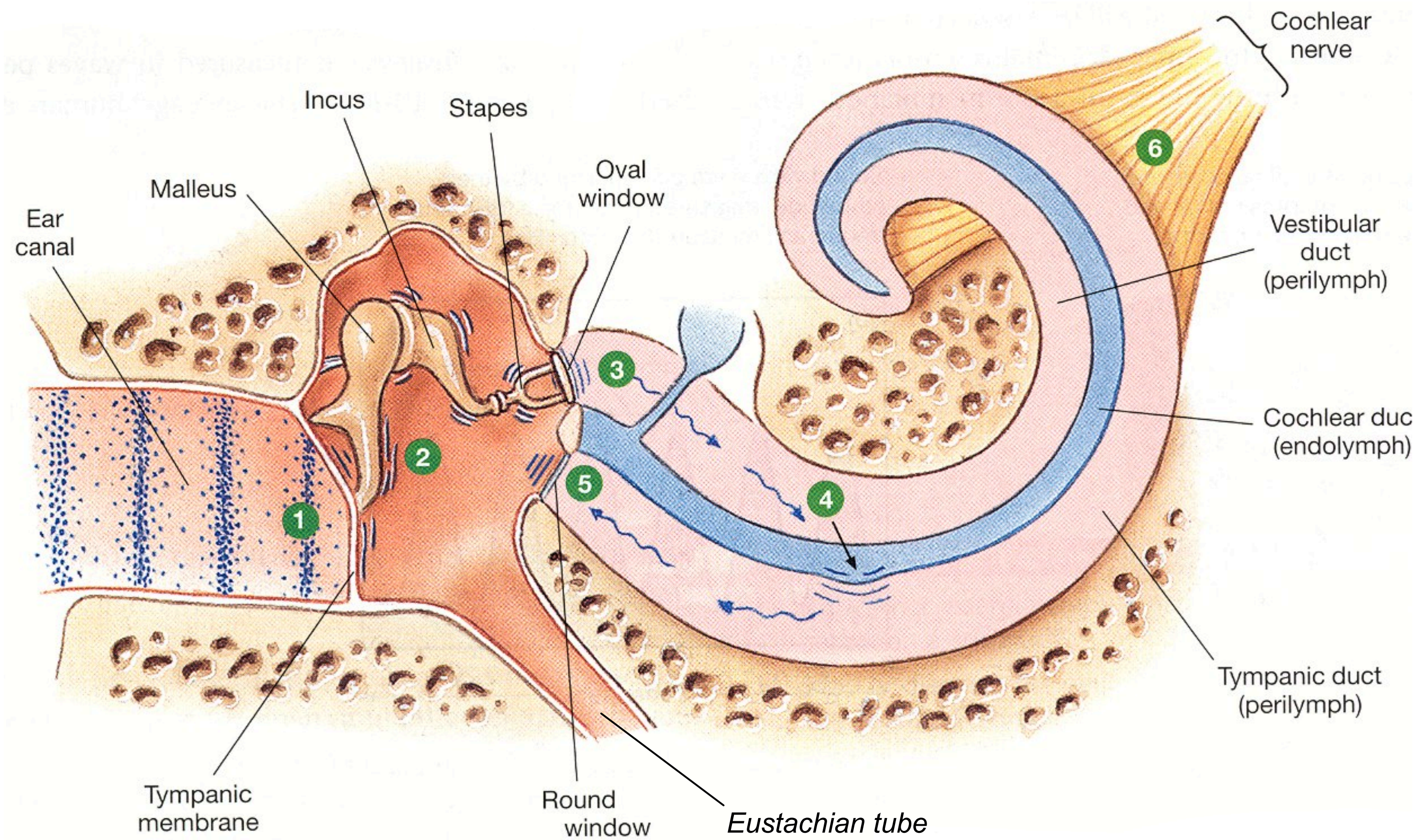
Sound Transmission through the Ear

3) Vibrations of staples' footplate against the oval window are converted into fluid waves within the vestibular duct.



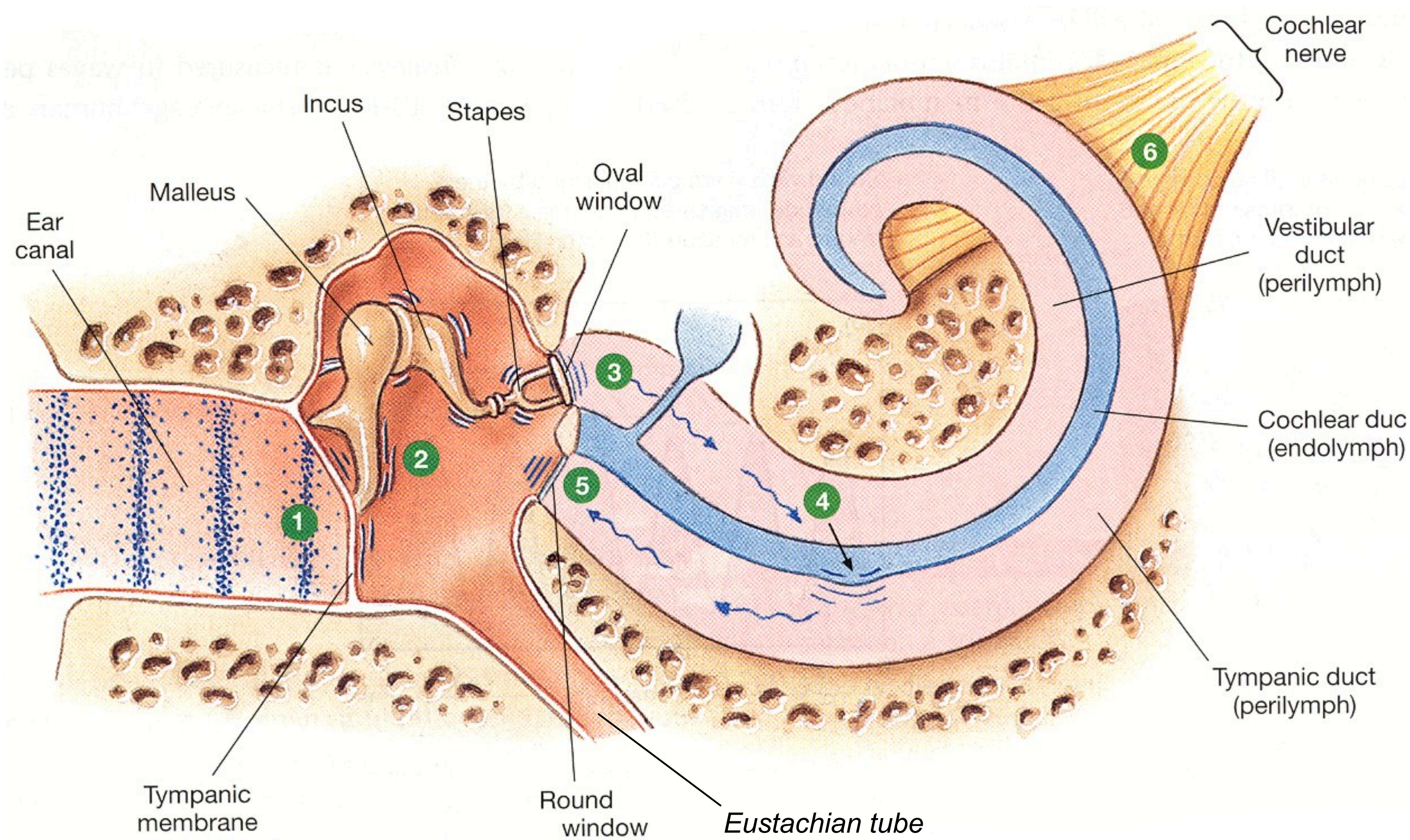
Sound Transmission through the Ear

4) Fluid waves push on the membranes of the cochlear duct, thereby activating the sensory hair cell receptors.



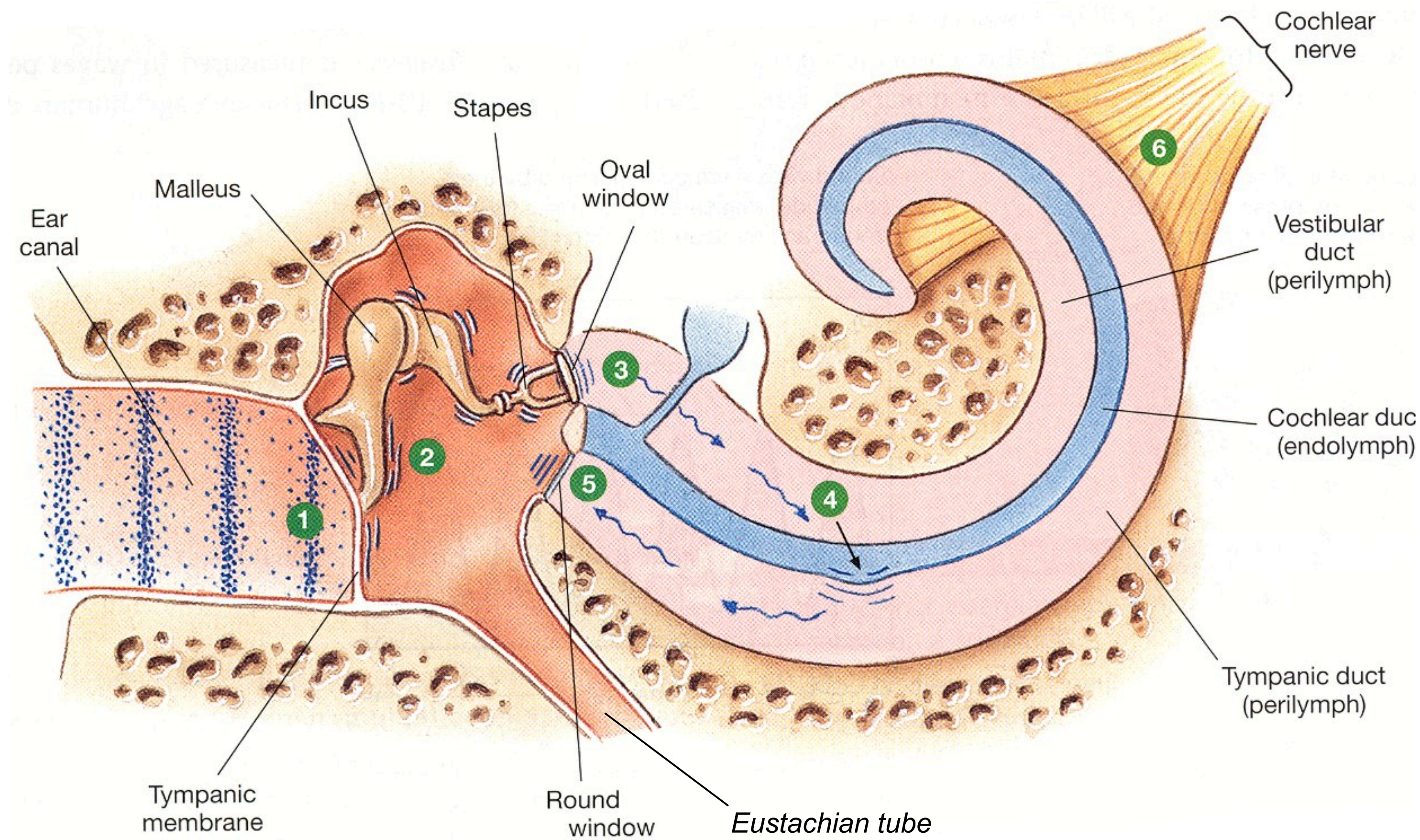
Sound Transmission through the Ear

5) Fluid waves energy transfers across the cochlear duct and into the tympanic duct and dissipated at the round window.

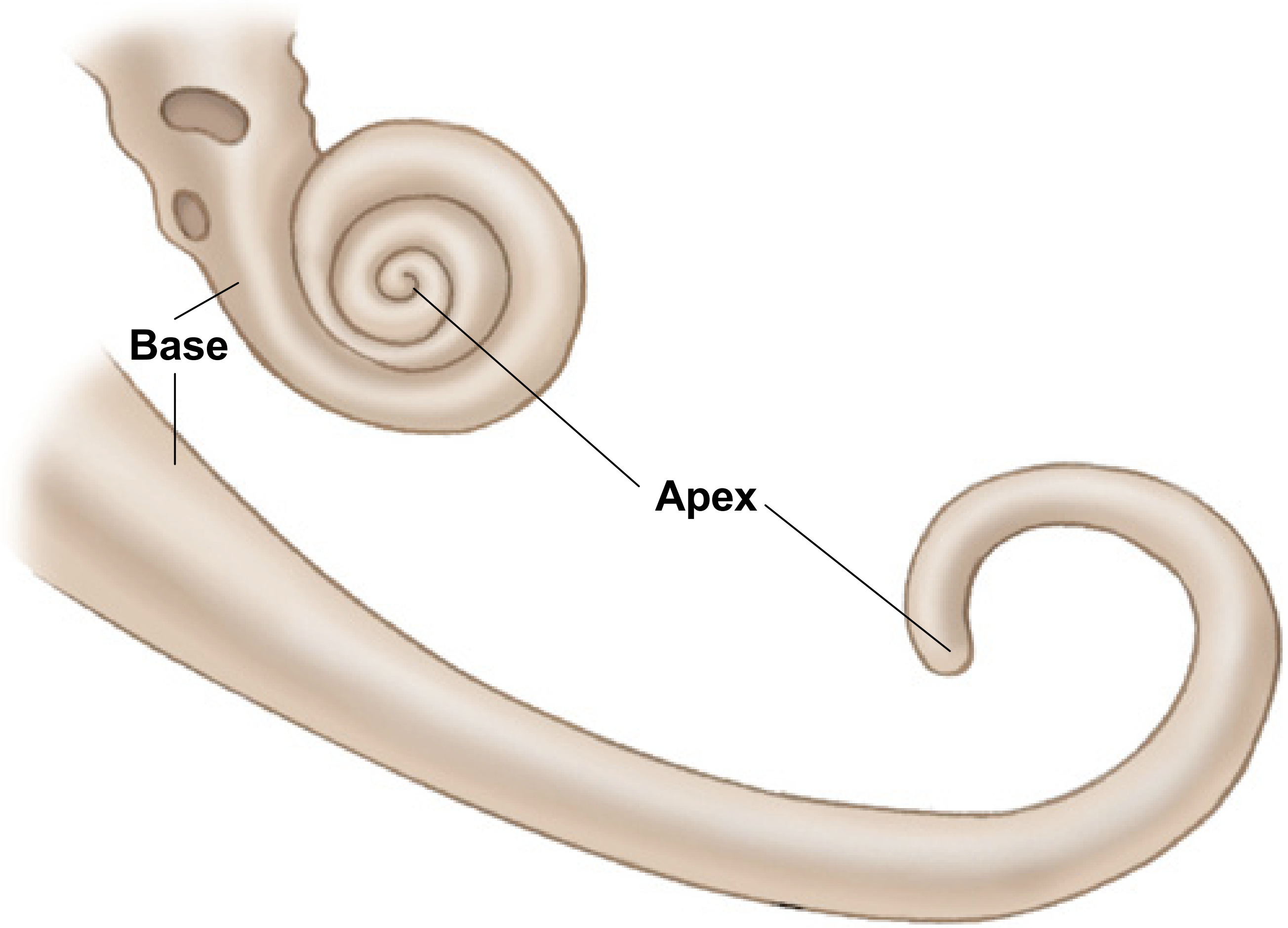


Sound Transmission through the Ear

6) Activated hair cells within the cochlear duct create action potentials in the sensory neurons of the cochlear nerve.



Cochlea

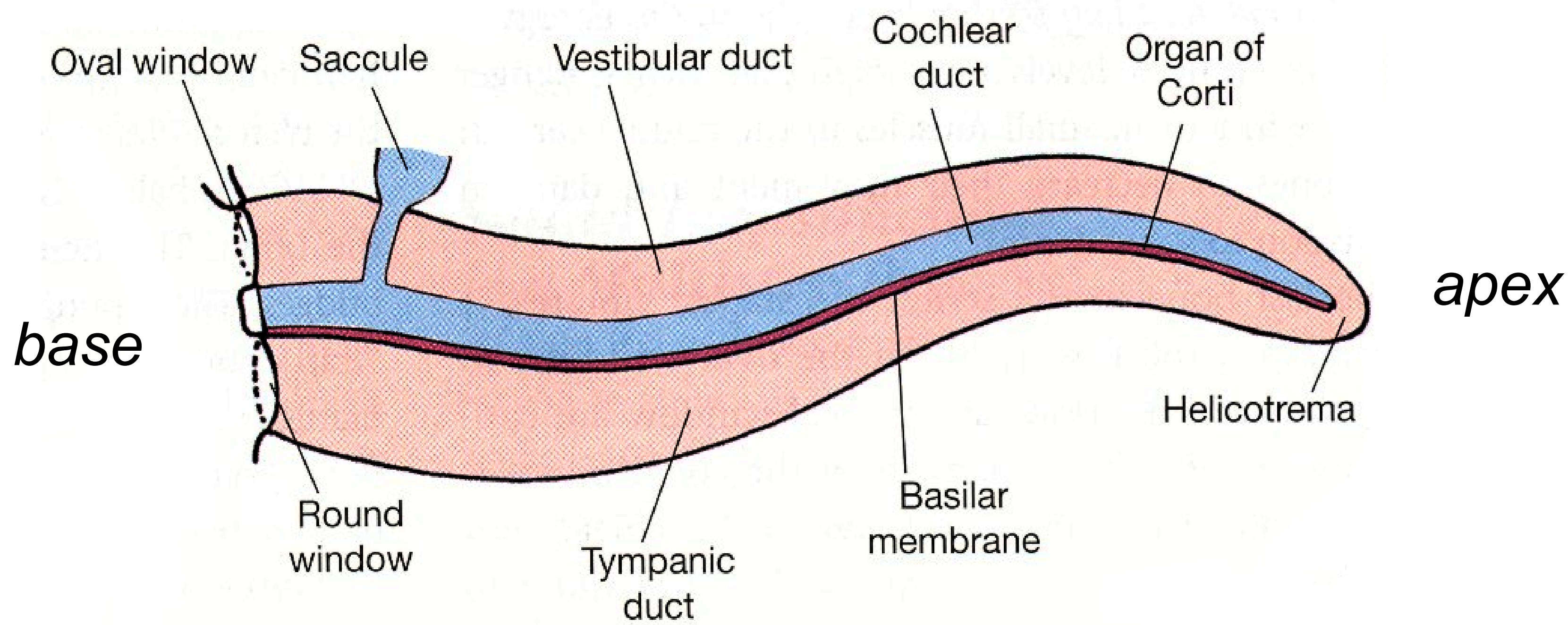


Cochlea

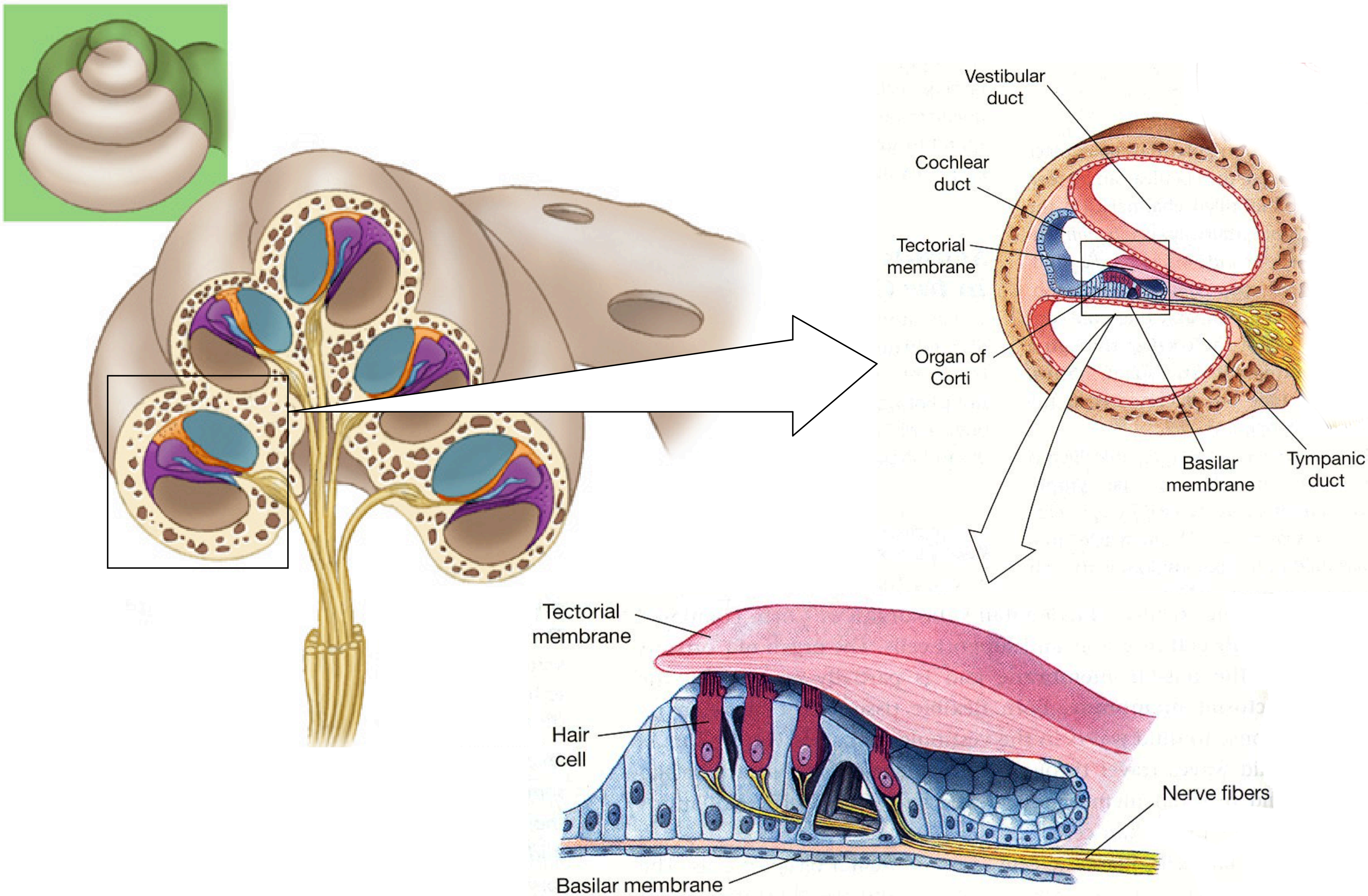
The cochlea consists of three fluid-filled compartments.

The vestibular and tympanic ducts are continuous and filled with **perilymph**, a fluid similar to plasma.

The cochlear duct is a dead-end tube filled with **endolymph**, a fluid resembling intracellular fluid (high K^+).

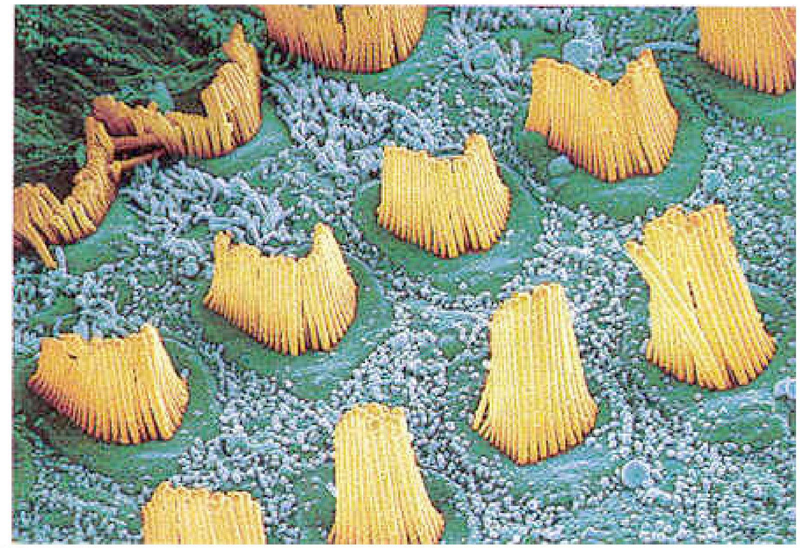


Cochlea


Vestibular duct
Cochlear duct
Tectorial membrane
Organ of Corti
Basilar membrane
Tympanic duct
Tectorial membrane
Hair cell
Nerve fibers
Basilar membrane

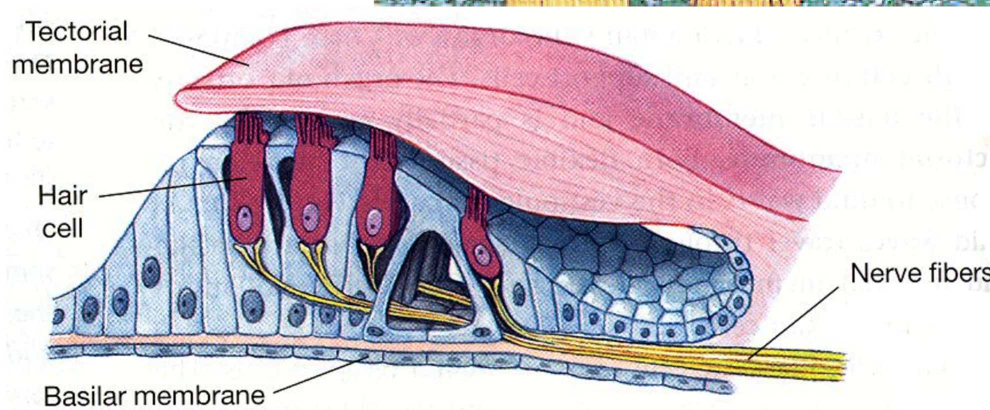
Cochlea

The cochlear duct contains the ***organ of Corti***, which contains the hair cells covered with **stereocilia**.



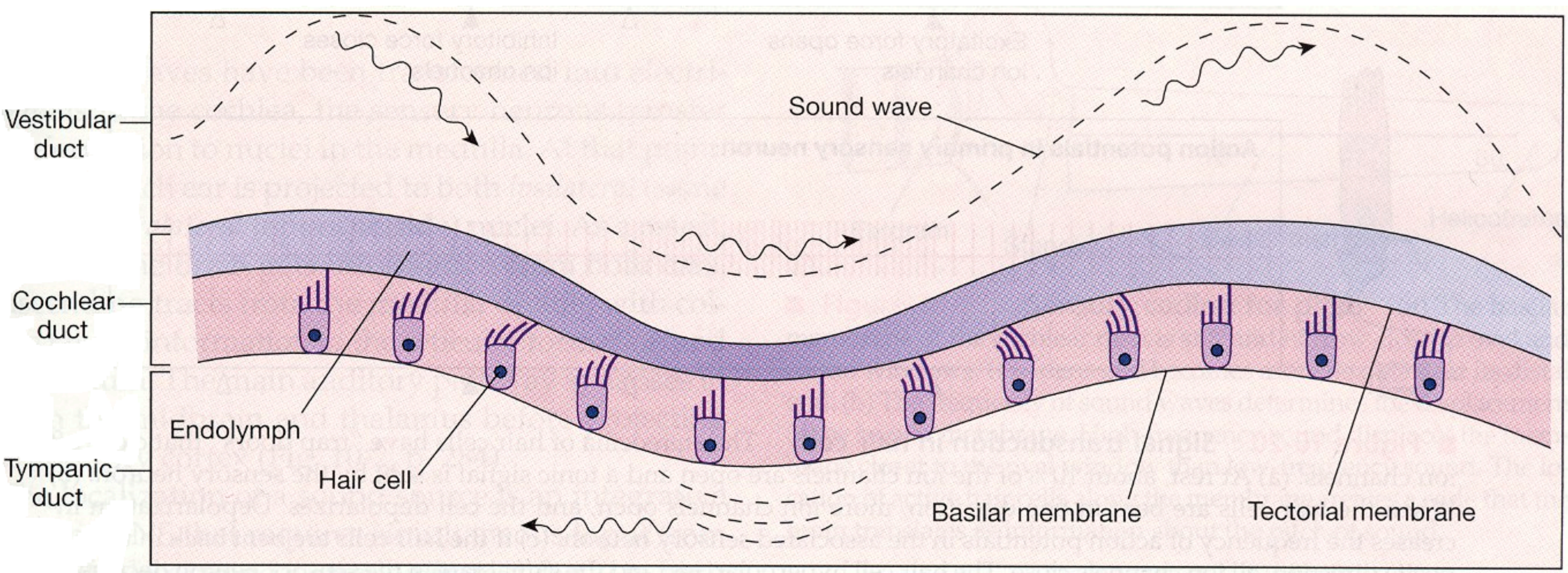
The *organ of Corti* rests on the **basilar membrane**.

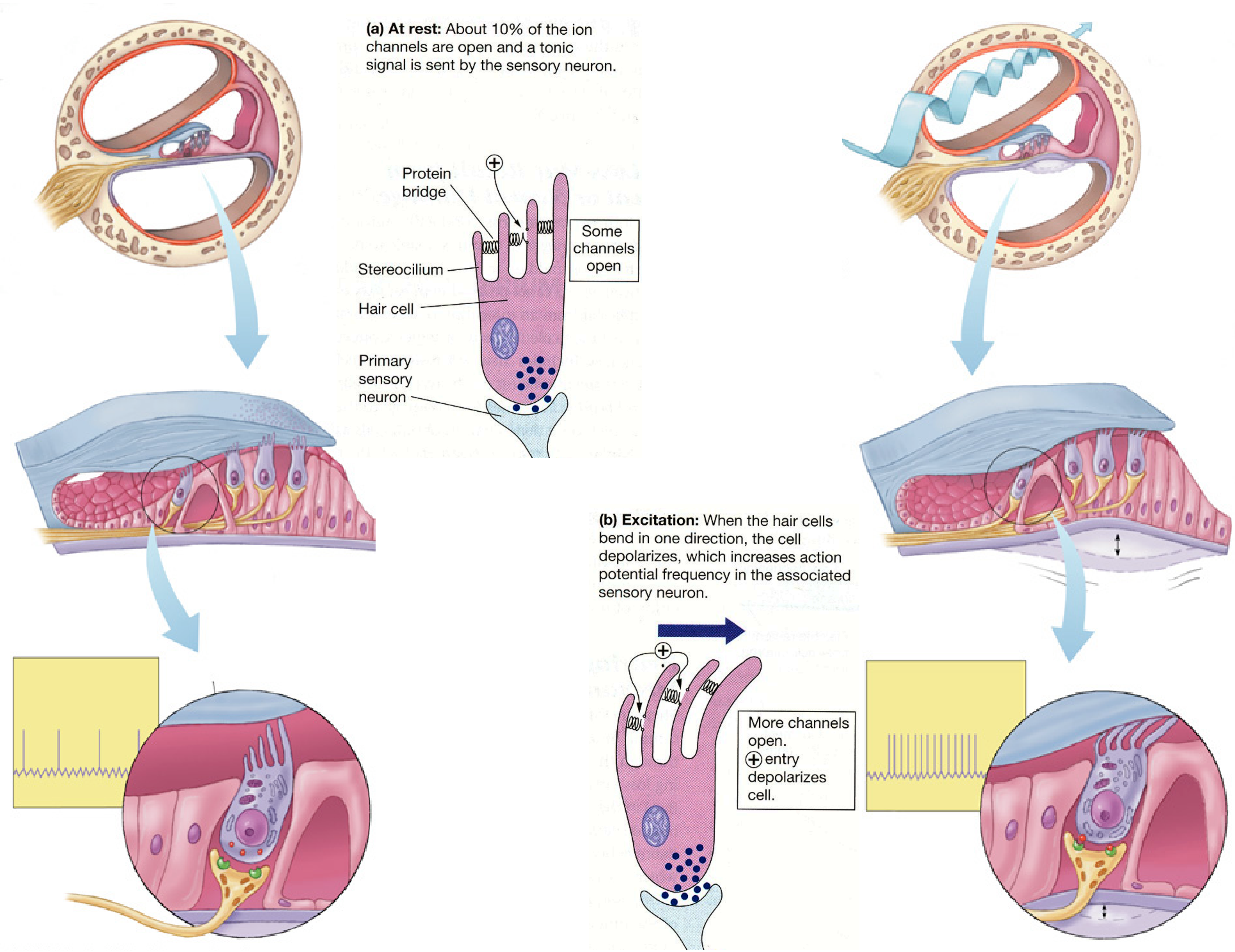
The longest stereocilia of hair cells are embedded in the overlying **tectorial membrane**.



Cochlea

Deformation of the cochlear duct by sound waves causes the tectorial membrane covering the organ of Corti to move. This motion bends the *stereocilia* of the hair cells and activates channels that let positive ions (Ca^{2+}) into the cells.





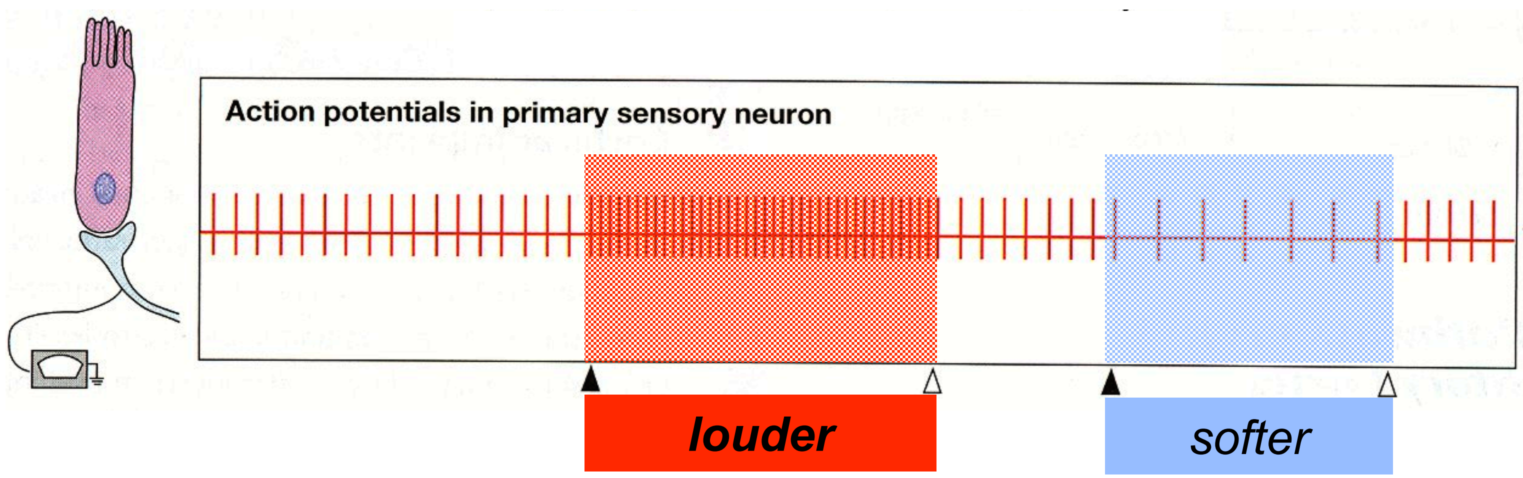
(a) At rest: About 10% of the ion channels are open and a tonic signal is sent by the sensory neuron.

(b) Excitation: When the hair cells bend in one direction, the cell depolarizes, which increases action potential frequency in the associated sensory neuron.

Coding Sound Loudness

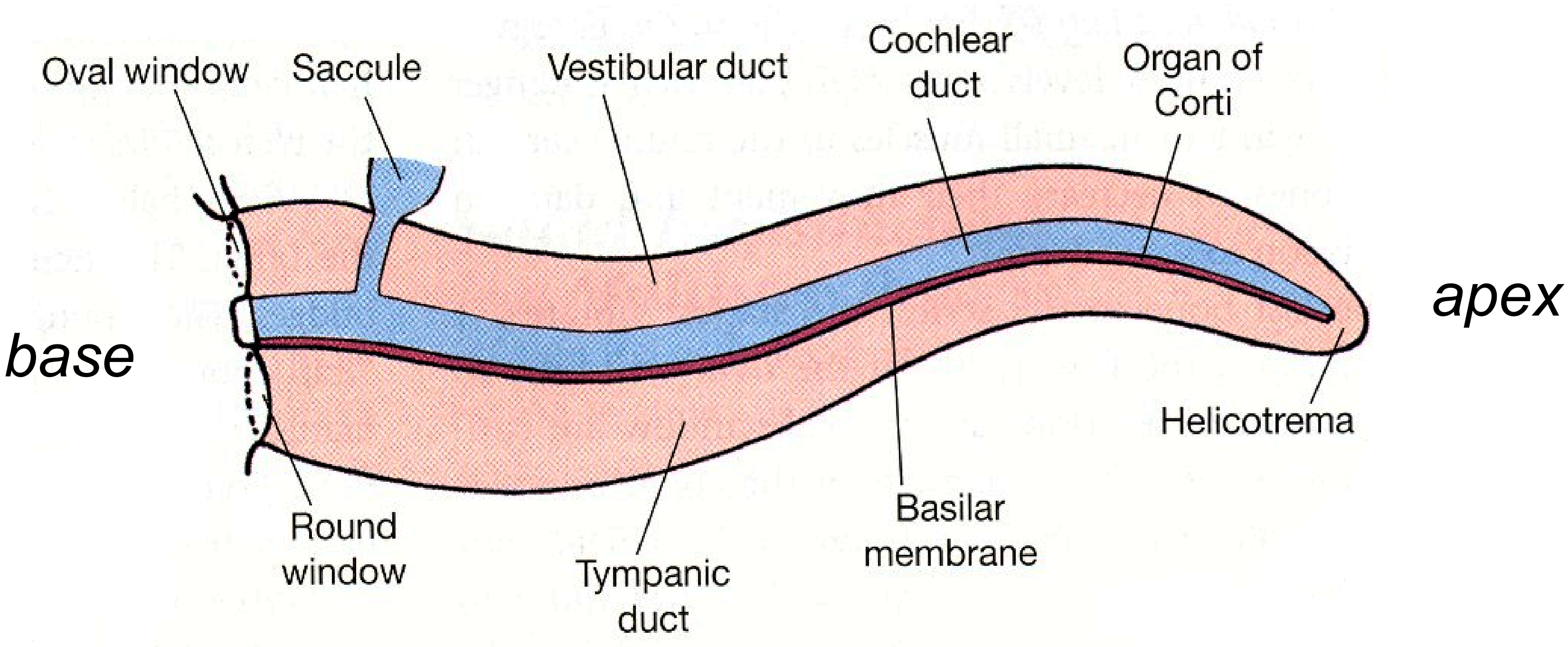
Sound loudness is coded in the frequency of action potentials in the cochlear nerve.

As sound gets louder, the frequency of action potentials generated by primary sensory neurons increases and more neurons are discharging.



Coding Sound Pitch

Coding sound for pitch is a function of the basilar membrane.

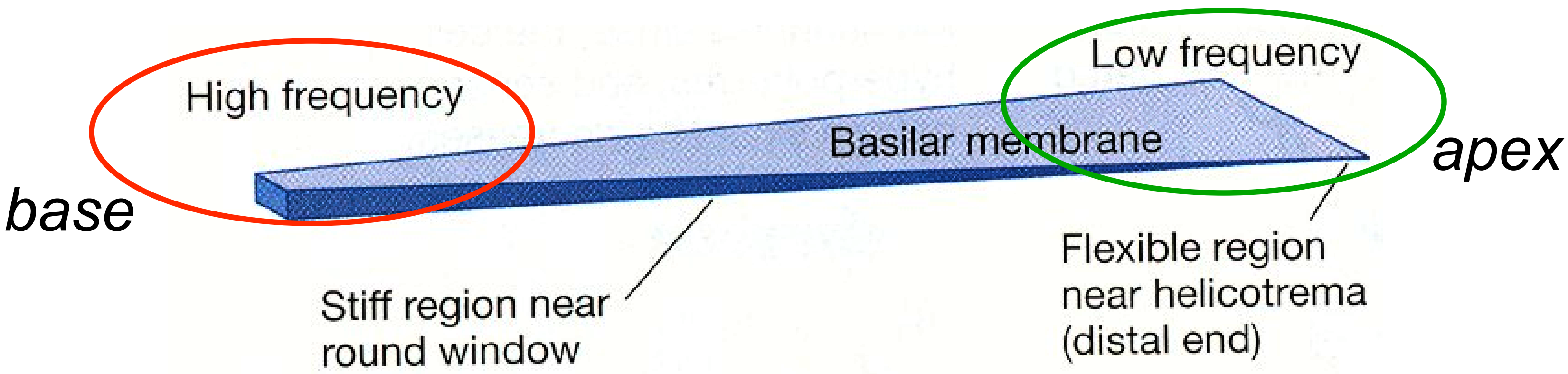


Coding Sound Pitch

Coding sound for pitch is a function of the basilar membrane.

High frequency waves create maximum displacement of the basilar membrane near the *oval-round window*.

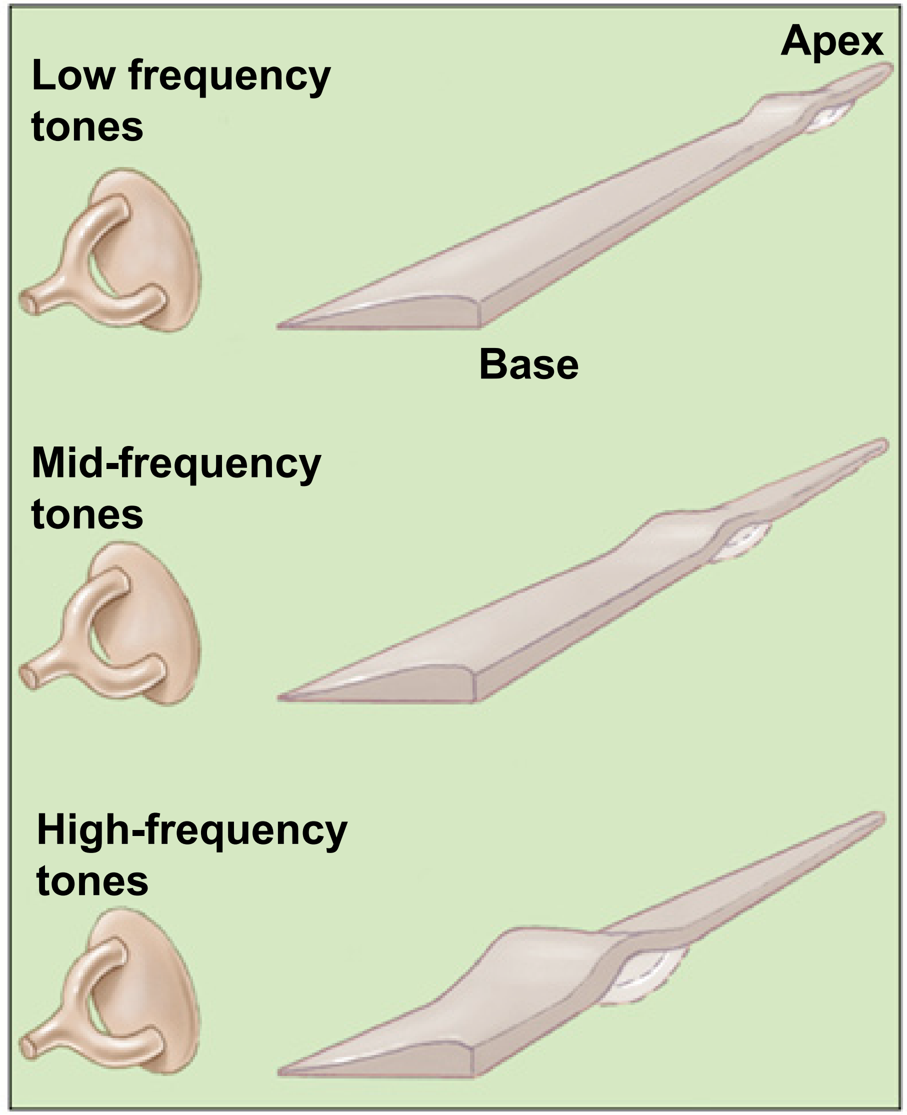
Low frequency waves travel along the length of the membrane and create maximum displacement near the *helicotrema*.



Coding Sound Pitch

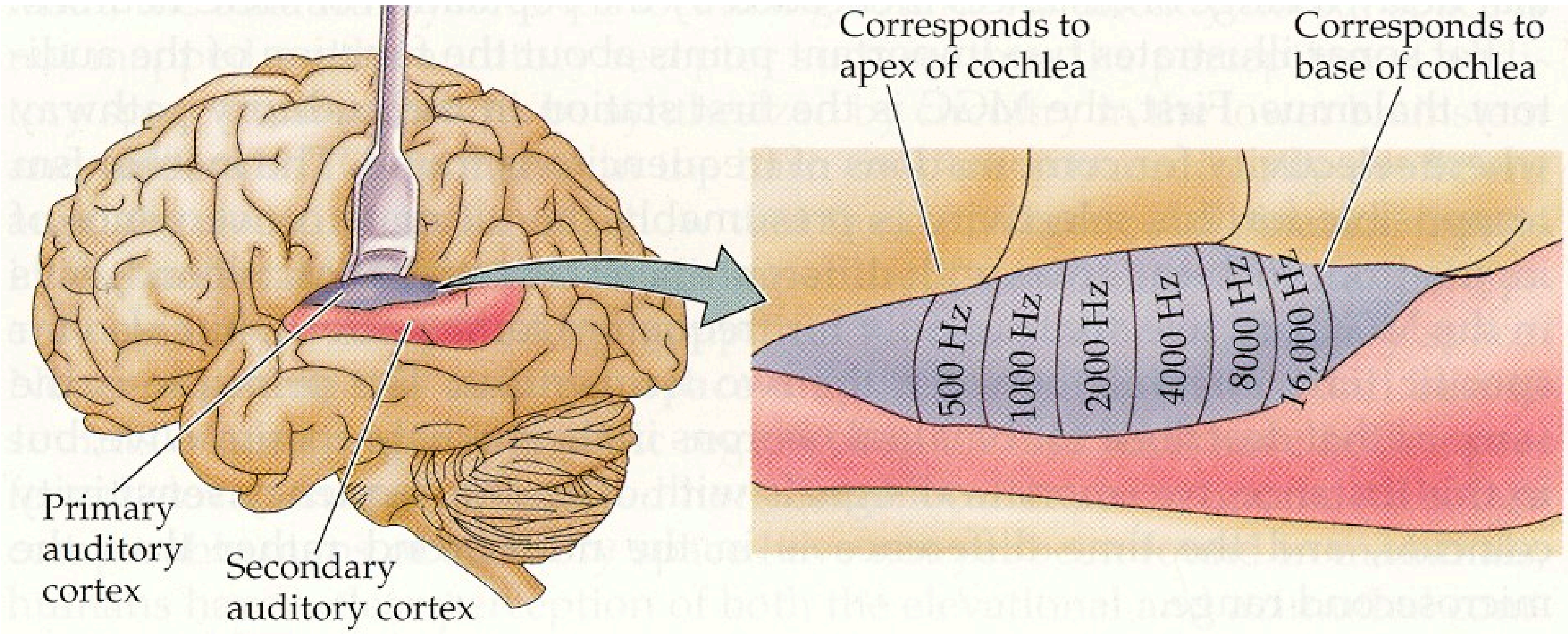
Sound pitch is coded spatially, i.e., by location of the hair cell receptors along the basilar membrane.

The cochlea's hair cell receptors are **tonotopically organized**.



Coding Sound Pitch

The spatial coding of pitch is preserved in the primary auditory cortex in the temporal lobe.

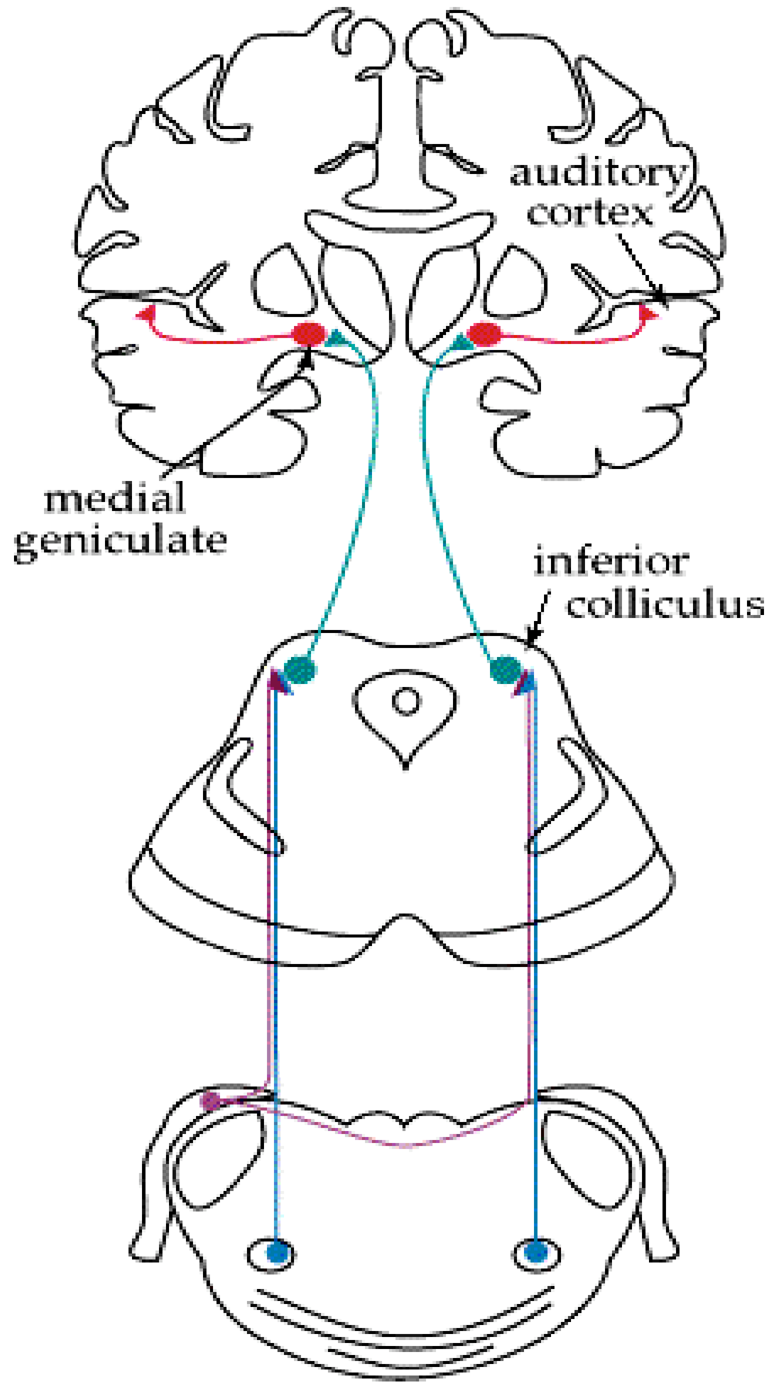


Auditory Pathways

Signals from the primary sensory neurons travels the cochlear nerve and reach the cochlear nucleus in the brain stem.

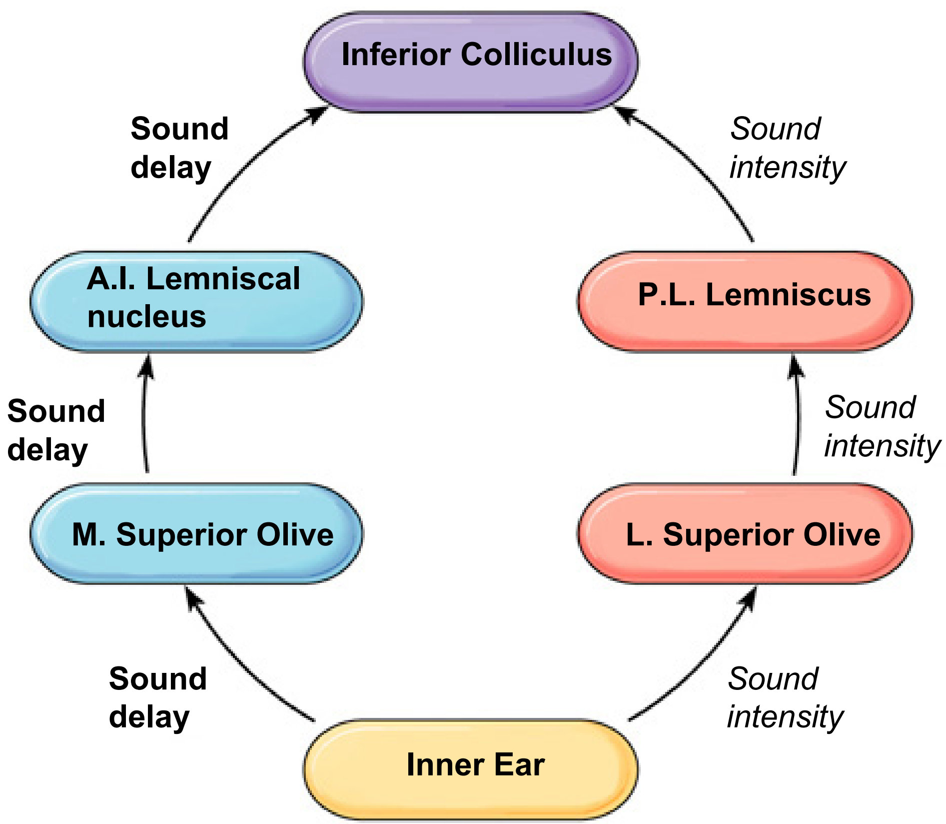
They are relayed to the thalamus and then to the primary auditory cortex in the temporal lobe.

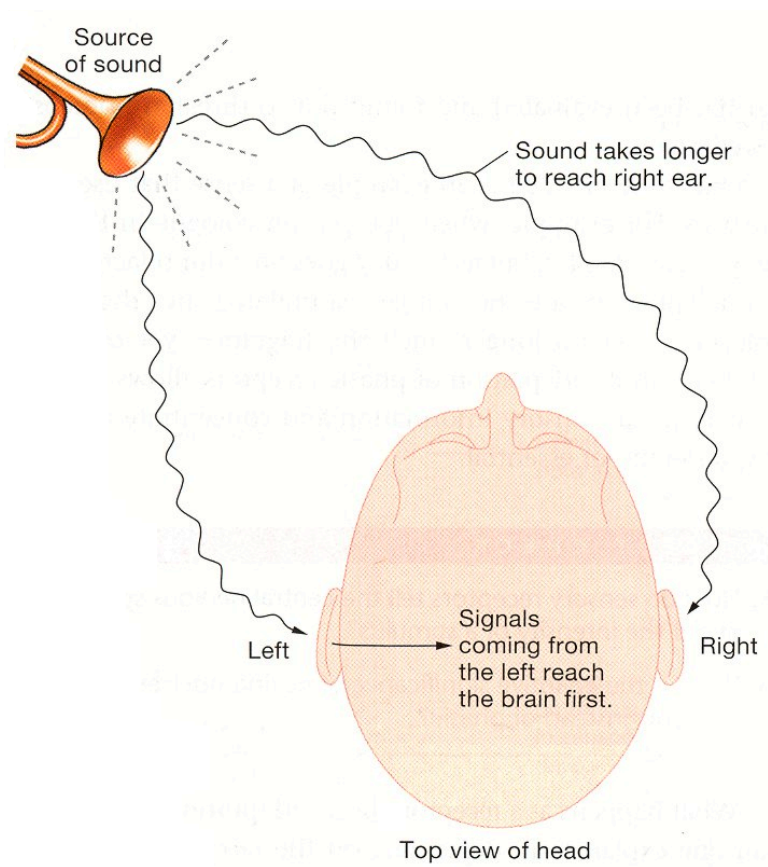
Any serious damage along this pathway can lead to **central hearing loss**.



Coding Sound Location

The time delay between the 2 ears (**interaural time difference**) - and to some extent the difference in sound intensity - form the basis of sound localization.





Coding Sound Location

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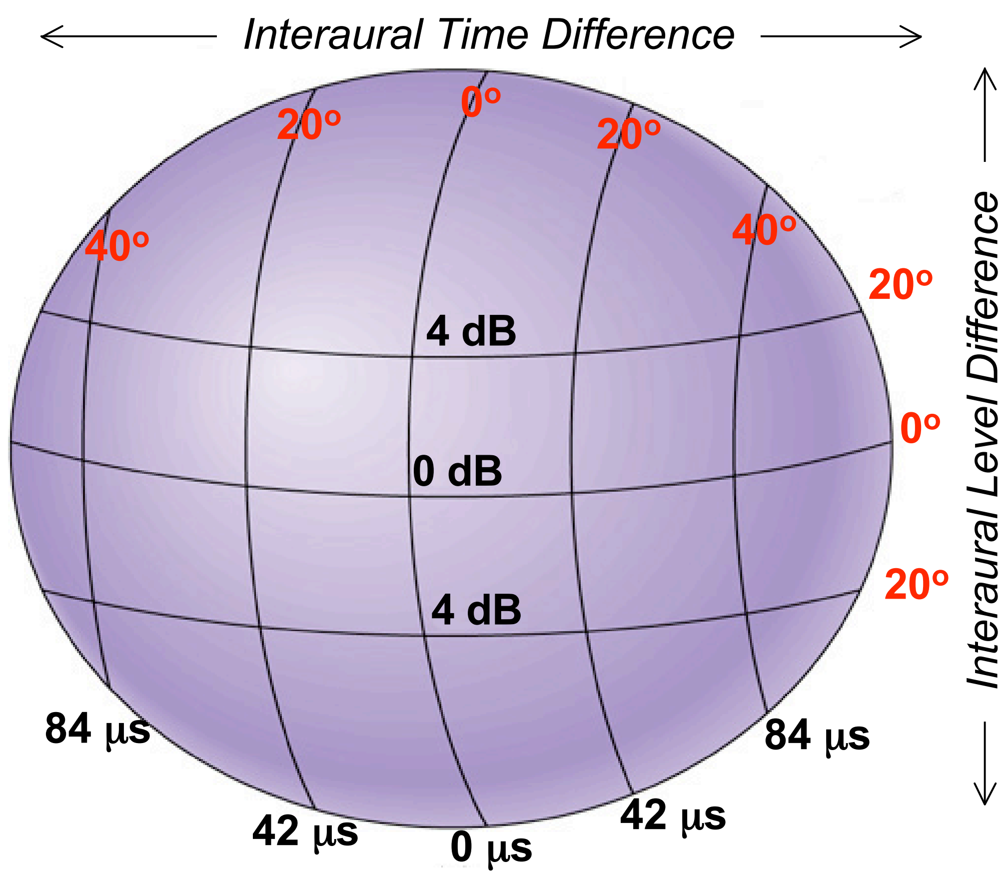
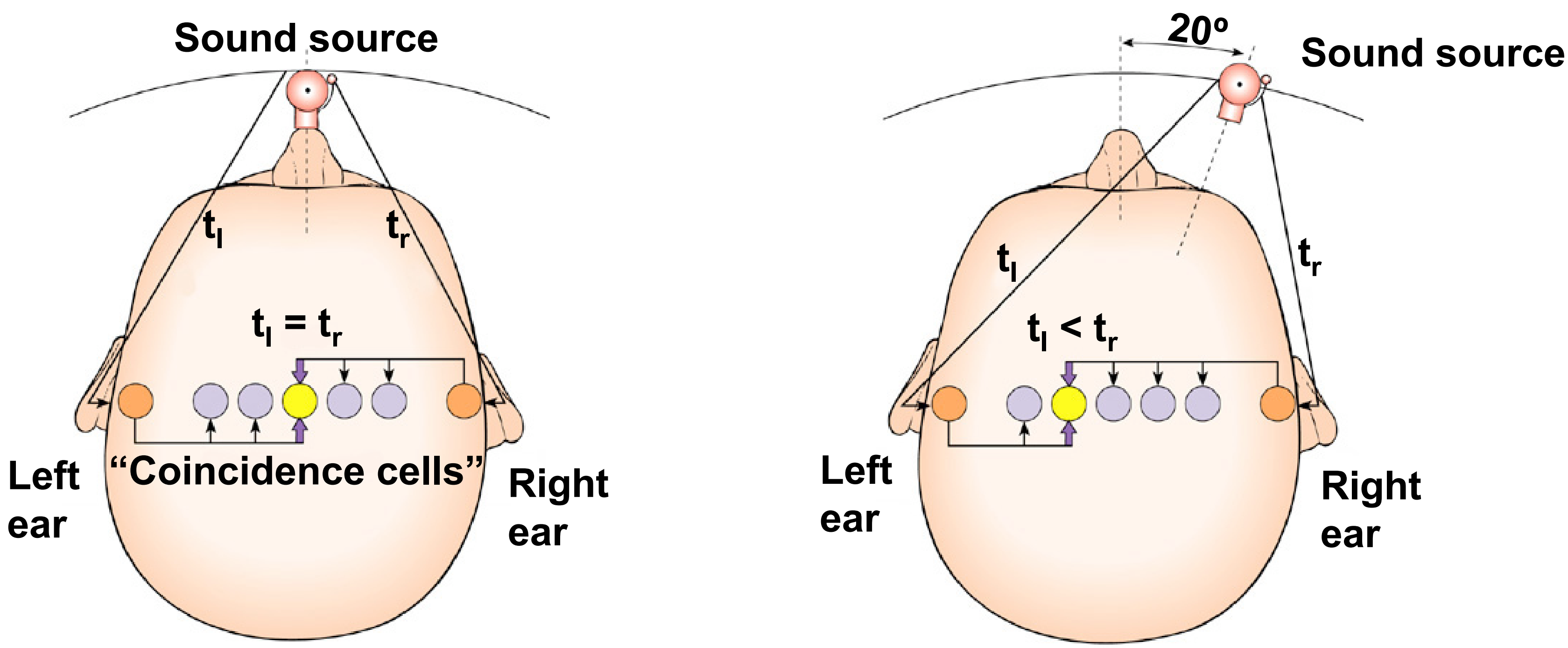


Coding Sound Location

Sound location is topographically encoded in the **medial superior olive** by neurons wired to detect the small time delays in the activation of sensory neurons in the left and right ears; they act as ***binaural coincidence detectors***.



PHGY 210,2,4 - Physiology

SENSORY PHYSIOLOGY

Equilibrium

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PHGY 210,2,4 - Physiology

SENSORY PHYSIOLOGY

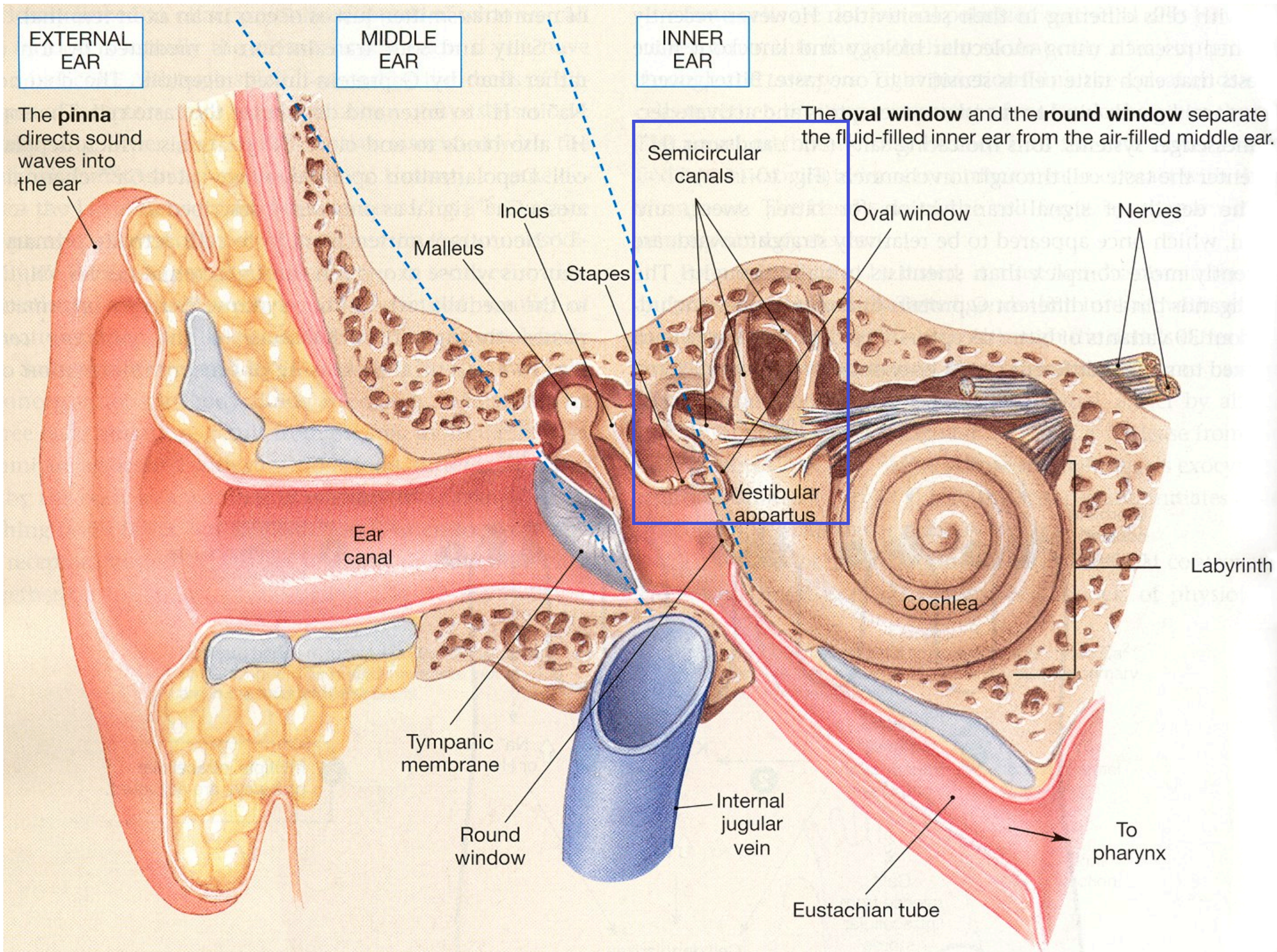
Equilibrium

Reading

Rhoades & Pflanzer (4th edition)

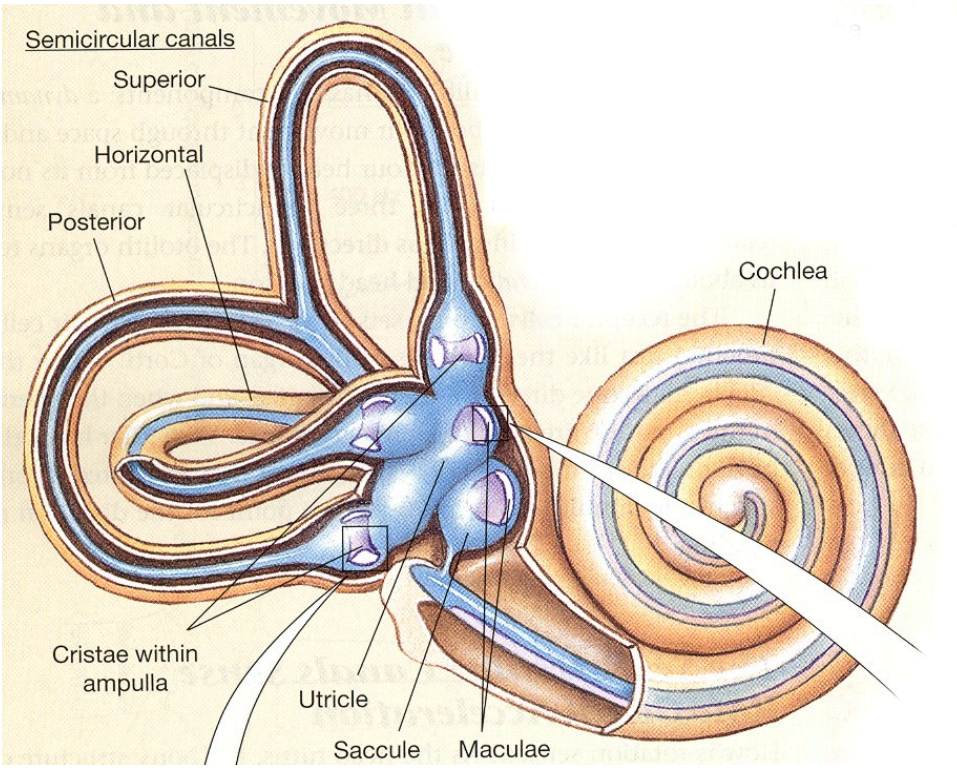
Chapter 8: *The Vestibular System* (p. 297-301)

Structure of the Ear



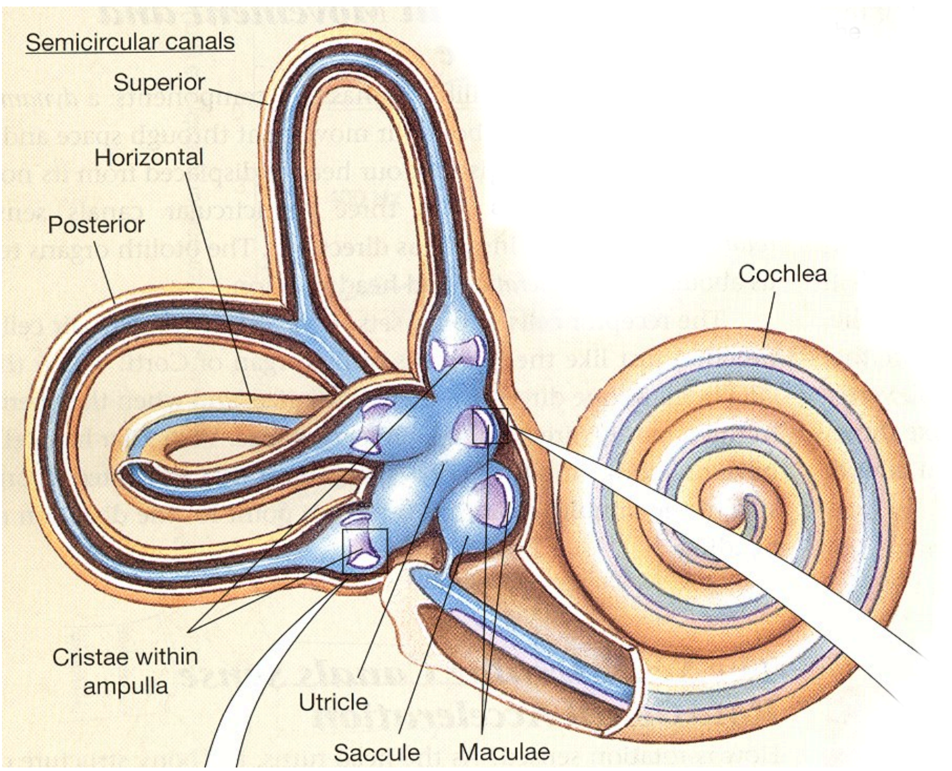
Equilibrium through the Ear

The **vestibular apparatus** responds to both **rotational** and **linear** changes in the body's position relative to space.



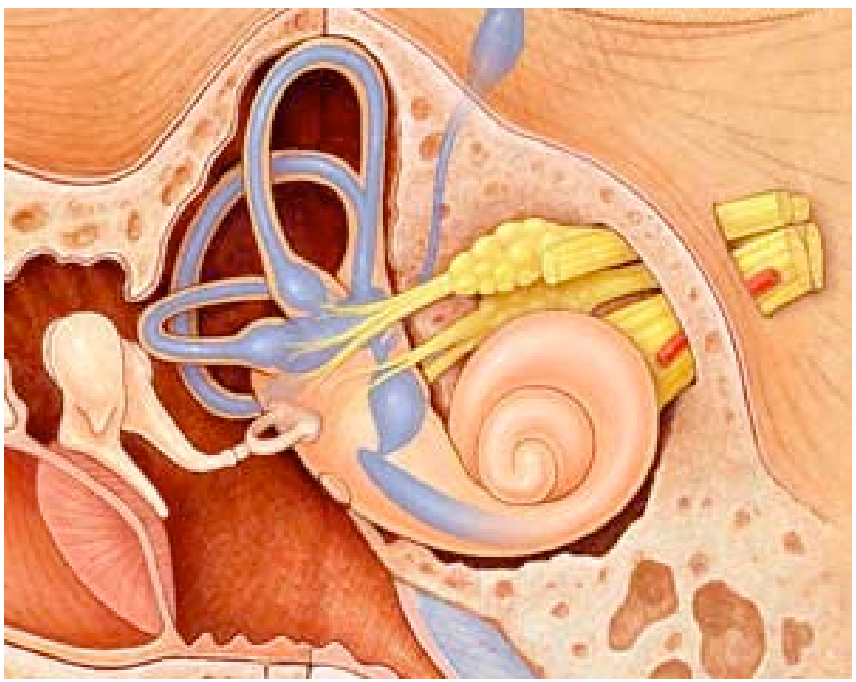
Equilibrium through the Ear

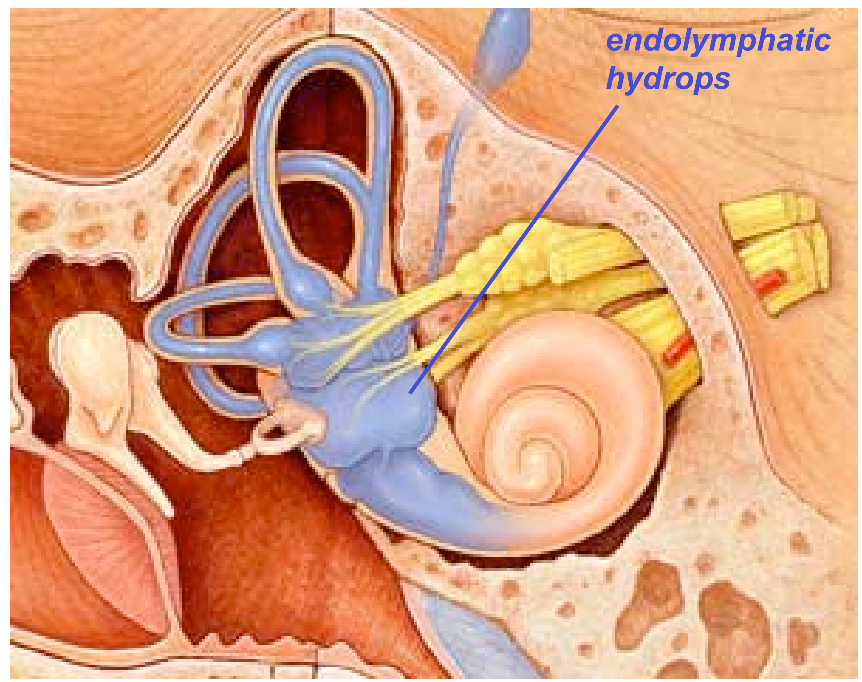
The vestibular apparatus consists of 3 **semicircular canals**, and 2 saclike **otolith** organs: **utricule** and **saccule**, which are filled with *endolymph*.



Equilibrium through the Ear

Buildup of endolymph (*endolymphatic hydrops*) can cause damage, e.g., **Meniere's Disease**, whose symptoms are vertigo, tinnitus, and progressive hearing loss.

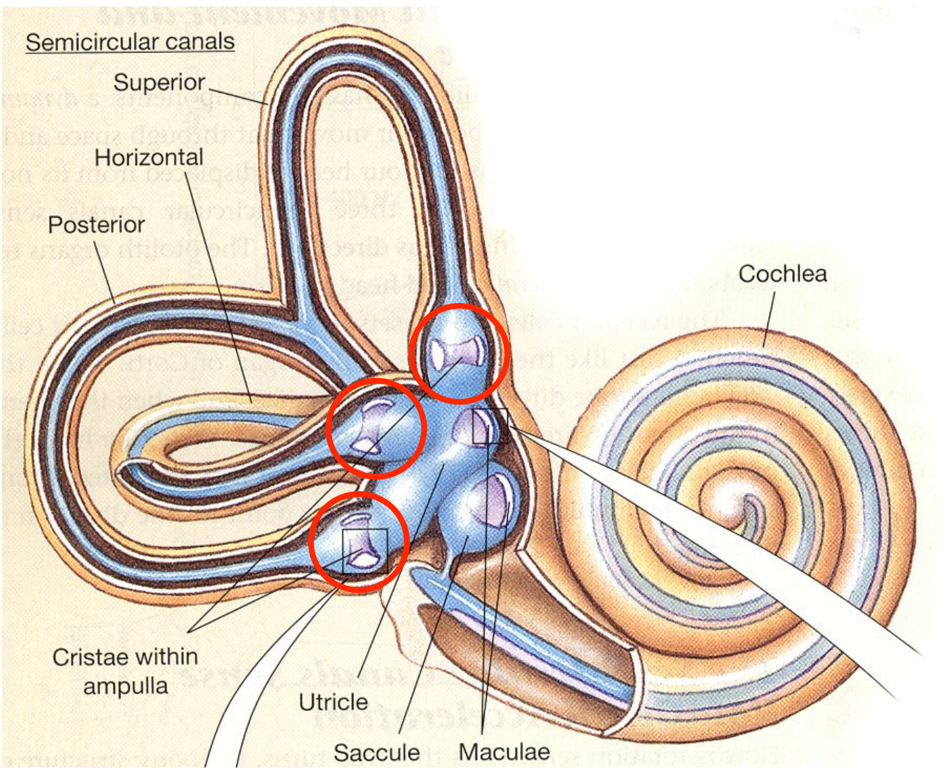




MD

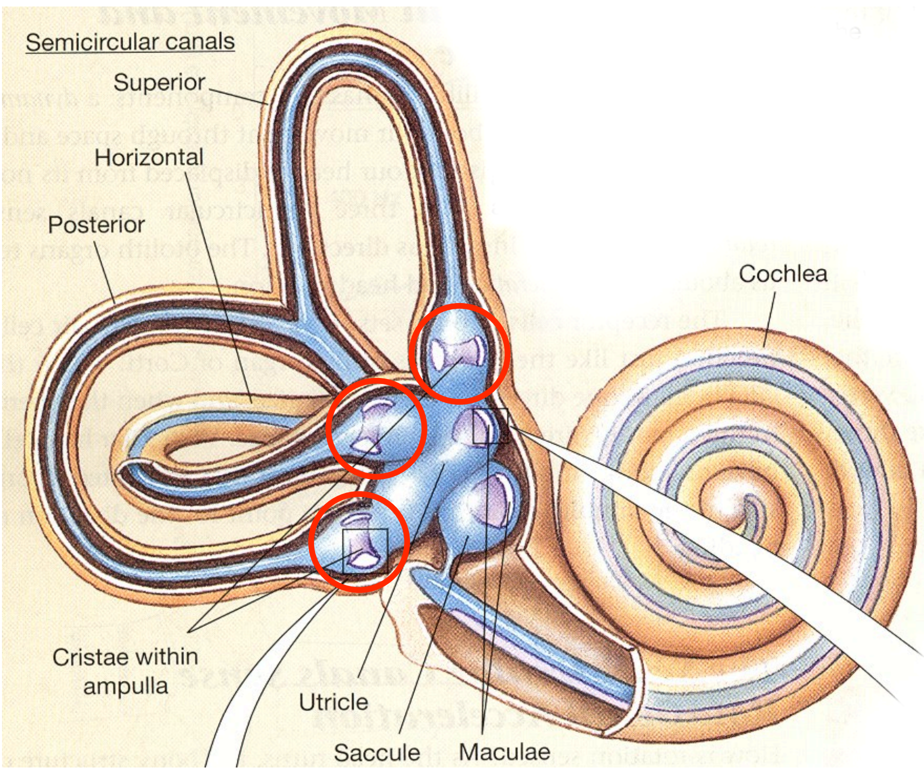
Semicircular Canals

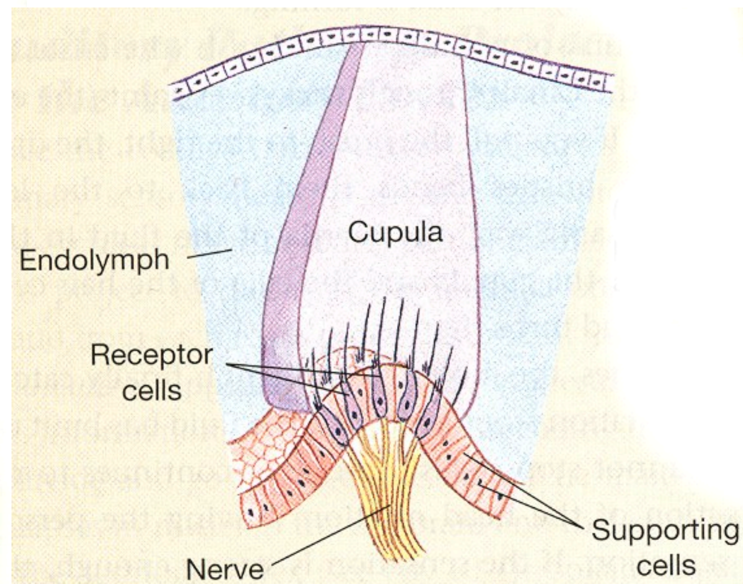
The base of each **semicircular canal** is
an enlarged chamber (**ampulla**), where are located
the sensory receptors for *rotational acceleration*: **cristae**.



Semicircular Canals

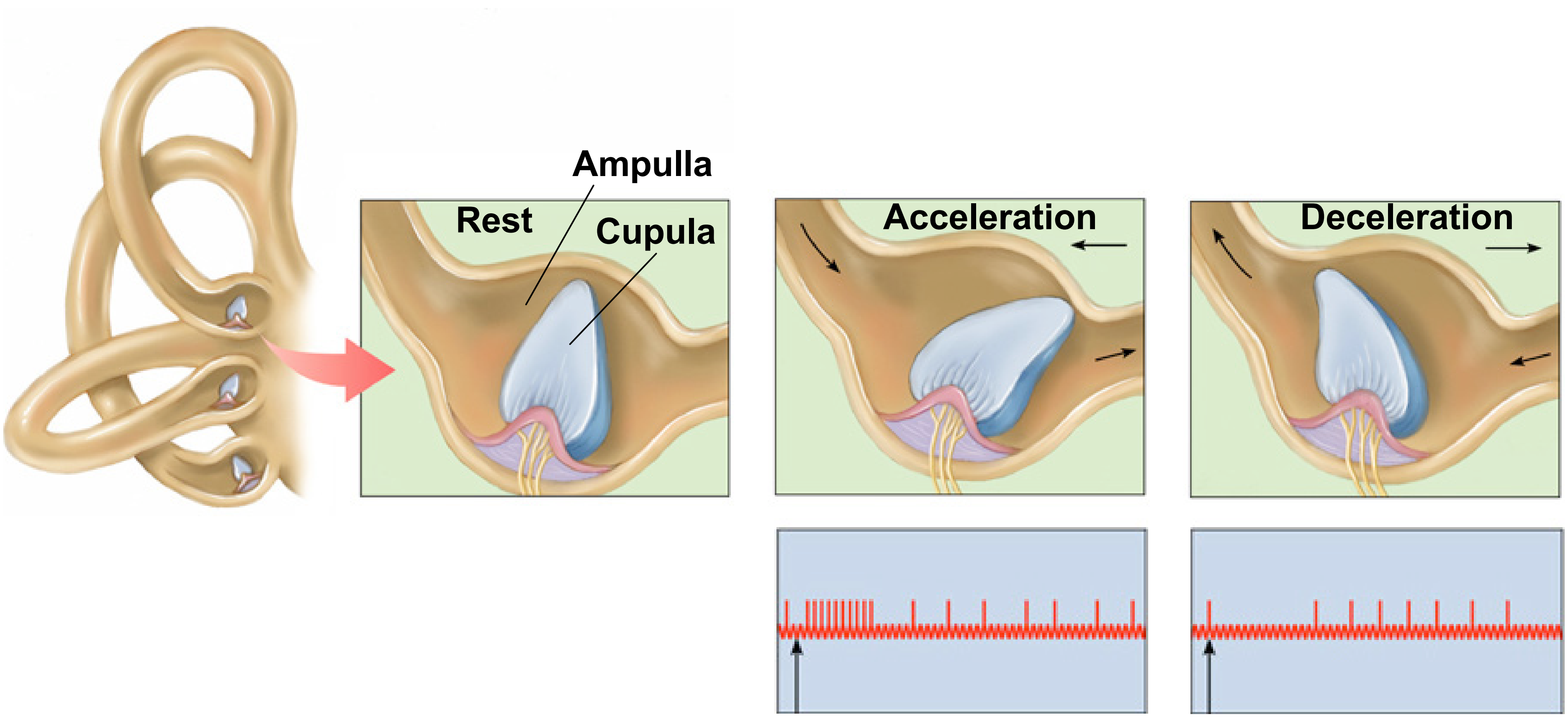
Each crista consist of a gelatinous mass (**cupula**) that, when pushed by the *endolymph*, bends the embedded cilia (and **kinocilium**) of each hair cell receptor.





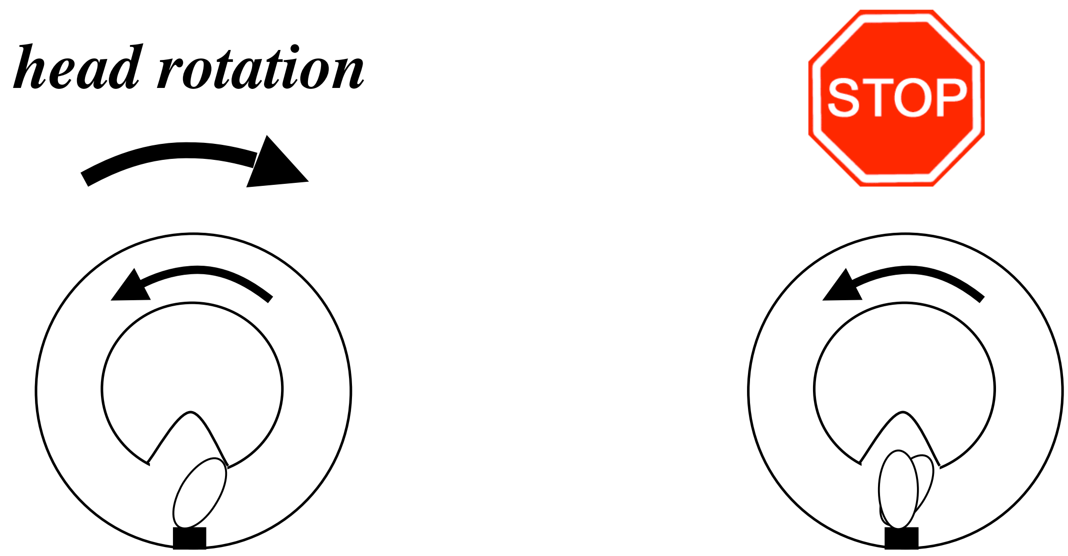
Semicircular Canals

When the head starts to turn, the *endolymph* cannot keep up because of inertia. This drag of the *endolymph* bends the cupula and its hair cells in the direction opposite to the head.



Semicircular Canals

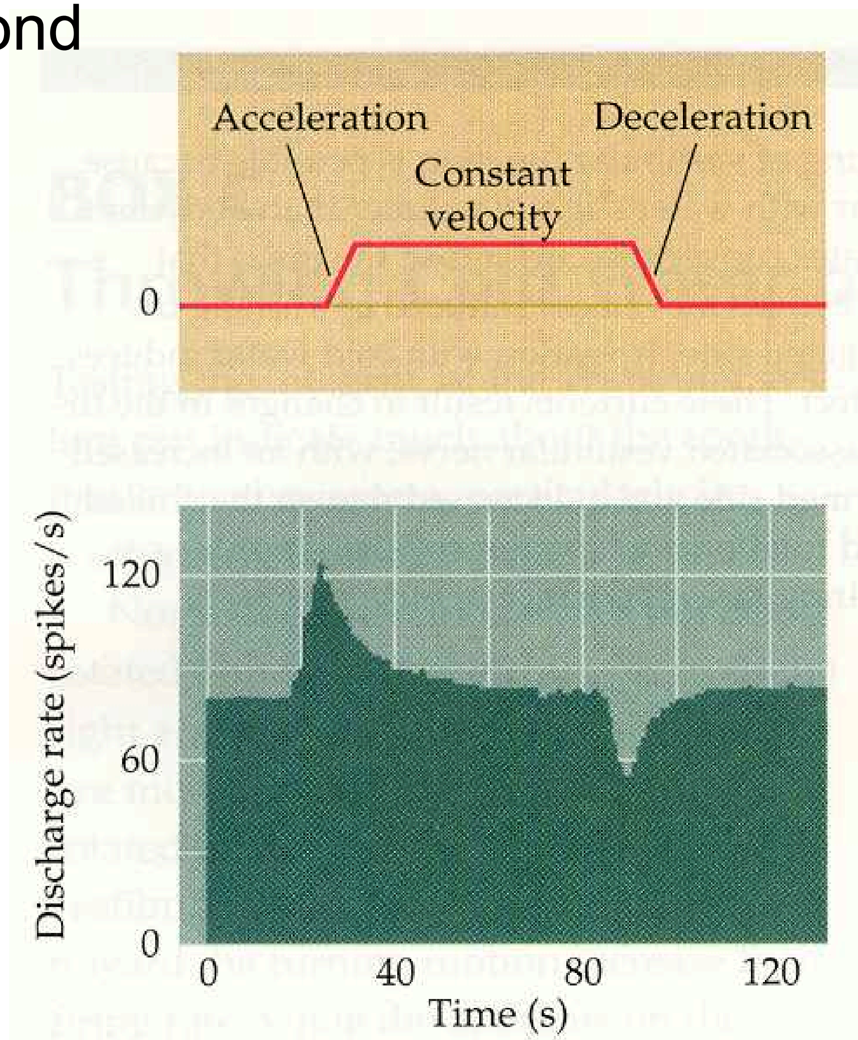
When the head stops, the *endolymph* keeps rotating momentarily and the cupula returns to its resting position only after a delay.



Semicircular Canals

Semicircular canals do not respond when the head is motionless or moving at a constant speed.

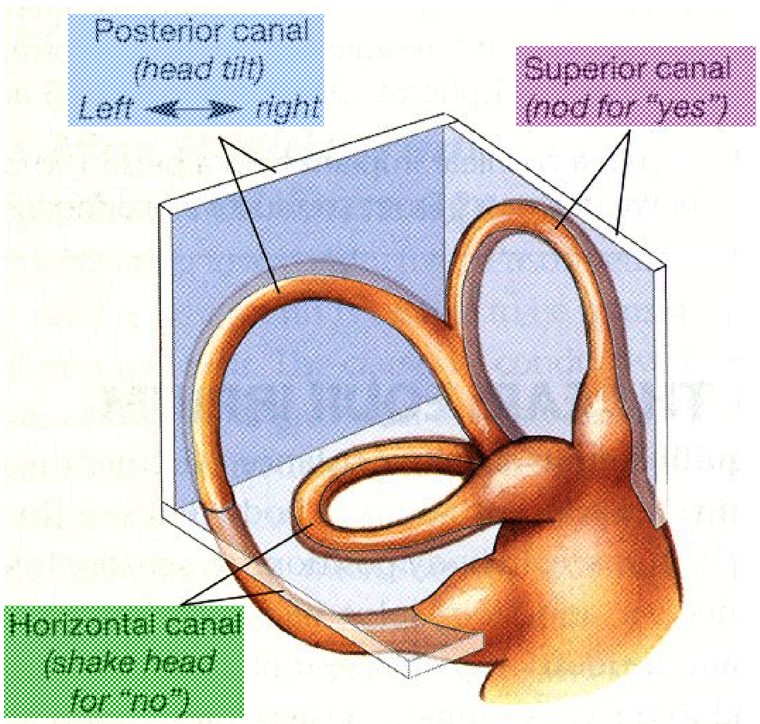
They detect changes in velocity!

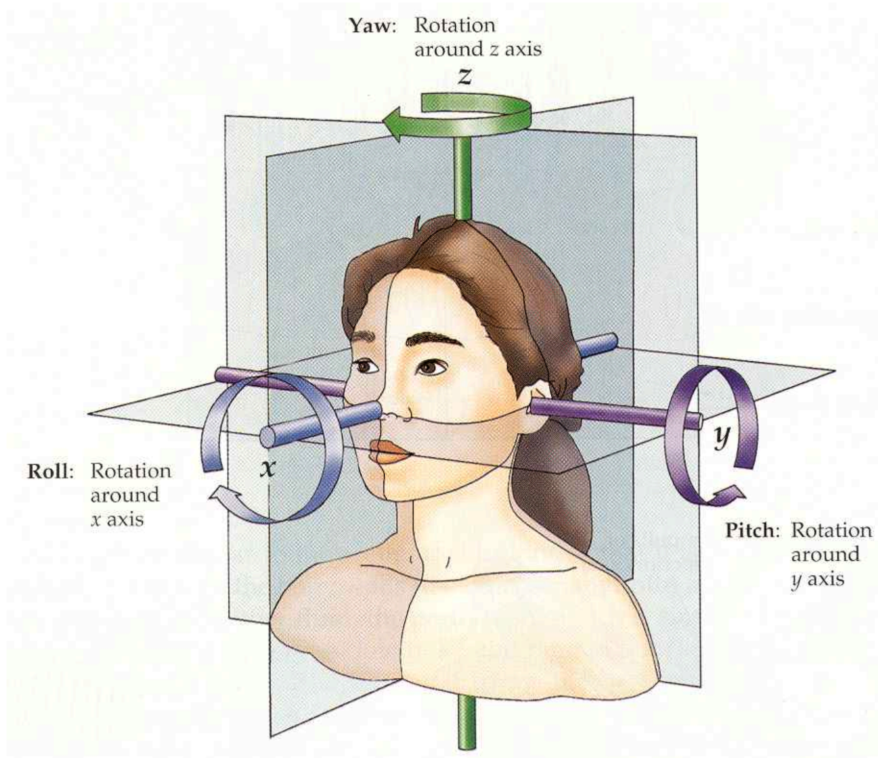


Semicircular Canals

The semicircular canals are oriented at **right angles** to each other.

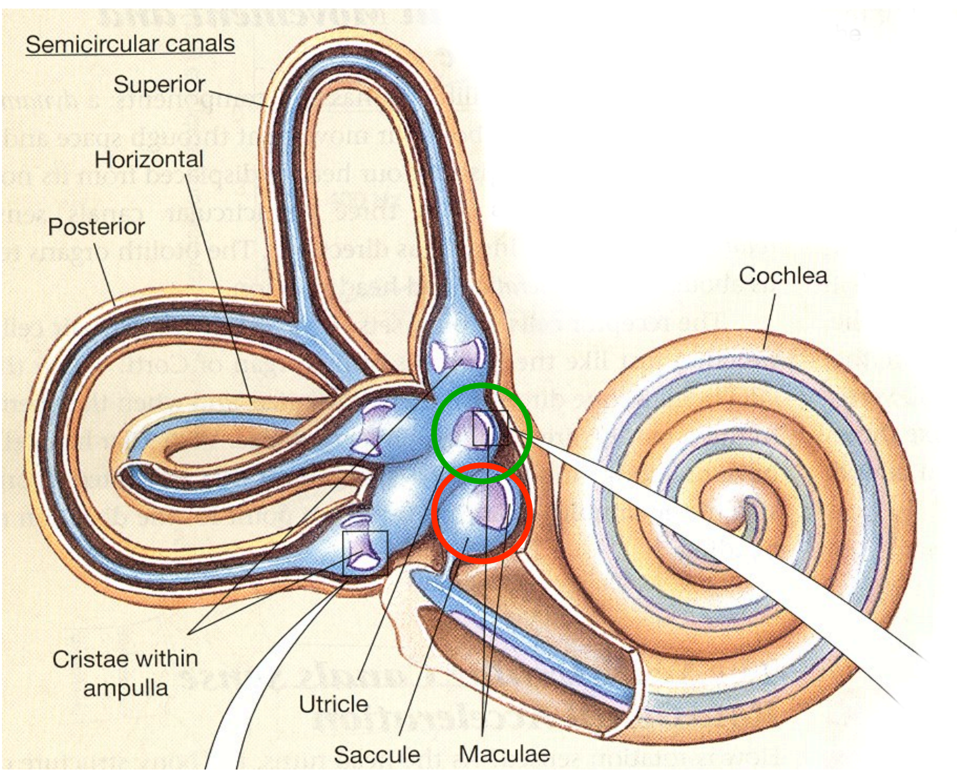
Together they can sense all **three degrees of rotation**.

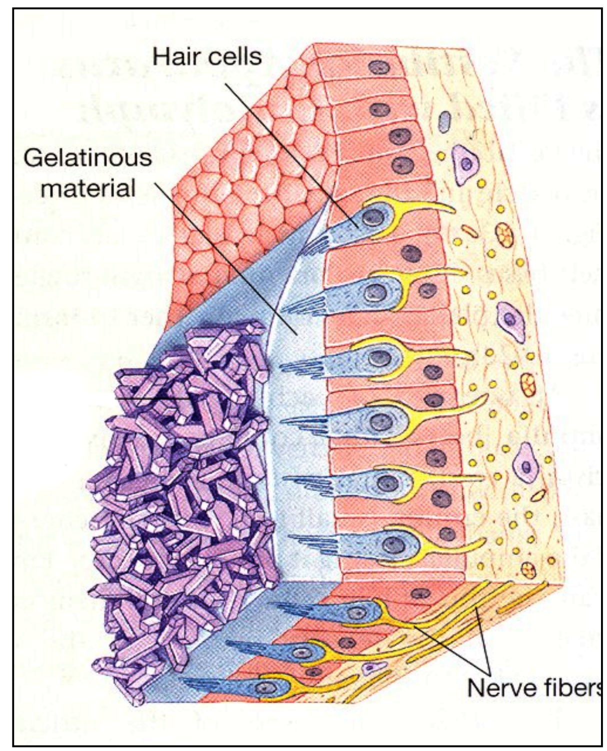




Otolith Organs

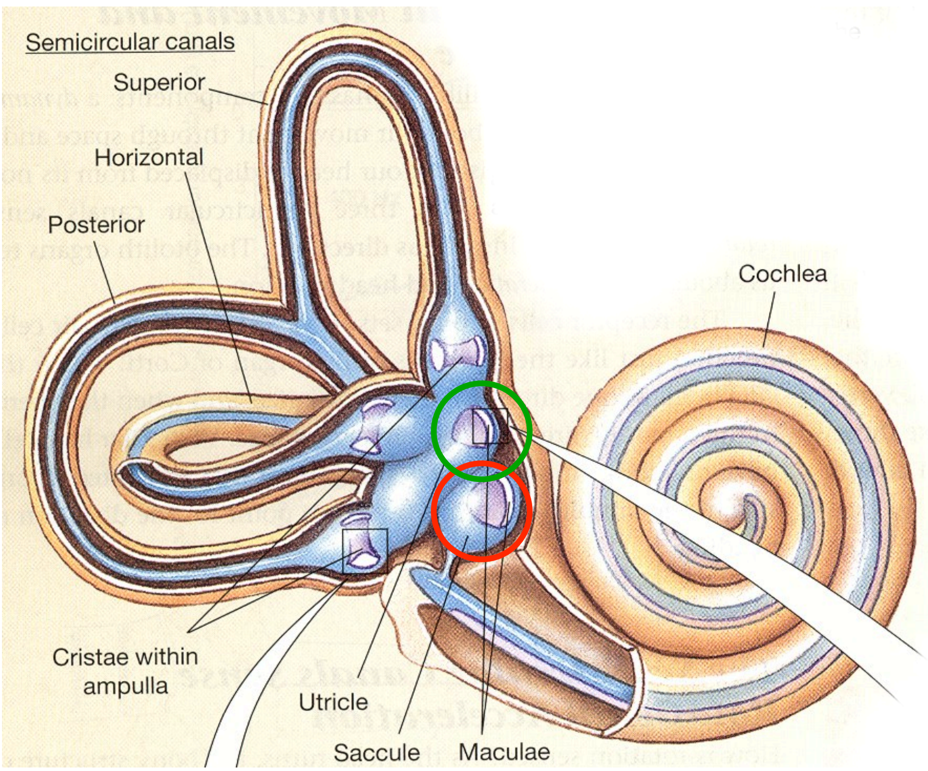
The sensory receptors for linear acceleration within the ***utricule*** and ***saccule*** are called **maculea**.

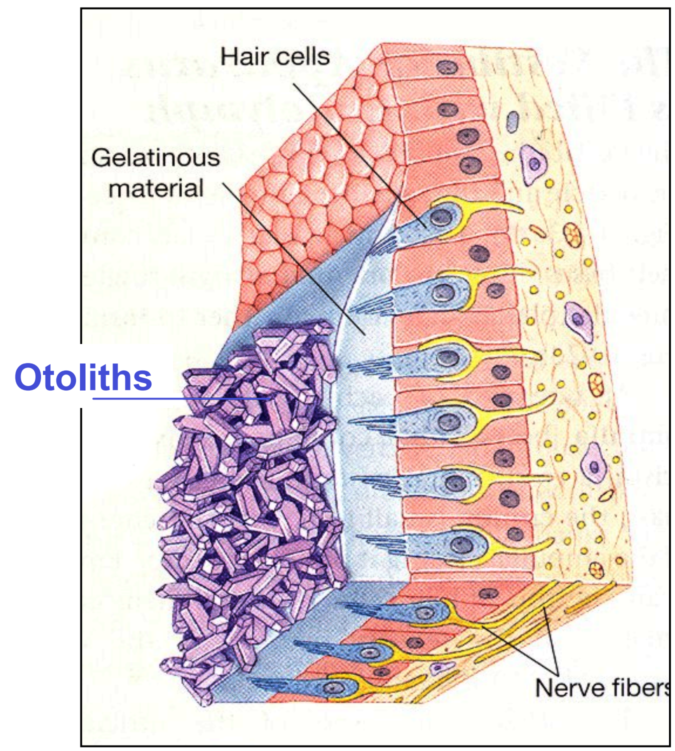




Otolith Organs

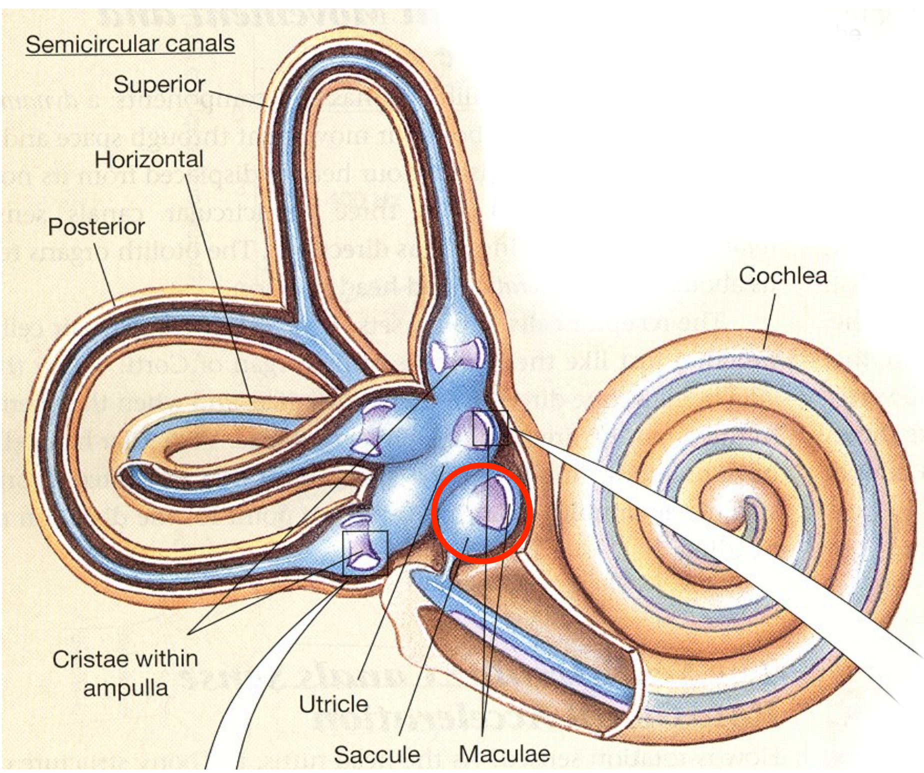
Each **macula** consist of a gelatinous mass (the **otolith membrane**), in which small crystals of calcium carbonate (**otoliths**) and the cilia of hair cell receptors are embedded.

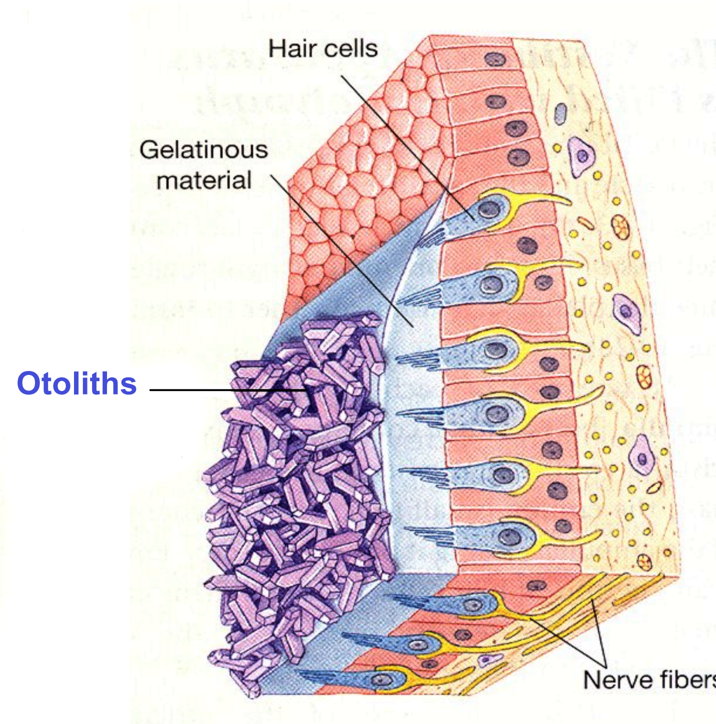




Otolith Organs

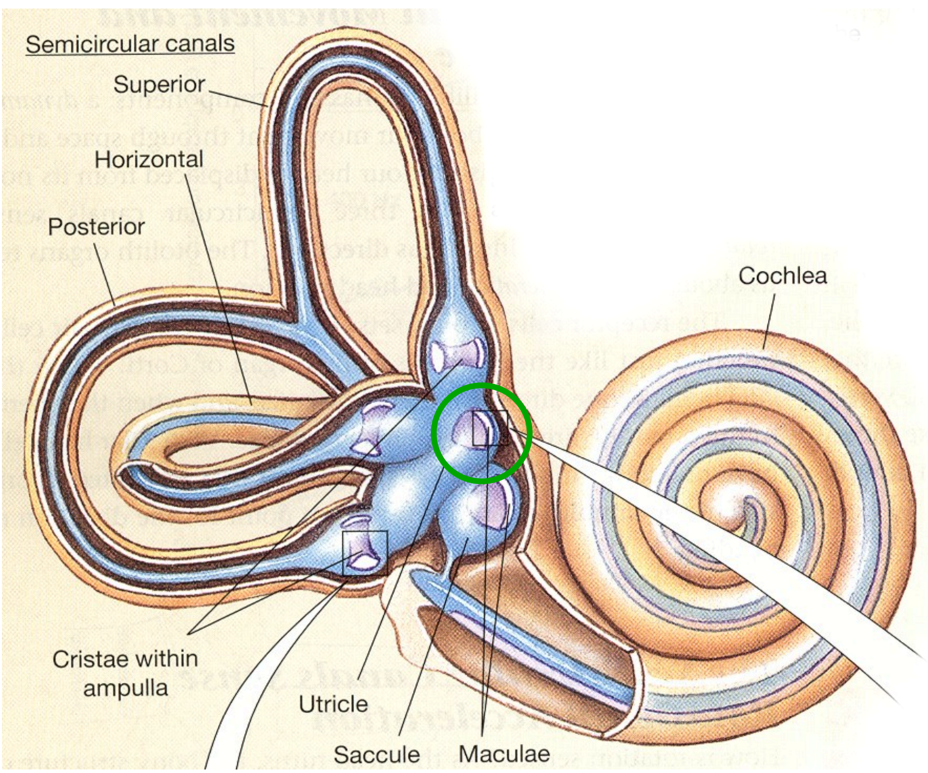
The **maculae** of the ***saccule*** are oriented vertically when the head is in its upright position.
They are <u>sensitive to vertical forces</u>.

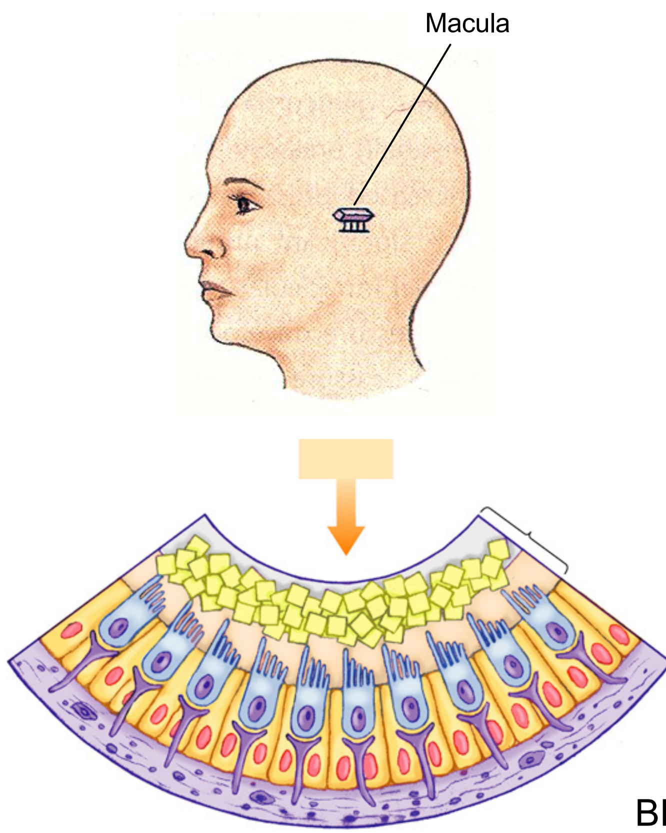




Otolith Organs

The **maculae** of the ***utricule*** are oriented horizontally when the head is in its upright position.
They are sensitive to horizontal forces.

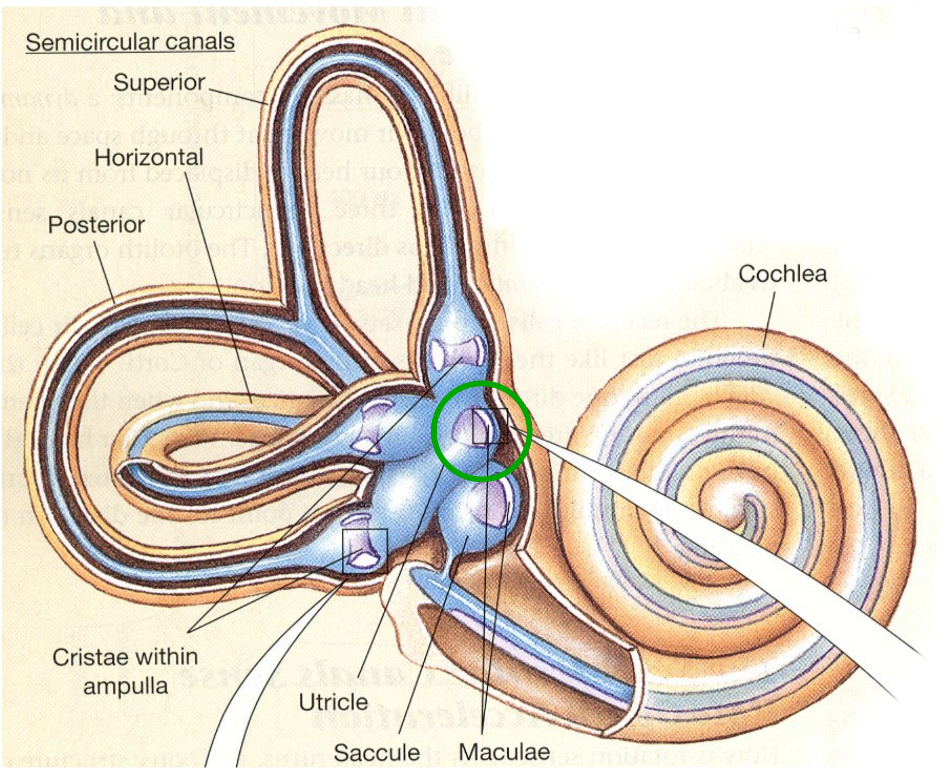


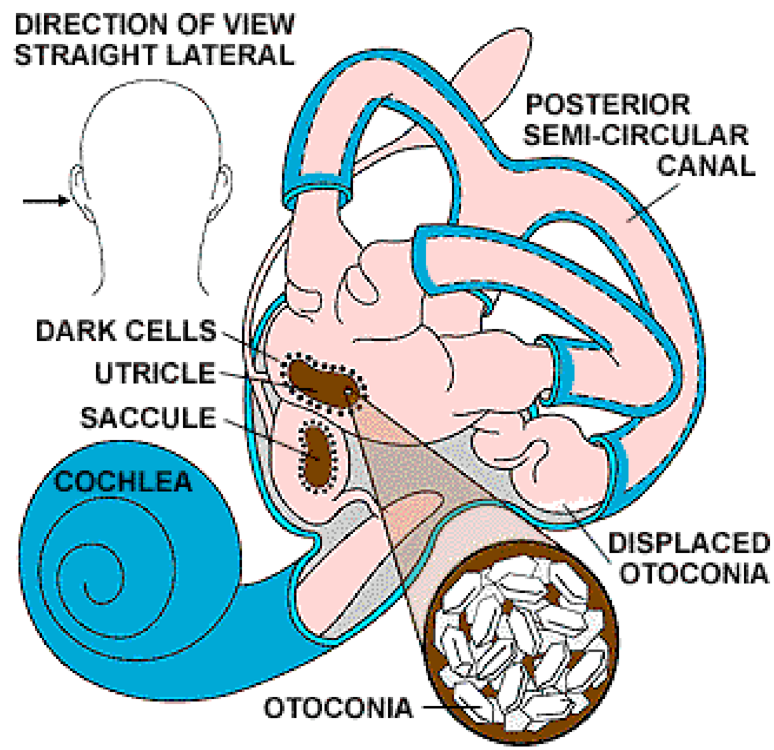


BPPV

Otolith Organs

Debris (*otoliths*) from the ***utricule*** and localized in the *semi-circular canals* can cause a severe vertigo symptom called **Benign Paroxymal Positional Vertigo**.





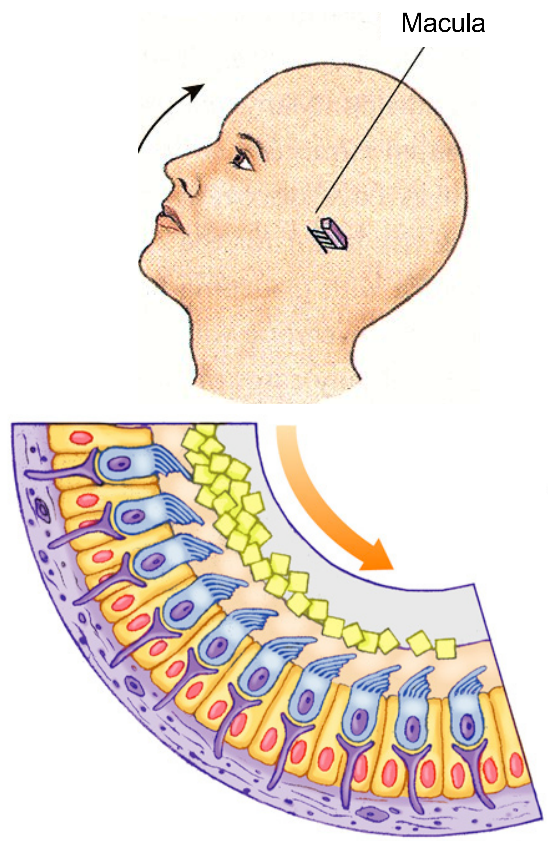
BPPV

Otolith Organs

When the head moves forward or tips back, the crystalline otoliths in the gelatinous membrane slide backward.

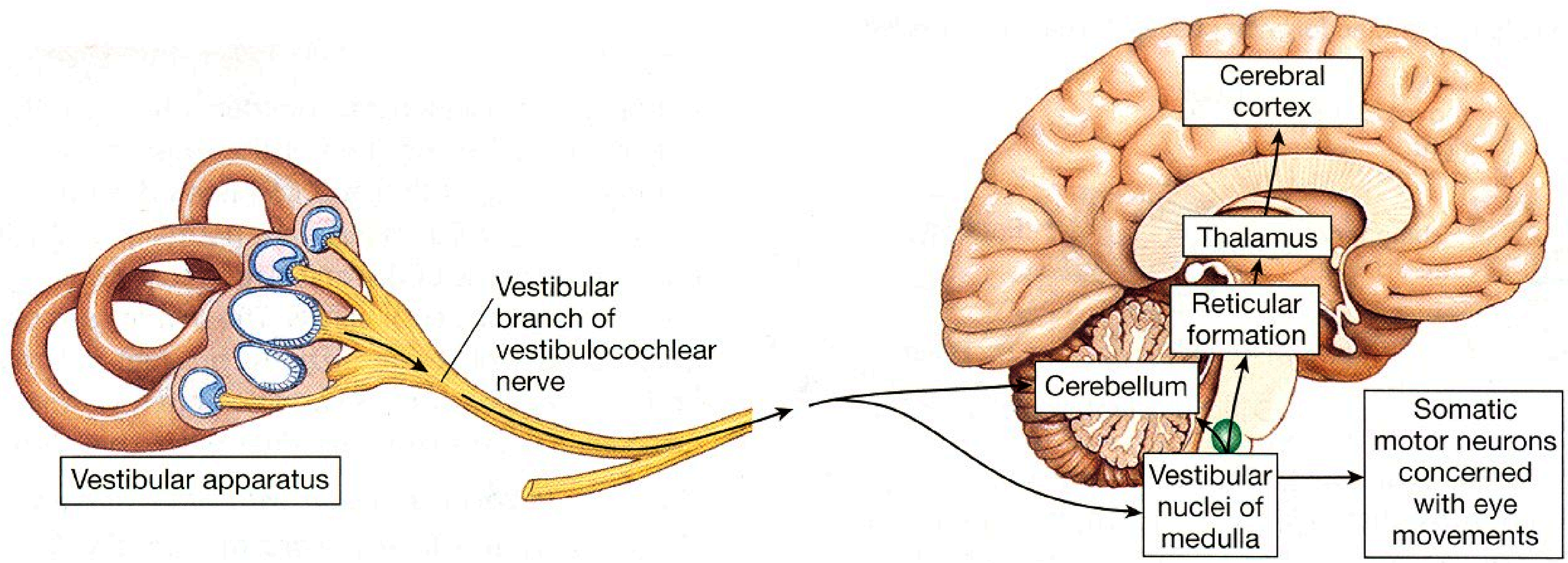
The cilia of the hair cells bend and the receptors' membranes become depolarized.

The primary sensory neurons increase their firing rates.



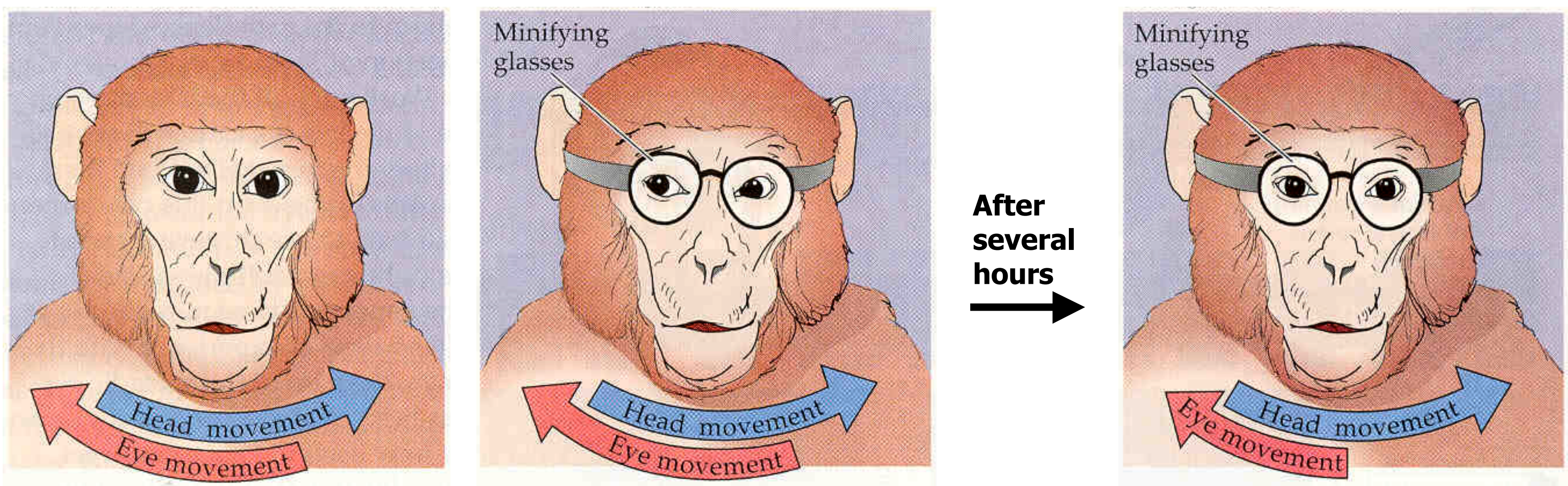
Equilibrium Pathway

Neural signals from the vestibular apparatus travel along the vestibulocochlear nerve and are transmitted to the vestibular nuclei in the brain stem and the cerebellum, where they are combined with proprioceptive inputs.



Equilibrium Pathway

Pathways from the vestibular nuclei provide signals that are important to move our eyes in their orbits while we move, so that images of the world are stabilized on our retina.



Head and eyes move in a coordinated manner to keep image on retina

Eyes move too far in relation to image movement on the retina when the head moves

Eyes move smaller distances in relation to head movement to compensate