PHGY 212 - Physiology

SENSORY PHYSIOLOGY

Hearing & Equilibrium

Martin Paré

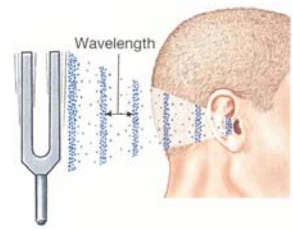
Assistant Professor of Physiology & Psychology

pare@biomed.queensu.ca

http://brain.phgy.queensu.ca/pare

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.



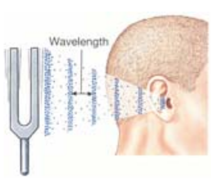
sound waves

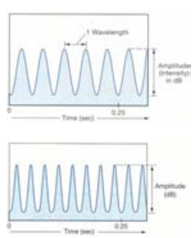
Sound Principles

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*).

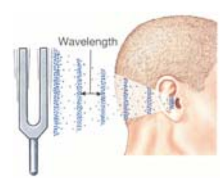
The range of frequencies audible to humans is 20 to 20kHz.

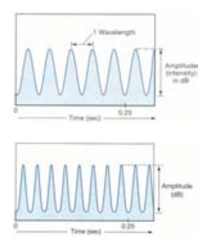




Sound Principles

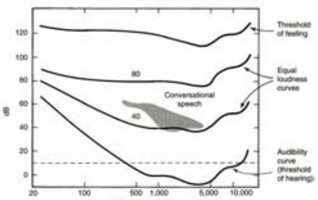
Loudness is our interpretation of sound **intensity**. It is a function of the wave amplitude, the pressure difference between waves. [measured in *decibels* (dB)]



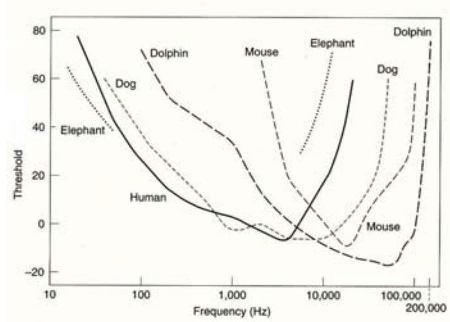


Sound Principles

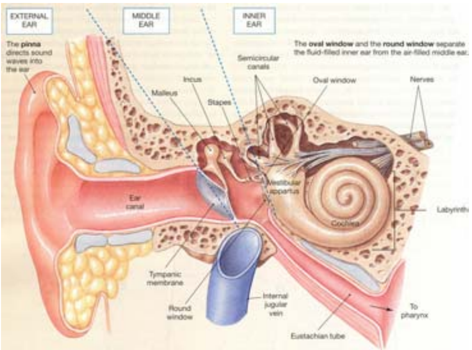
The faintest audible sound has ~0 dB loudness.
Each 10-dB increase represents a 10-fold increase in loudness.
Loudness in normal conversation is typically 60 dB.
Prolonged exposure to noise levels >100 dB can be painful and cause damage resulting in hearing loss.



Sound Principles

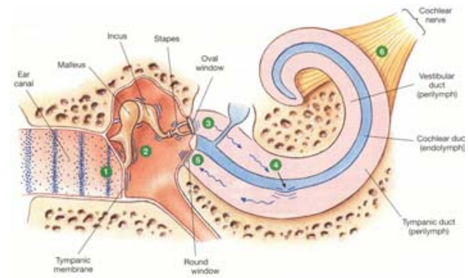


Structure of the Ear



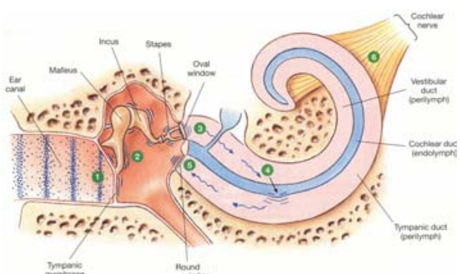
Sound Transmission through the Ear

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



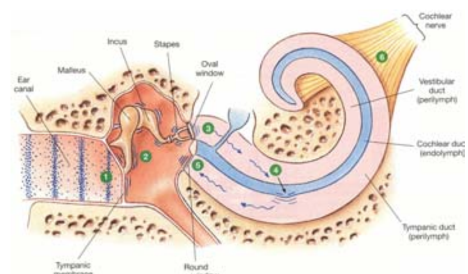
Sound Transmission through the Ear

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



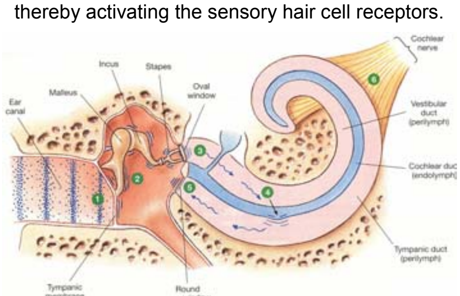
Sound Transmission through the Ear

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



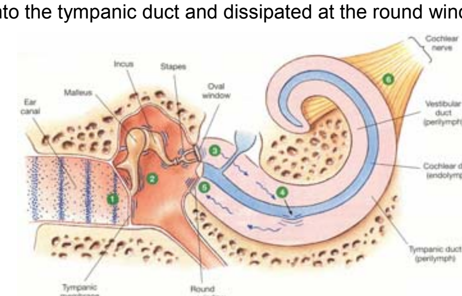
Sound Transmission through the Ear

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



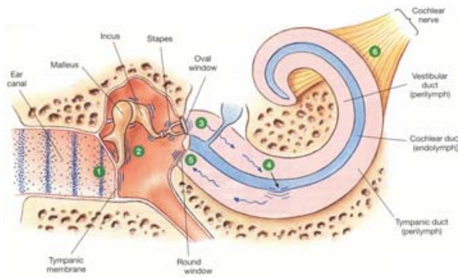
Sound Transmission through the Ear

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.

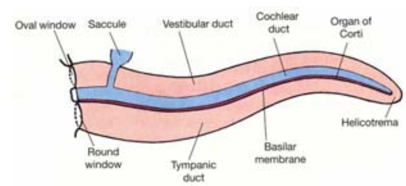


Cochlea

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^+).

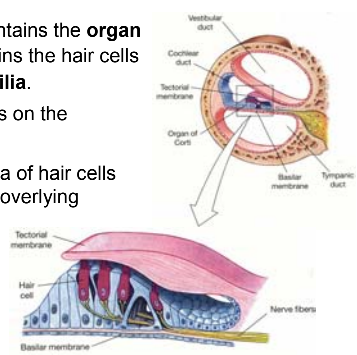


Cochlea

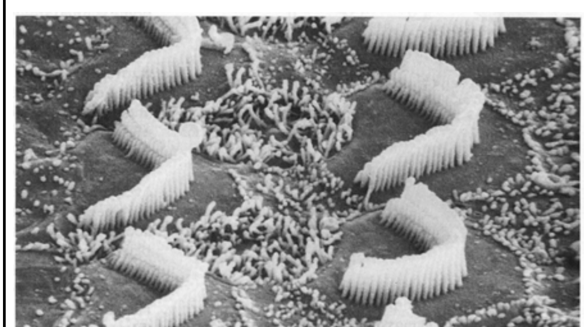
The cochlear duct contains the **organ of Corti**, which contains the hair cells covered with **stereocilia**.

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

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

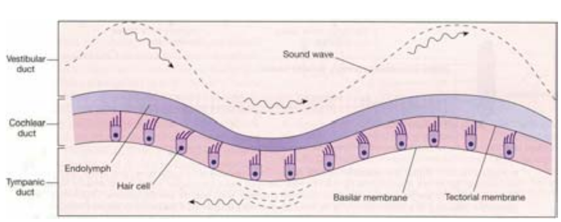


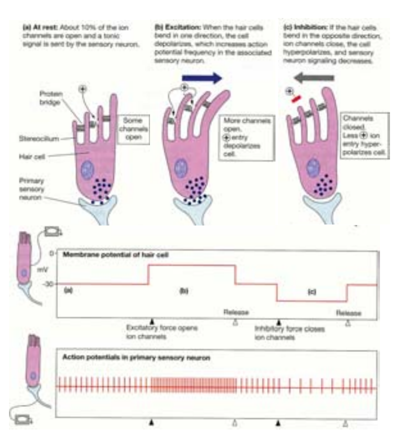
Cochlea



Cochlea

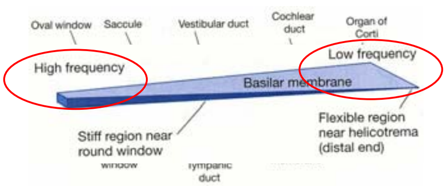
Deformation of the cochlear duct by sound waves causes the tectorial membrane covering the organ of Corti to move. This motion bends stereocilia of the hair cells.





Coding Sound for Pitch

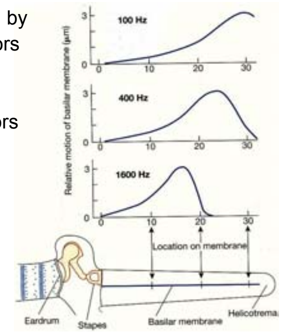
Coding sound for pitch is a function of the basilar membrane.
High frequency waves create maximum displacement of the basilar membrane near the *oval window*.
Low frequency waves travel along the length of the membrane and create maximum displacement near the *helicotrema*.



Coding Sound for Pitch

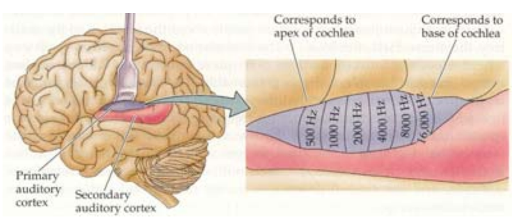
Sound pitch is coded spatially, by location of the hair cell receptors along the basilar membrane.

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



Coding Sound for Pitch

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



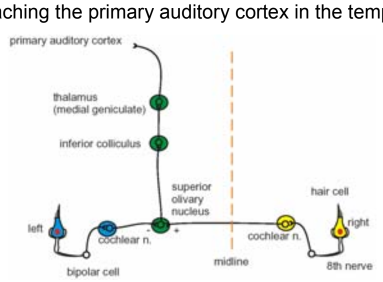
Coding Sound for Loudness

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 sensory neurons increases and more neurons are discharging.

Auditory Pathways

Signals from the two ears come together in the brain stem (superior olivary nucleus) and are then relayed to the thalamus before reaching the primary auditory cortex in the temporal lobe.



Reading

Silverthorn (2nd edition)
pages 298 - 306 (*hearing*)
pages 306 - 308 (*equilibrium*)

Silverthorn (1st edition)
pages 280 - 287
pages 287 - 289

PHGY 212 - Physiology

SENSORY PHYSIOLOGY

Hearing & Equilibrium

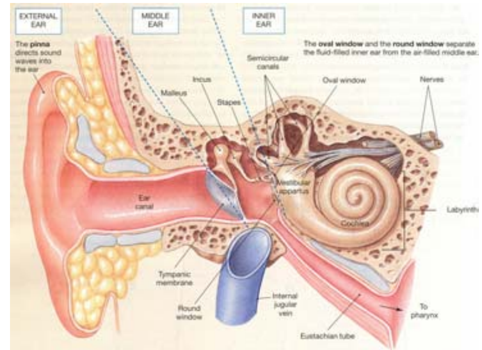
Martin Paré

Assistant Professor of Physiology & Psychology

pare@biomed.queensu.ca

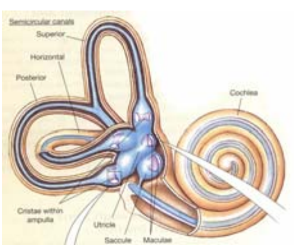
http://brain.phgy.queensu.ca/pare

Structure of the Ear



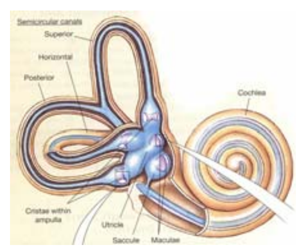
Equilibrium through the Ear

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



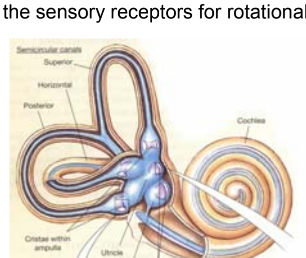
Equilibrium through the Ear

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



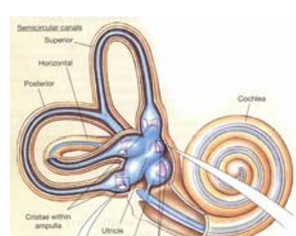
Semicircular Canals

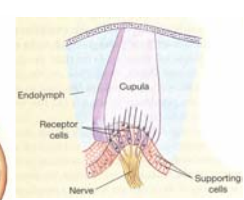
The base of each **semicircular canal** is an enlarged chamber (**ampulla**), where are located the sensory receptors for rotational acceleration: **cristae**.



Semicircular Canals

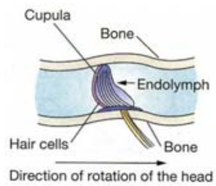
Each crista consist of a gelatinous mass (**cupula**) that, when pushed by the endolymph, bends the embedded **kinocilium** of each hair cell receptor.

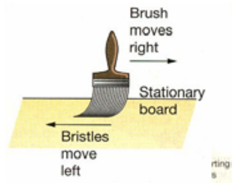




Semicircular Canals

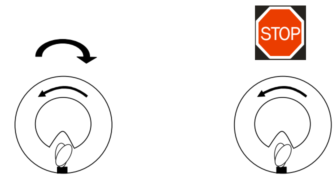
When the head starts to turn, the endolymph cannot keep up because of inertia. This drag of the endolymph bends the cupula and its hair cells in the direction opposite to the head.





Semicircular Canals

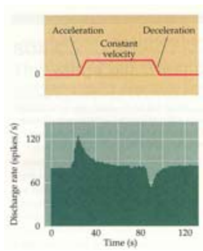
When the head stops, the endolymph keeps rotating momentarily and the cupula returns to its resting position only after a delay.



Semicircular Canals

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

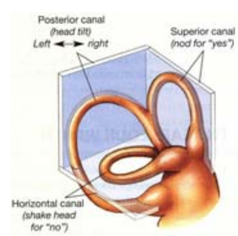
They detect changes in velocity.

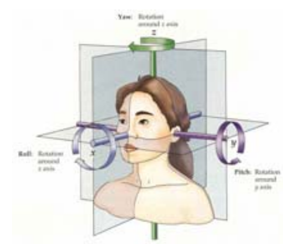


Semicircular Canals

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

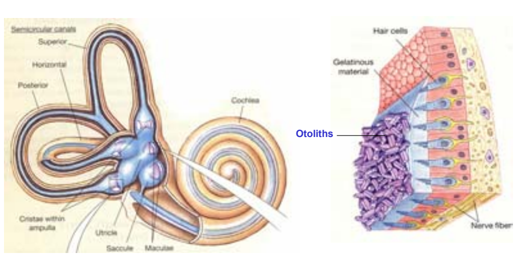
Together they can sense all **three degrees of rotation**.





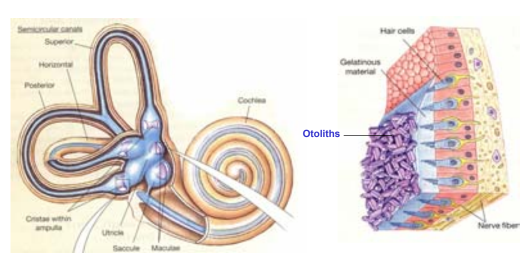
Otholith Organs

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



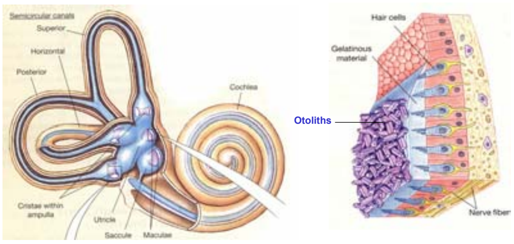
Otolith Organs

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.



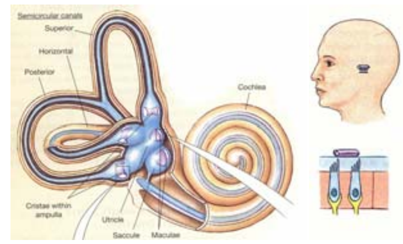
Otolith Organs

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



Otolith Organs

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

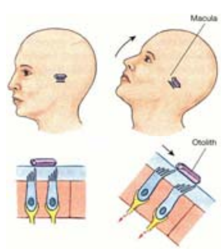


Otolith Organs

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

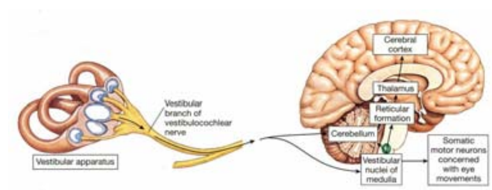
The cilia of the hair cells bend and the receptors' membranes become depolarized.

The sensory neurons increase their firing rates.



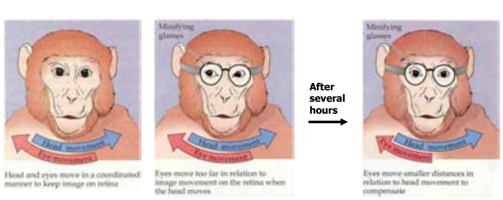
Equilibrium Pathway

Neural signals from the vestibular apparatus travel along the vestibulocochlear nerve and are transmitted to the cerebellum and the brain stem vestibular nuclei, 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.



Reading

Silverthorn (2nd edition)
- pages 298 - 306 (*hearing*)
- pages 306 - 308 (*equilibrium*)

Silverthorn (1st edition)
- pages 280 - 287
- pages 287 - 289