PHSL2101 - PHSL2121 – PHSL2501 **Dr Richard Vickery**

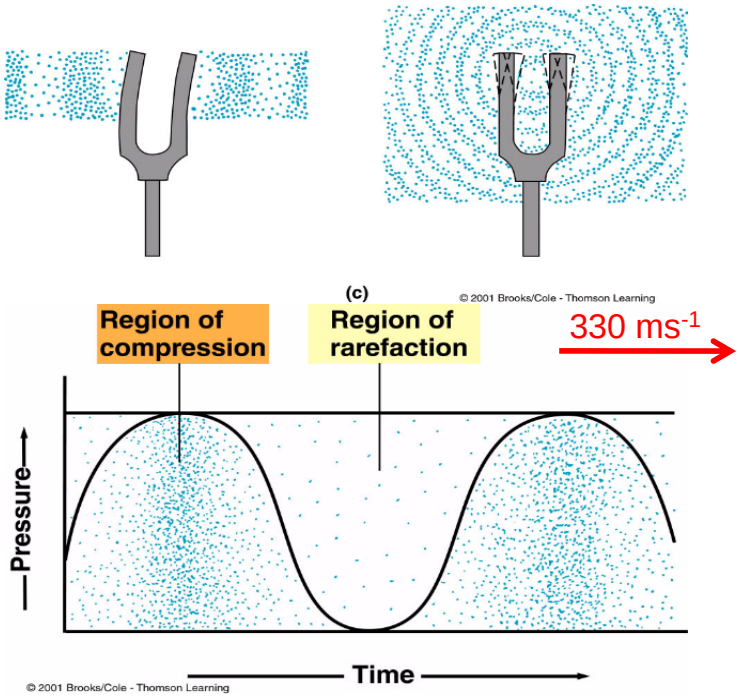
Neurophysiology 3 – Auditory and vestibular system

Objectives

- Describe the structure and function of the outer, middle and inner ear.
- Explain how mechanical energy is transduced into a neural signal by the cochlear hair cells.
- Explain the cochlear place code for pitch.
- Explain how the semi-circular canals and the otolith organs both use hair cells to transduce different mechanical signals.

Properties of sound

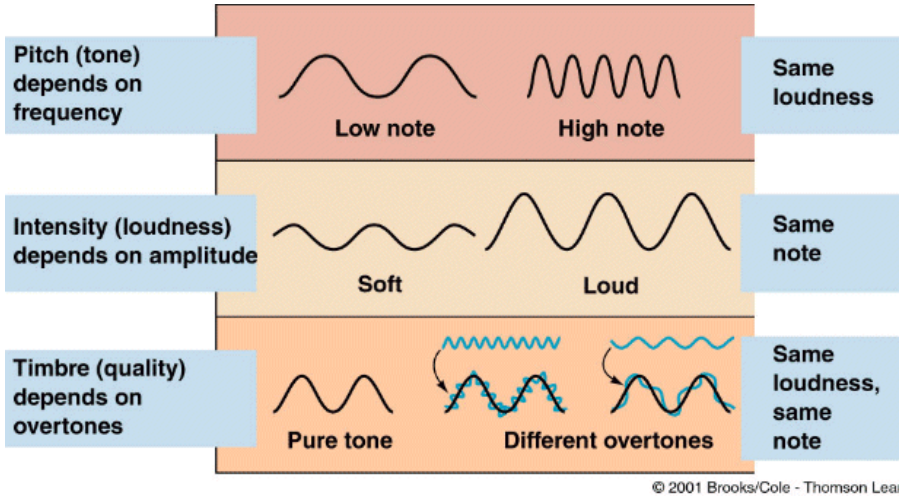
Sound is a wave of mechanical disturbance



from Sherwood, Human Physiology

Properties of sound

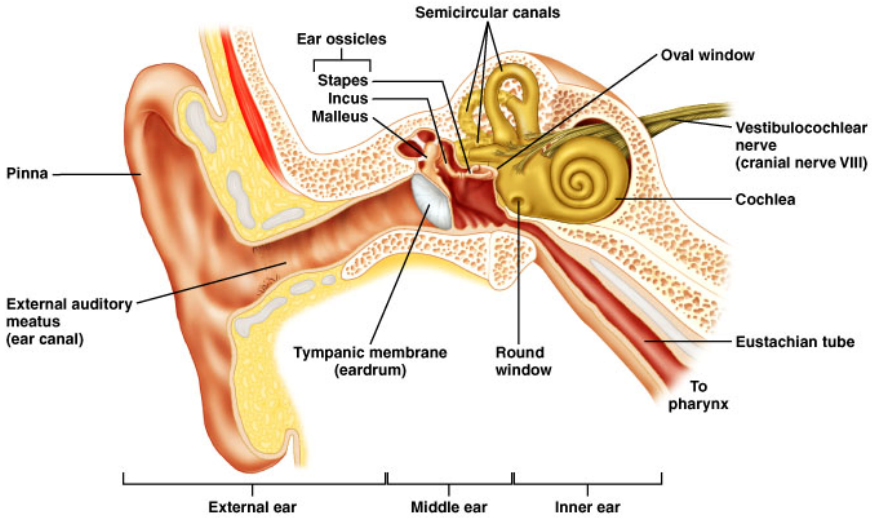
Sound has several qualities that relate to physical characteristics of the wave



from Sherwood, Human Physiology

Structure of the ear

Structure of the ear

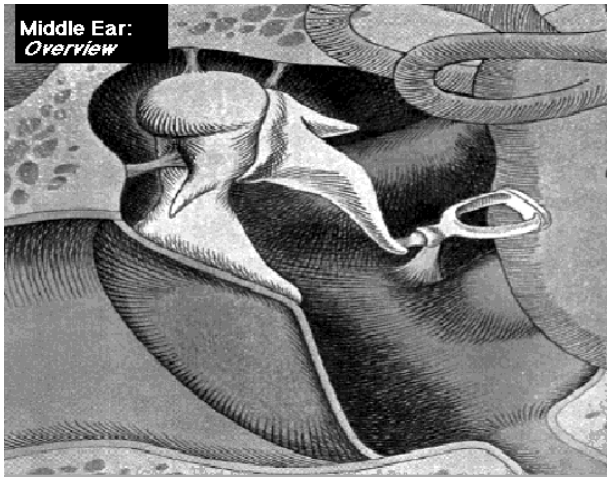


Pinna modifies incoming sounds, by creating reflections of different intensities and delays, which helps in localising the sound source.
Auditory canal allows sound waves to reach the tympanic membrane.

from Stanfield & Germann, Principles of Human Physiology

Structure of the ear

Middle ear is for impedance matching - allows sound waves in air to move water molecules



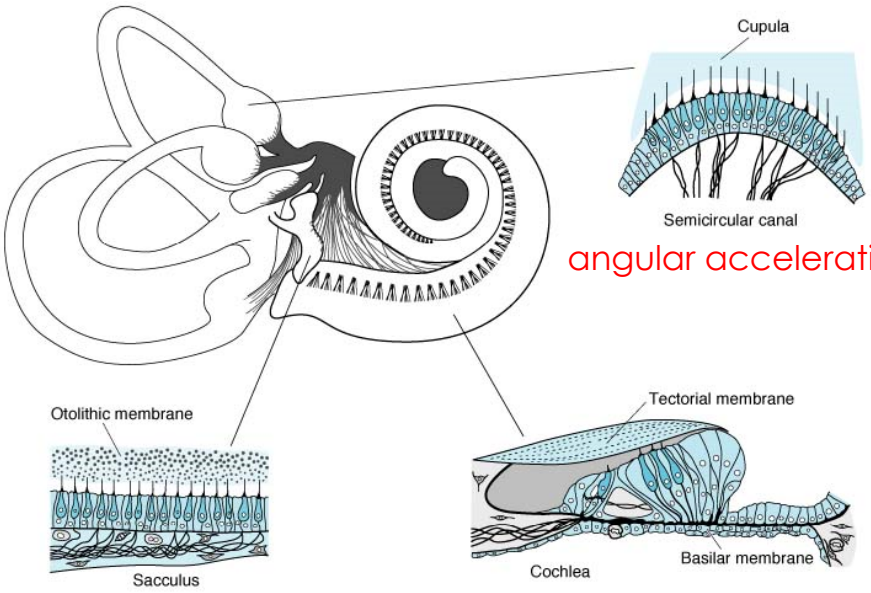
Normally 97% of energy is lost at an air/water interface.

Impedance matching allows 75% of energy to be transmitted.

This is due to a piston effect (x 17) from tympanic membrane to oval window;
and a lever effect (x 1.3) from ossicles

Structure of the ear

Labyrinth (inner ear) contains 3 types of hair cell each transducing a different stimulus



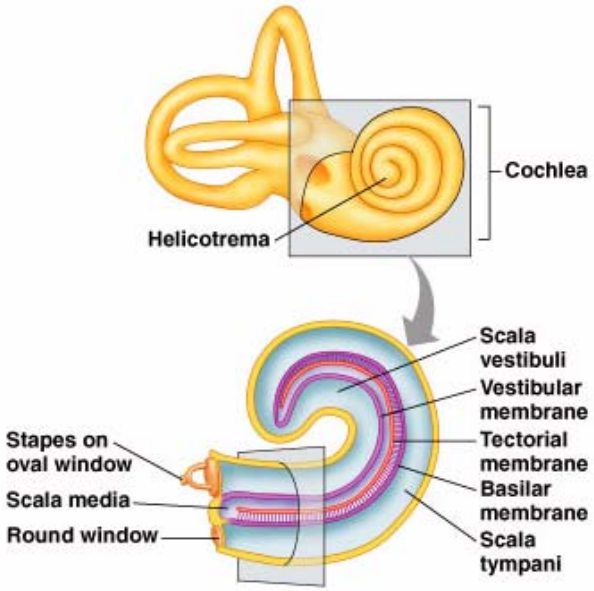
angular acceleration

linear acceleration

sound waves

Transduction of sound

Cochlea is a long coil made of three chambers. The stapes pushes on scala vestibuli.



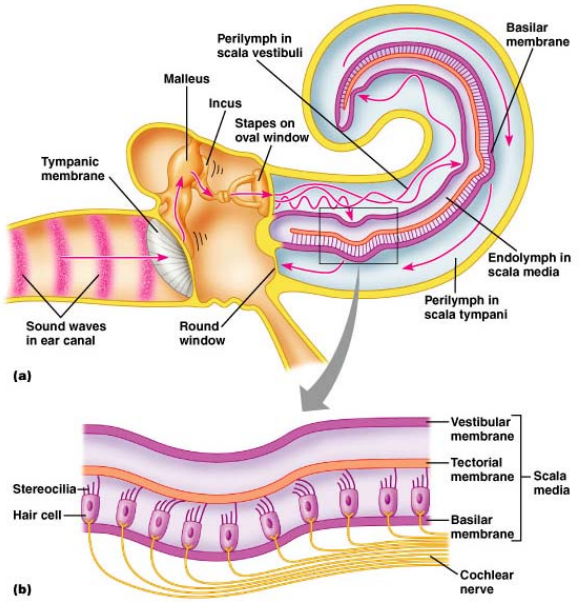
The cochlea is the hearing part of the inner ear, the other segments relate to balance: the vestibular sense.

The pushing of the stapes creates mechanical pressure pulses inside the cochlea.

from Stanfield & Germann, Principles of Human Physiology

Transduction of sound

Stapes sets up fluid standing waves, that ultimately cause the round window to bulge

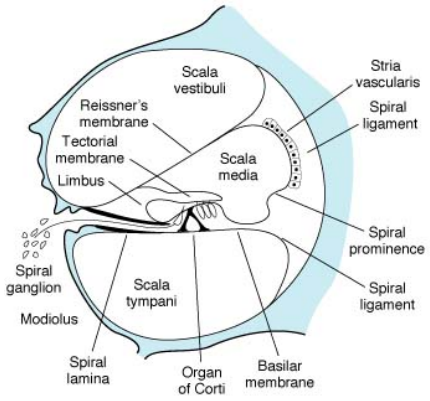


Standing waves are mechanical disturbances that propagate along the basilar membrane. The basilar membrane stiffness (and hence its resonance) varies along its length. Eventually the energy passes through the membrane to scala tympani and finally causes deflection of the round window.

from Stanfield & Germann, Principles of Human Physiology

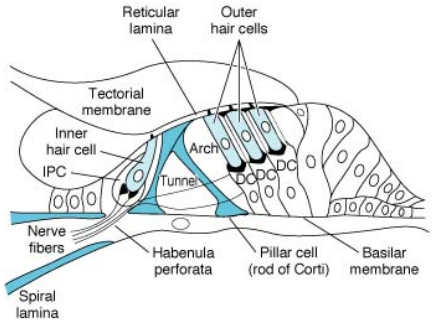
Transduction of sound

Cross-section of cochlea



Scala vestibuli and *scala tympani* are filled with perilymph.
Scala media is filled with endolymph, which gives rise to a potential of +80mV

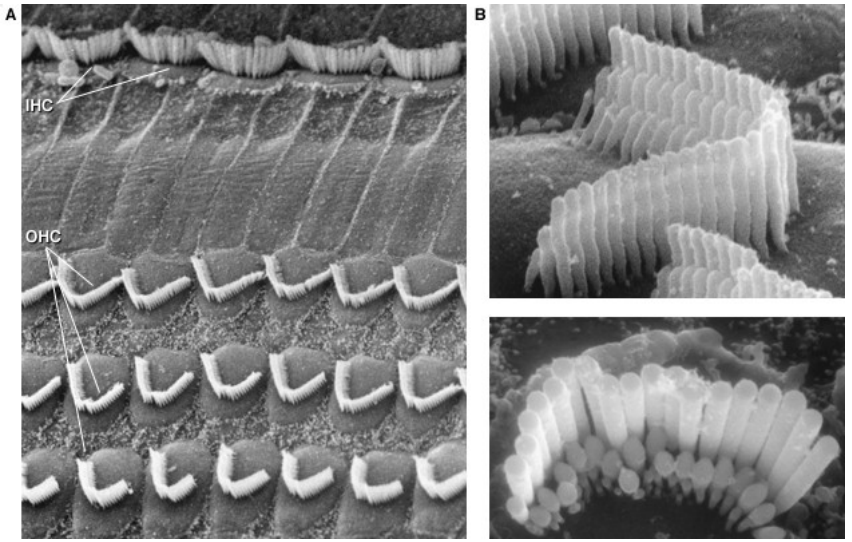
The membrane potential is then about -150mV, and this big driving force assists ion movement during the brief channel openings.



Organ of Corti

Transduction of sound

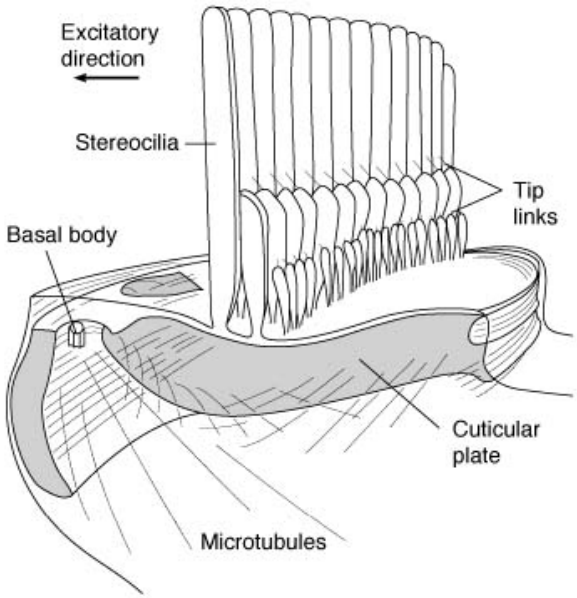
The organ of Corti has 3 outer hair cells (OHC) per inner hair cell (IHC). OHC amplify the signal.



there are only ~4000 inner hair cells (IHC) in each cochlea

Transduction of sound

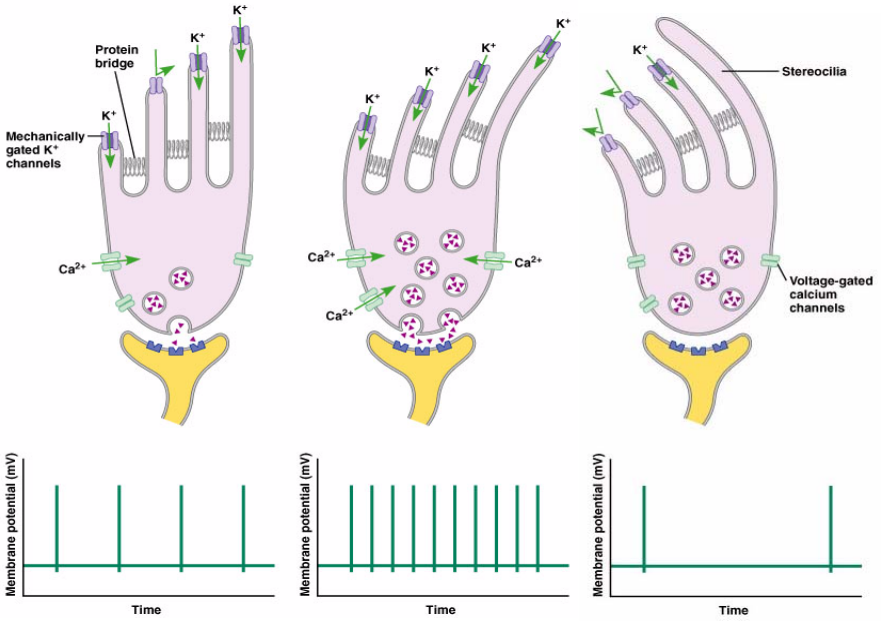
Tip links connect stereocilia, and attach to the mechano-gated channels



By attaching to the channels, the tip links serve to focus the forces from the tiny movements of the stereocilia on to the mechano-gates channels. This is one reason why the ears are so sensitive.

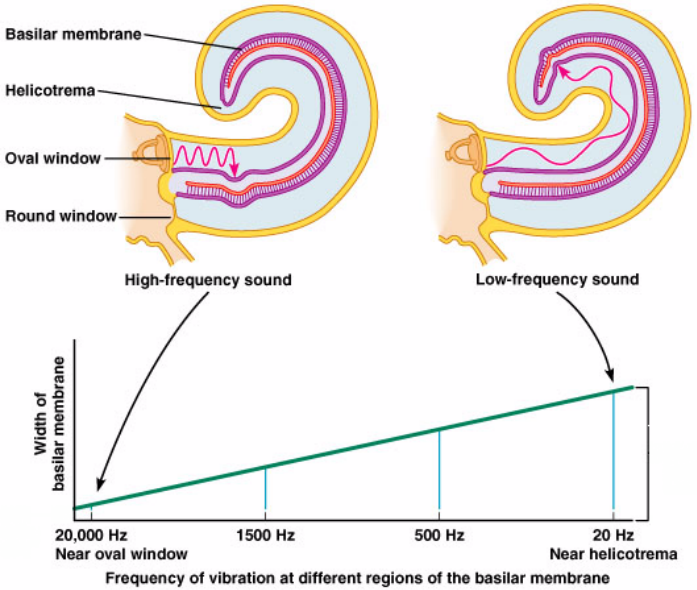
Transduction of sound

Bending of stereocilia gates mechanoceptor ion channels to increase or decrease firing rate



Coding of pitch

Pitch coding results from localised hair cell activity due to the varying resonant frequency along the basilar membrane

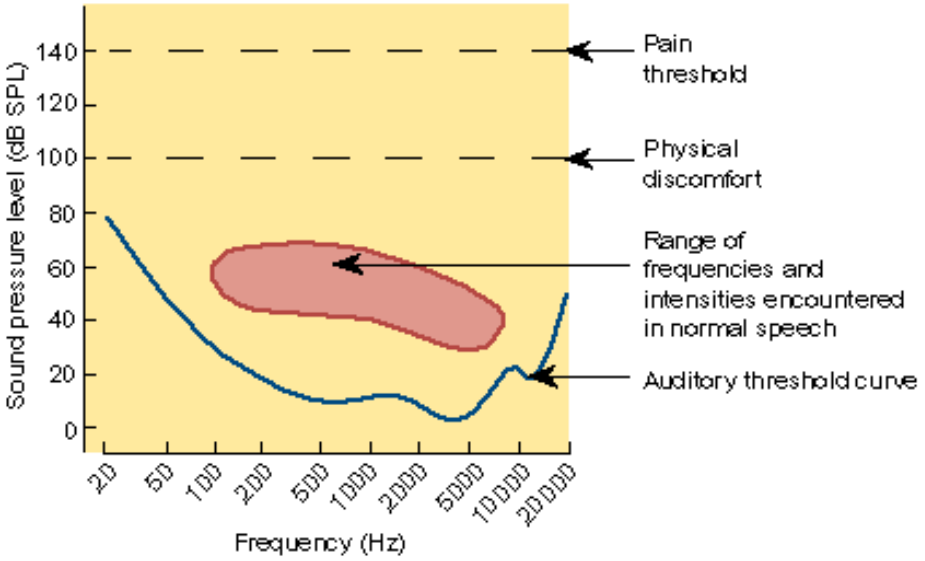


At the point where the basilar membrane resonance matches the travelling wave frequency, the membrane movement is maximal and so strongly activates the hair cells.

from Pocock & Richards, Human Physiology

Coding of pitch

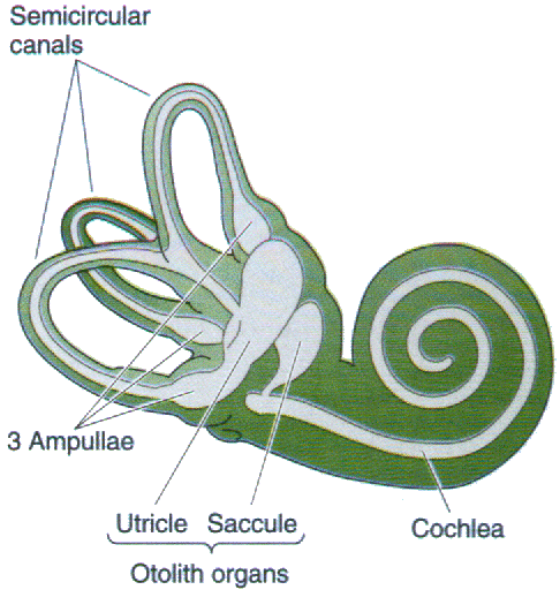
Relationship of frequency and apparent loudness



from Pocock & Richards, Human Physiology

Vestibular system

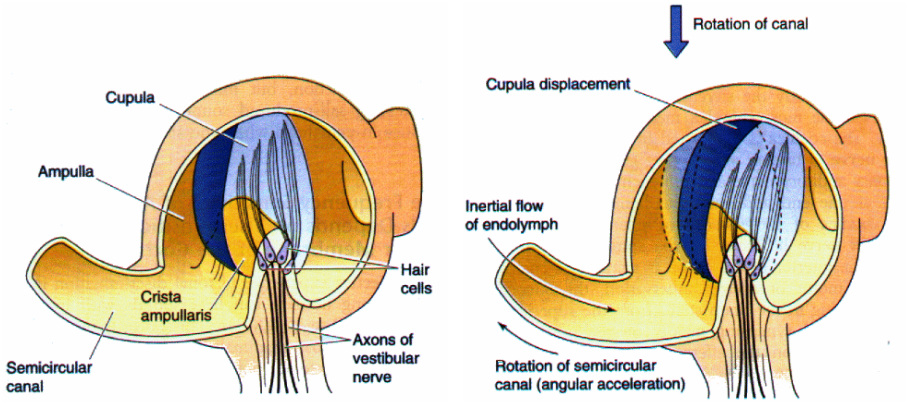
Labyrinth is filled with endolymph shared between cochlea and vestibular organs



from Boron and Boulpaep, Medical Physiology

Vestibular system

Operation of hair cells in semi-circular canals due to inertial flow of endolymph

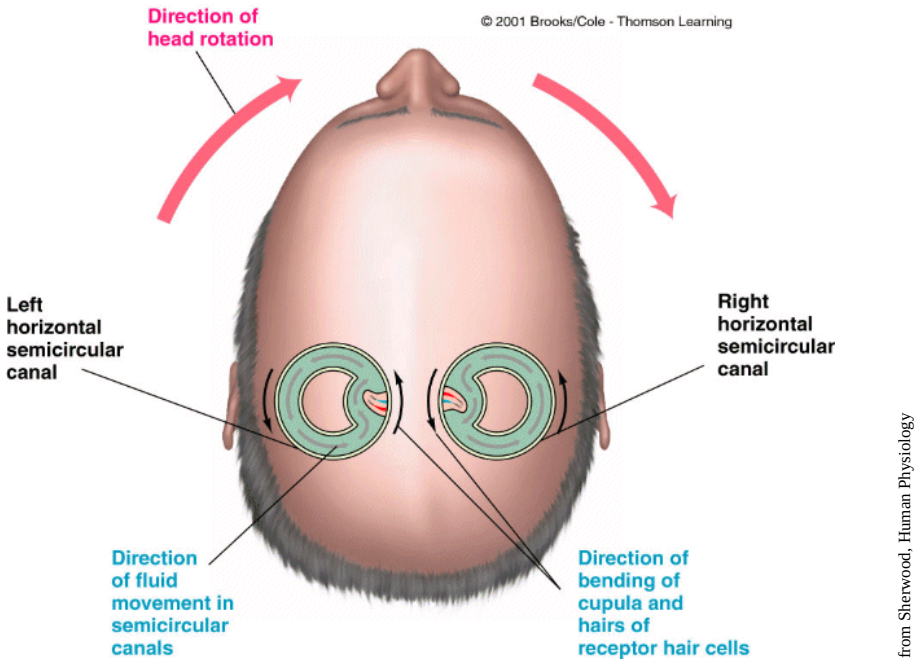


In the semi-circular canals the hair cells are activated by rotation, which causes deflection of stereocilia due to the inertia of the endolymph.

from Boron and Boulpaep, Medical Physiology

Vestibular system

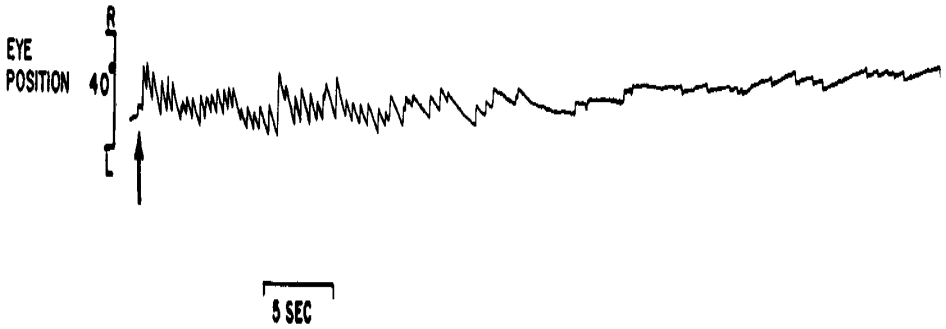
Head rotation & endolymph movement



from Sherwood, Human Physiology

Vestibular system

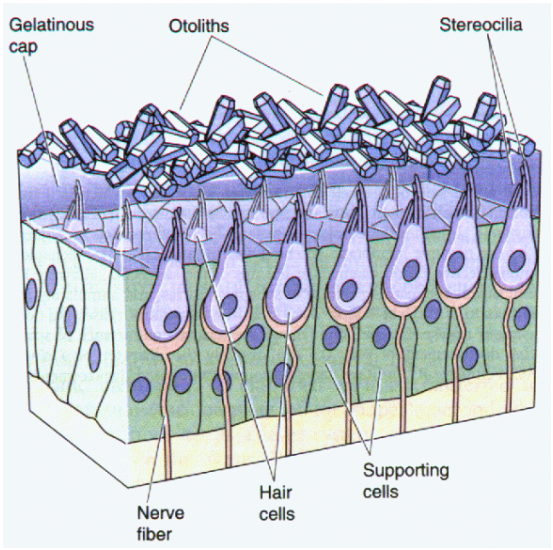
Eye movements are driven by the semi-circular canals and show adaptation over ~30s



The vertical axis plots horizontal eye position during sustained rotation in the dark. The sharp initial saw tooth waveforms are eye movements (called a rotatory nystagmus) with the slower phase matching the velocity of head rotation.

Vestibular system

Otolith organs: utricle & saccule



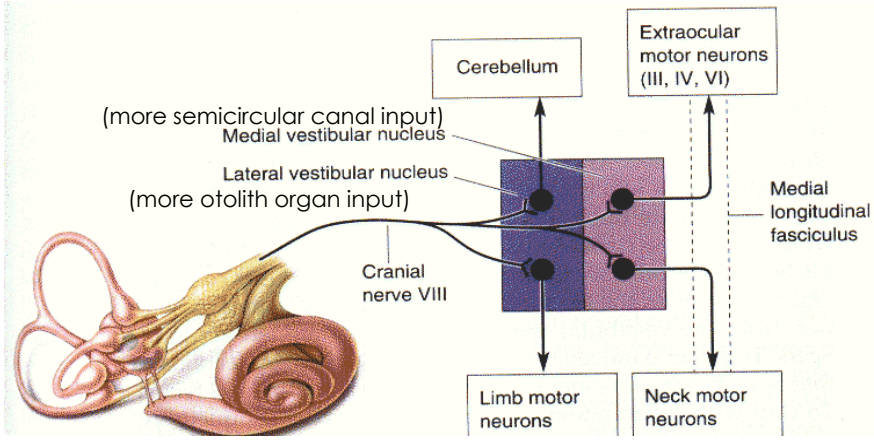
The otoliths are calcium chloride crystals, and are more dense than the endolymph. The inertia they confer makes these hair cells respond to linear acceleration from movement or from gravity.

The utricle and saccule can each signal two dimensions, and together have coverage of all three dimensions.

from Boron and Boulpaep, Medical Physiology

Vestibular system

Brainstem vestibular pathways



The vestibular system has a dedicated nucleus in the brainstem. From here the signals are used for control of posture and eye movements.

from Bear, Connors & Paradiso, Neuroscience: exploring the brain