Hearing

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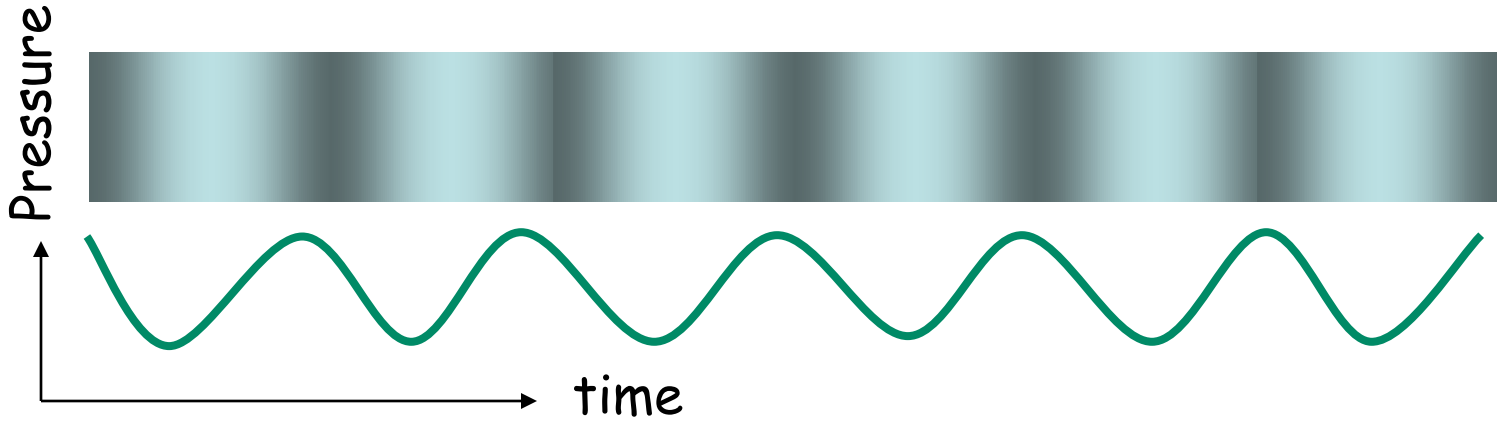
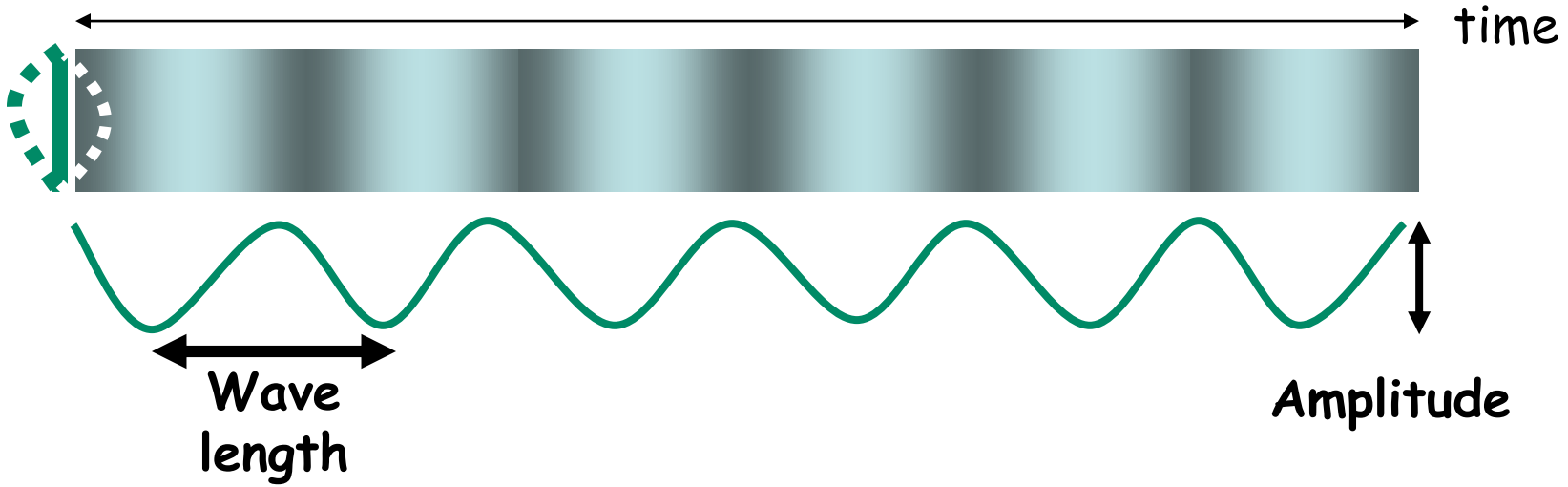
What is sound?

- Vibration of an object causes its surrounding medium (e.g. air, water) to vibrate
- This causes alternating compressions (with a rise in pressure) and expansions (fall in pressure) resulting in sound
- The speed of sound changes
  - Lower in air but faster in water



Qualities of sound waves

- **Amplitude**- the size (height: magnitude of displacement) of a sound wave: Loudness
  - Measured using a logarithmic scale
  - Unit decibel (dB)
- **Frequency** (waves /sec)- pitch of a sound
  - Number of compressions/ expansions /sec
  - Measured in Hertz (Hz)
  - **Human hearing 20 – 20,000 Hz**

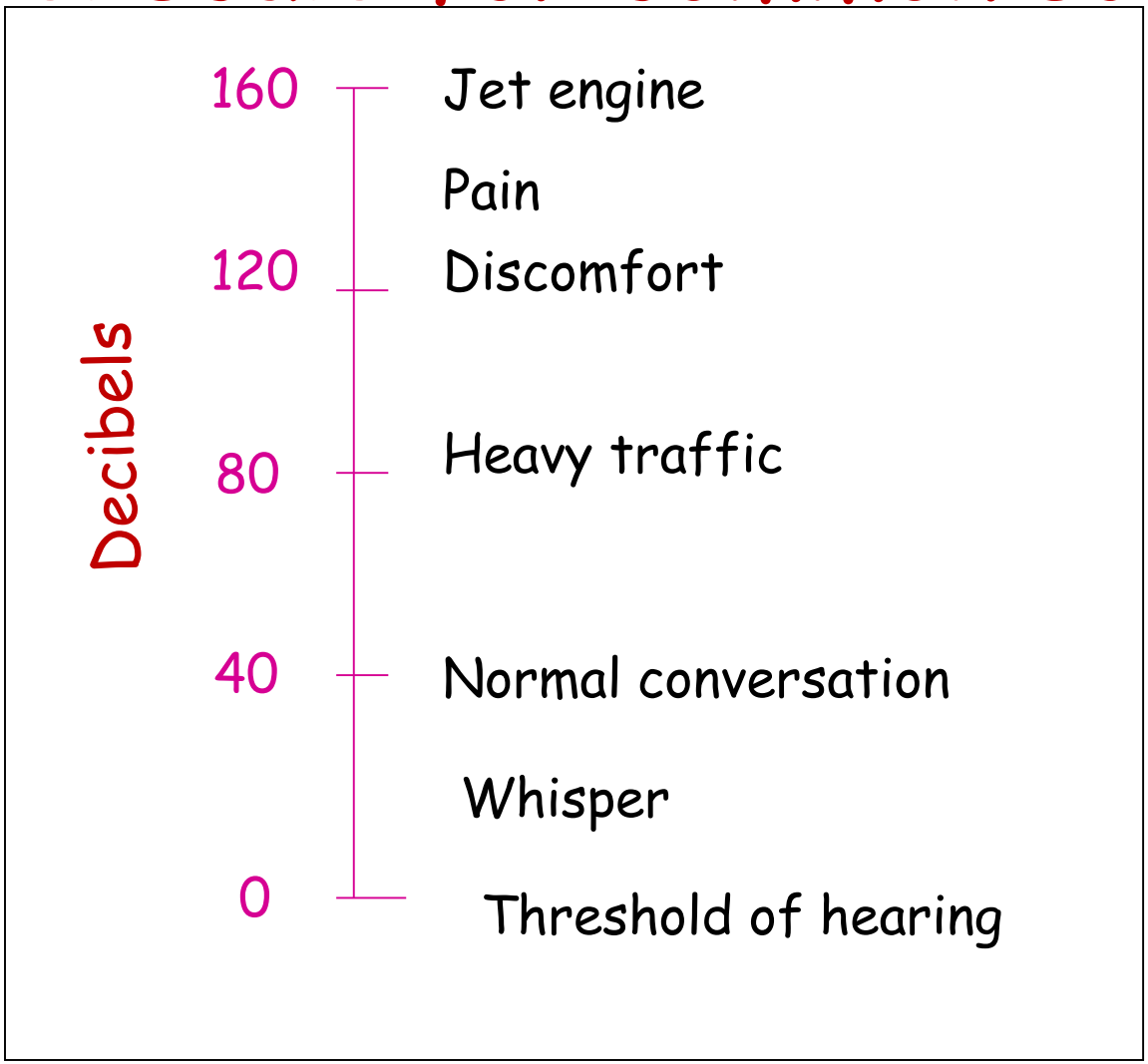


Decibel scale: loudness of sounds

- Measure of sound intensity (loudness) using a logarithmic scale
  - Measures intensity in reference to a standard sound (Sound pressure = 2x log sound/standard sound)
  - From 0 to 140 dB is a 10^7 increase in sound pressure

- 0 dB is threshold for hearing
  - x 100 of threshold sound pressure would be 40dB
  - 140dB is a potentially damaging sound to the hearing apparatus

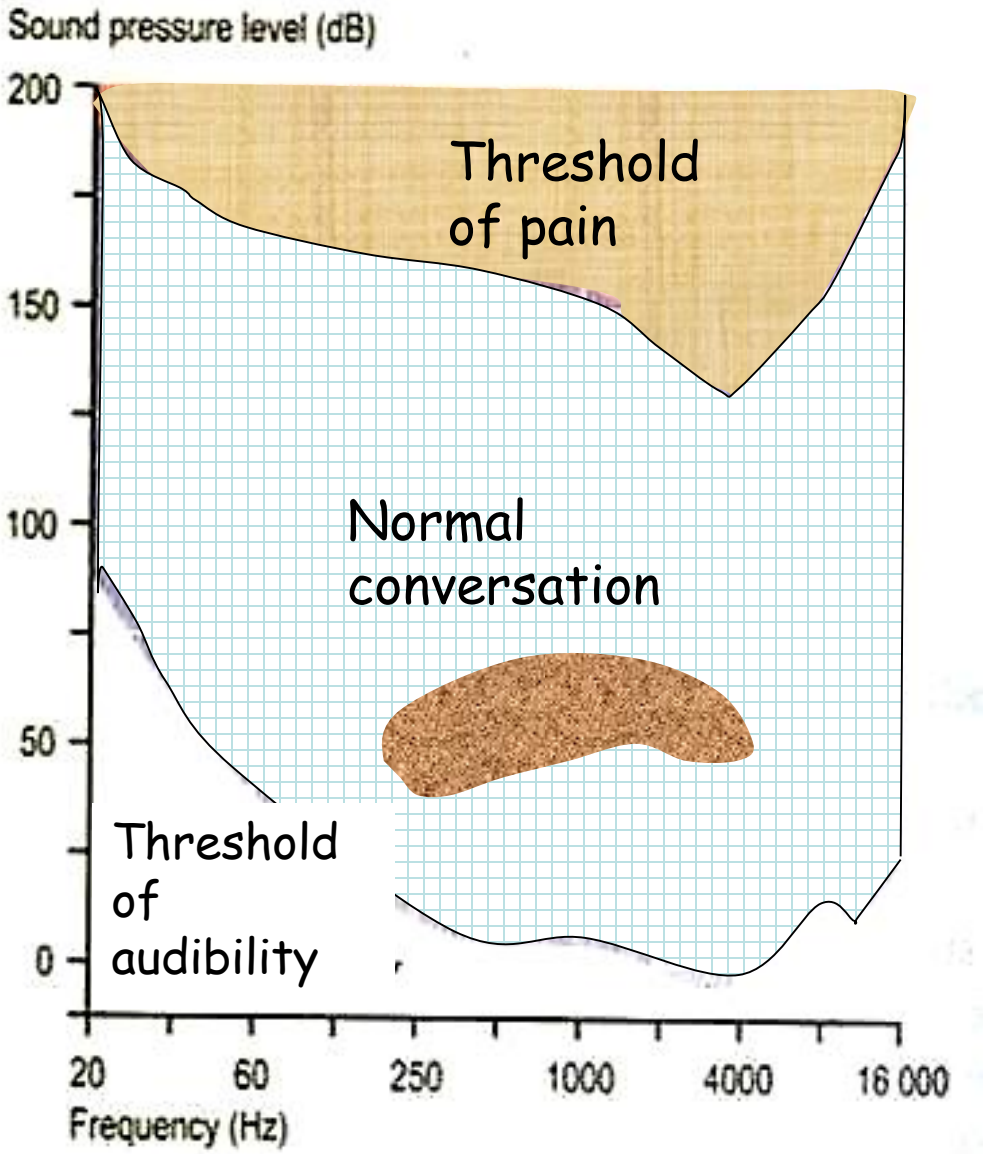
Decibel scale for common sounds



- Threshold for hearing varies with the pitch of sounds
  - Sounds that are low frequency or high frequency need to be louder before they can be heard

- Human hearing sensitivity 1000-4000Hz
  - At these frequencies sound of 0dB can be detected in ideal conditions

Threshold for hearing



- Normal speech around 65dB
- Best hearing 1000-4000 Hz
  - Higher and lower frequencies need to be louder
- Sound more than 100dB damaging to hearing

Masking

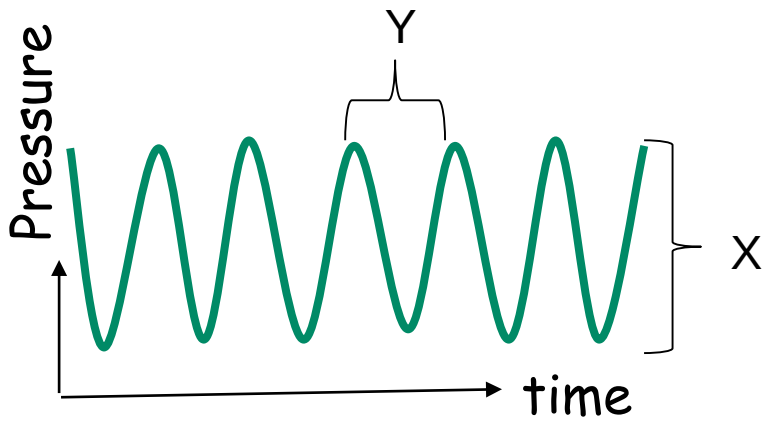
- Presence of one sounds reduces the ability to hear a second sound
  - ? Related to the refractoriness of receptors and afferent fibres
- Raises the auditory threshold

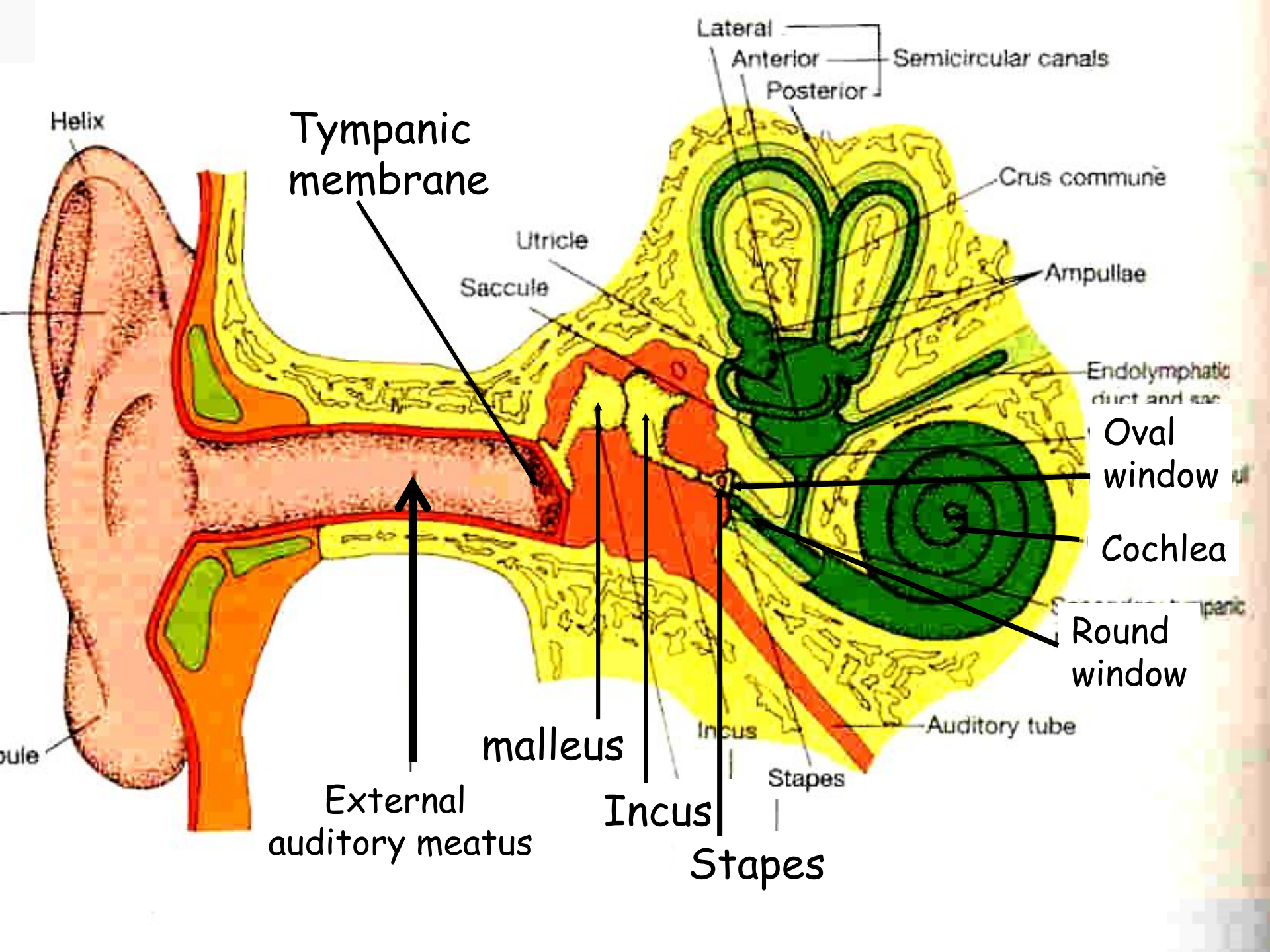
True or false?

1. Sounds waves are produced by the vibration of air.
2. Increased pressure causes compression of sounds waves.
3. The amplitude of a sound wave indicates its loudness.
4. A sound of 2000Hz heard at 0dB is not heard by a person with normal hearing.
5. The auditory threshold for a sound of 15,000Hz is higher than a sound of 3000Hz

The following diagram is of a sound wave of 3000Hz. Which of the following statements regarding this sound wave is correct?

1. At 10dB, it is x10 the intensity of the sound at 0dB.
2. The value of 'X' is recorded in Hz.
3. A sound that is twice 'Y' is of a higher frequency than this sound.
4. Increasing the size of 'X' will increase the loudness.
5. This sound has a higher threshold compared to a sound of 300Hz.




Lateral
Anterior
Posterior
Semicircular canals
Helix
Tympanic membrane
Crus commune
Utricle
Ampullae
Saccule
Endolymphatic
Oval window
Cochlea
Round window
malleus
Incus
Auditory tube
Stapes
External auditory meatus
Incus
Stapes

External ear

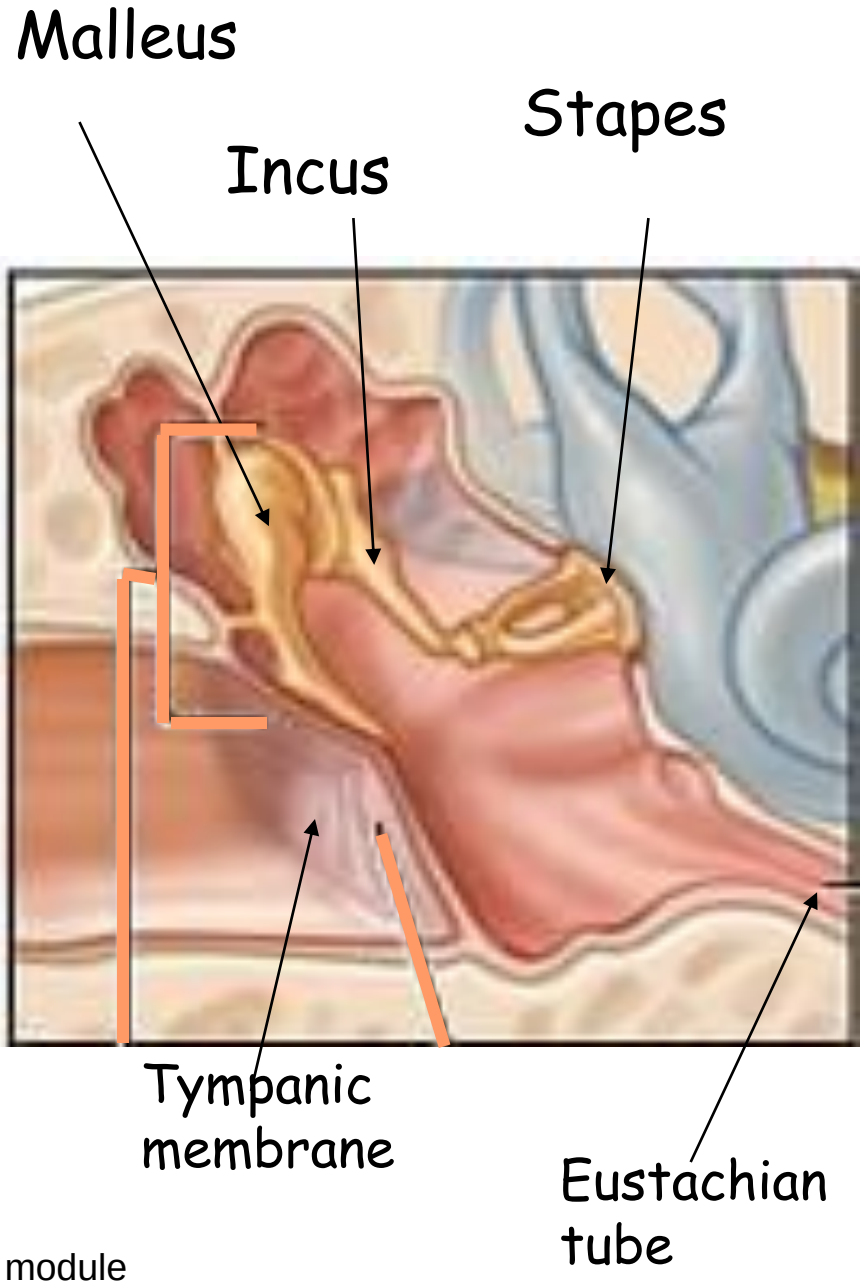
- auricle
- external auditory canal

Function: direct sound waves into middle ear

Middle Ear

- Air filled cavity within the temporal bone
  - Tympanic membrane
  - auditory ossicles (malleus, incus & stapes)

Function- amplifies sound pressure transmitted from air filled middle ear to fluid filled inner ear



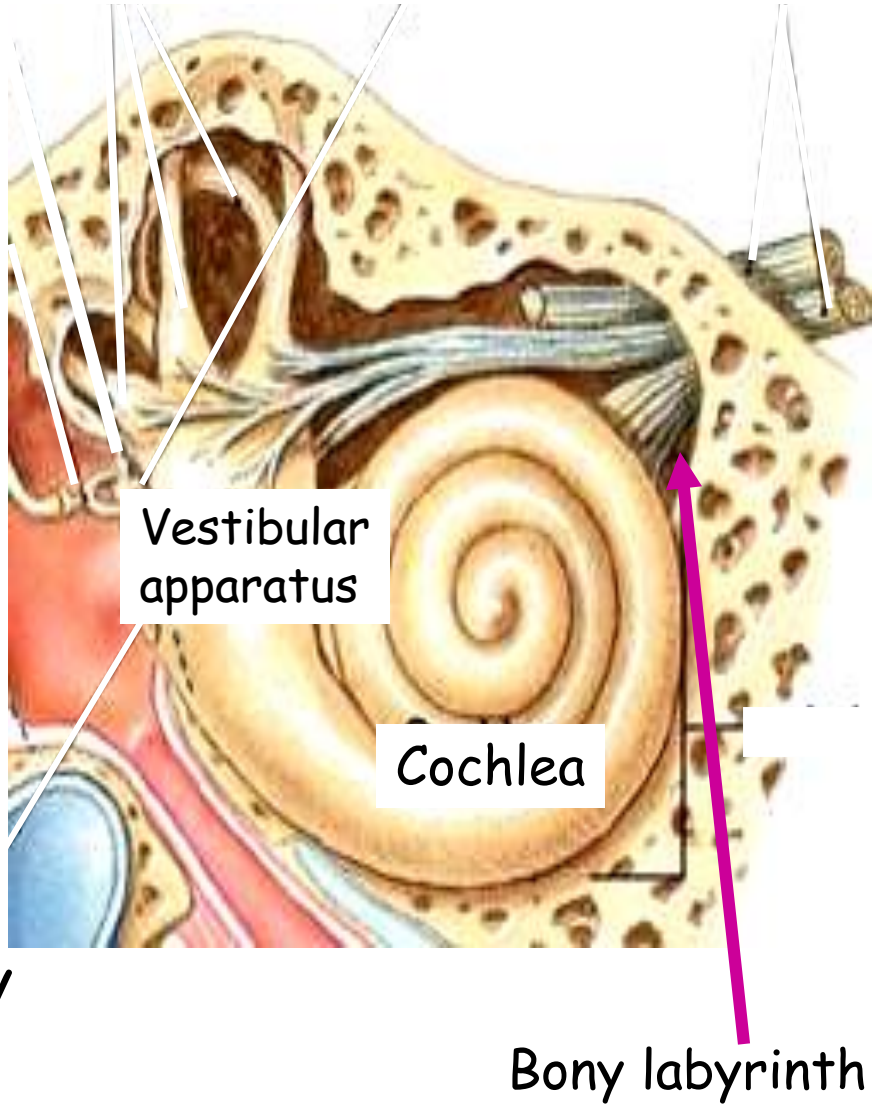
- Tensor tympani muscle: pulls malleus medially
- Stapedius : pulls stapes away from oval window

Reduce the sound pressure reaching the inner ear when the ear is exposed to intense sounds

Inner Ear

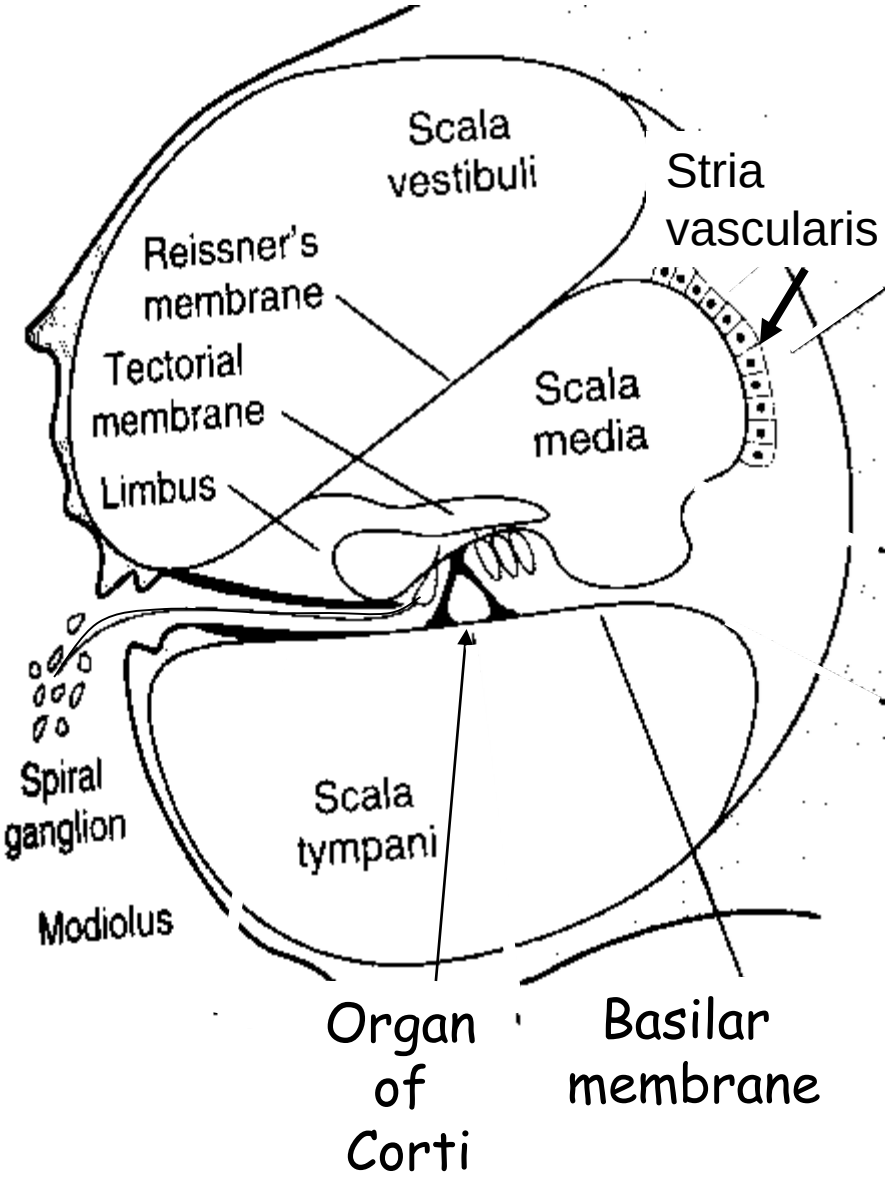
- Within the petrous temporal bone
- Consists of cochlea and vestibular apparatus

- Bony labyrinth
  - network of cavities within the petrous temporal bone
  - Contains perilymph
- Membranous labyrinth
  - Fluid filled cavity inside bony labyrinth
  - Contains endolymph



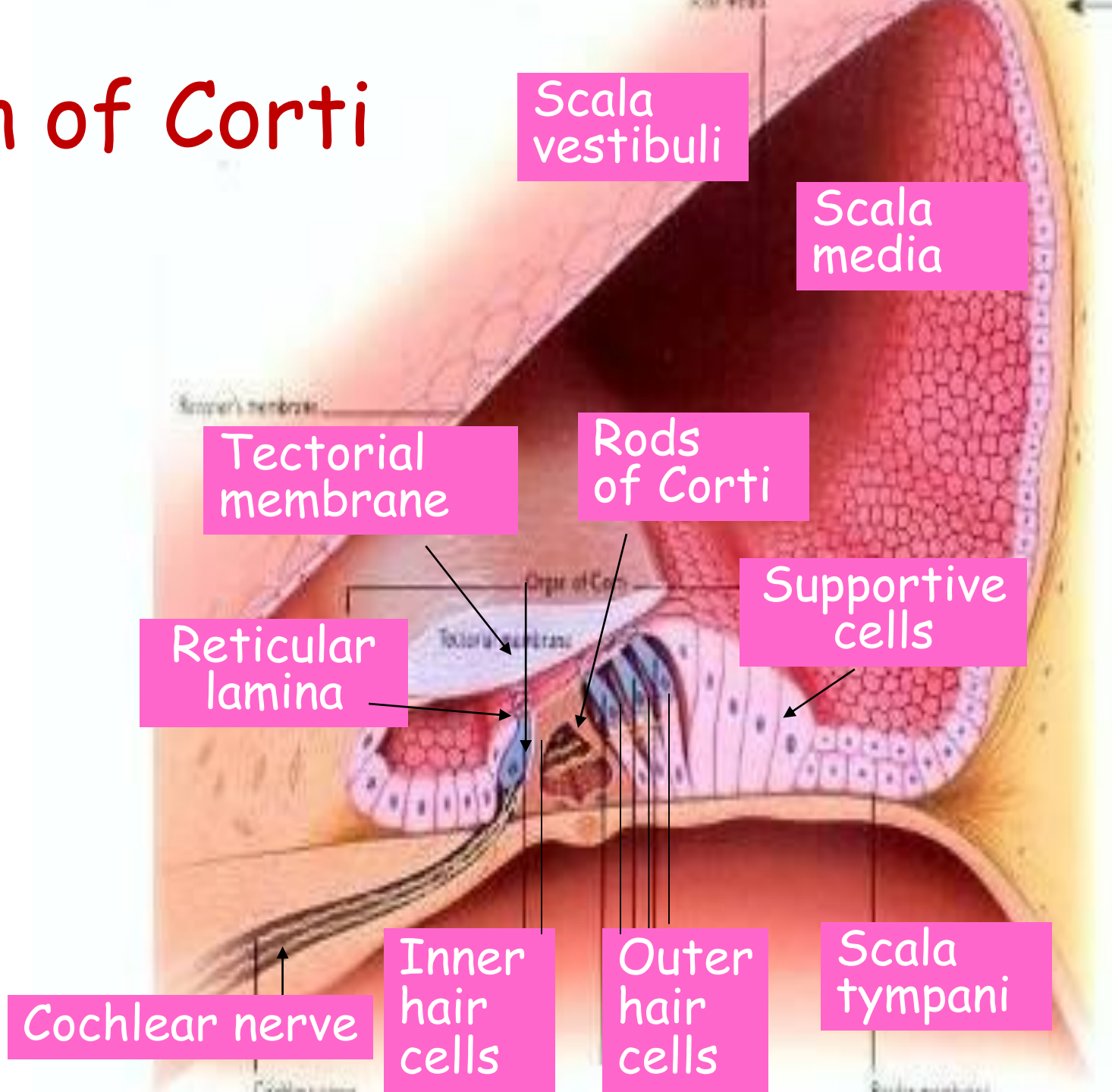
- Cochlea (Auditory part)
  - Coiled $2\frac{3}{4}$ turns
  - Separated by basilar & Reissner membrane

    to 3 chambers (scalae)
  - Scala tympani and vestibule: perilymph
  - Scala media: endolymph



- Vestibular apparatus
  - Position sense of the head

Organ of Corti

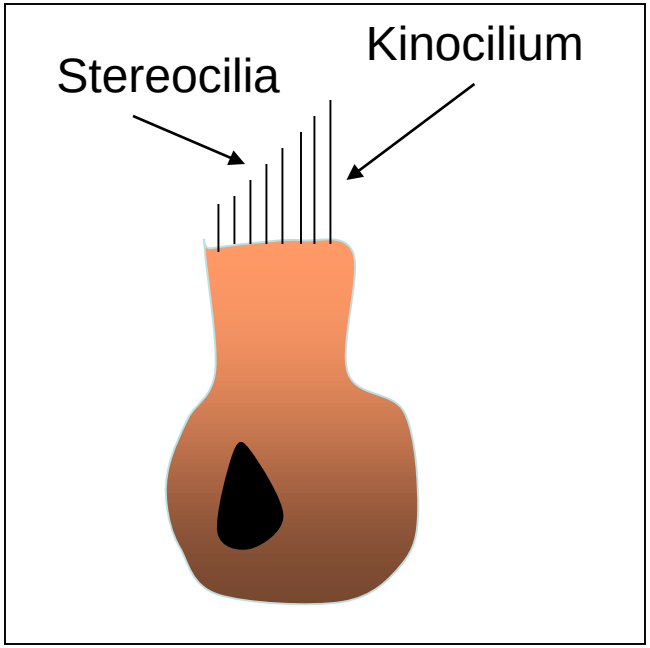


The organ of Corti

- On basilar membrane
- Hair cells (auditory receptors)
  - 3 outer (lateral to rods of Corti)
  - 1 inner (medial to rods)
- Processes of hair cells penetrate reticular lamina
- Outer hair cells in contact with tectorial membrane
- Afferent neurons mainly from inner hair cells
  - Form VIII cranial nerve (auditory division)
- Most efferent fibres end in outer hair cells

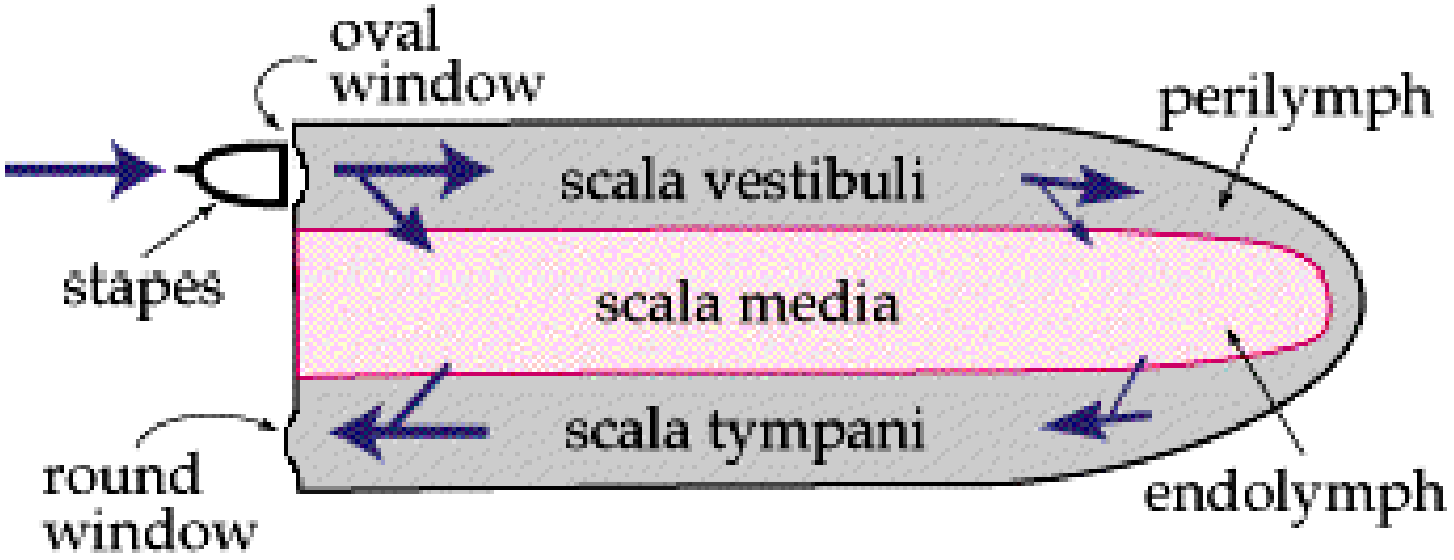
Hair cells

- Receptors in inner ear
- Apical end has stereocilia
- Get progressively longer
- *[In some hair cells, non motile kinocilium is the largest cilium]*
  - *Not found in cochlear hair cells*
- Resting membrane potential -60mV
- Bases bathed in perilymph; hair cell tips in endolymph



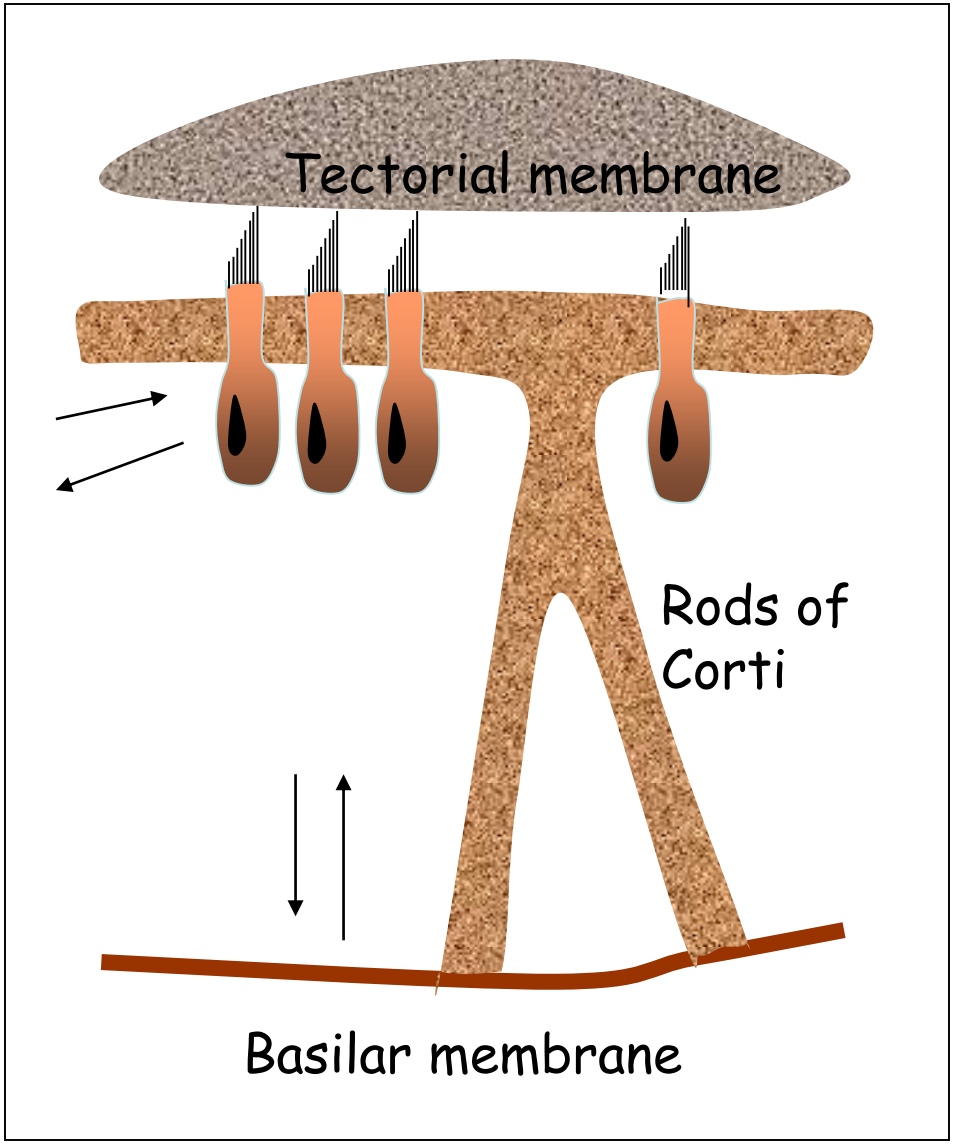
Sound waves in Cochlea

- Displacement of foot of stapes causes pressure wave in perilymph
- *[Reissner's membrane very thin- pressure wave passes easily through scala vestibuli & media]*
- Causes movement of the basilar membrane



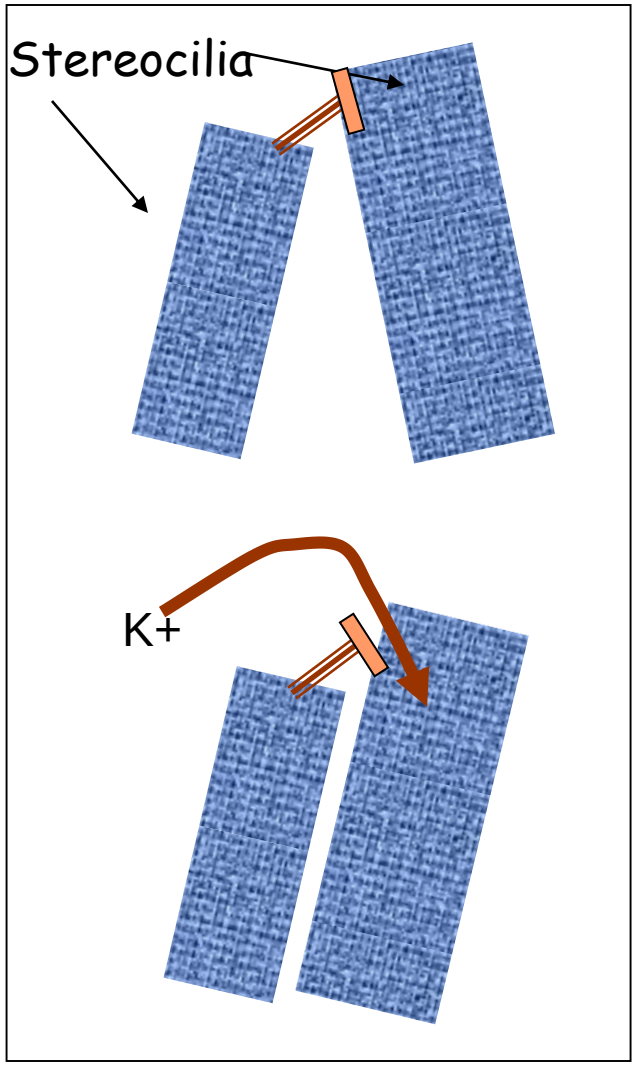
Transduction of sound

- Movement of basilar membrane causes hair cell cilia to bend / straighten
  - Up & inward/ down & outward movement
- Bending of cilia towards largest one causes depolarisation
- Opposite direction causes hyperpolarisation



Mechanism of depolarisation

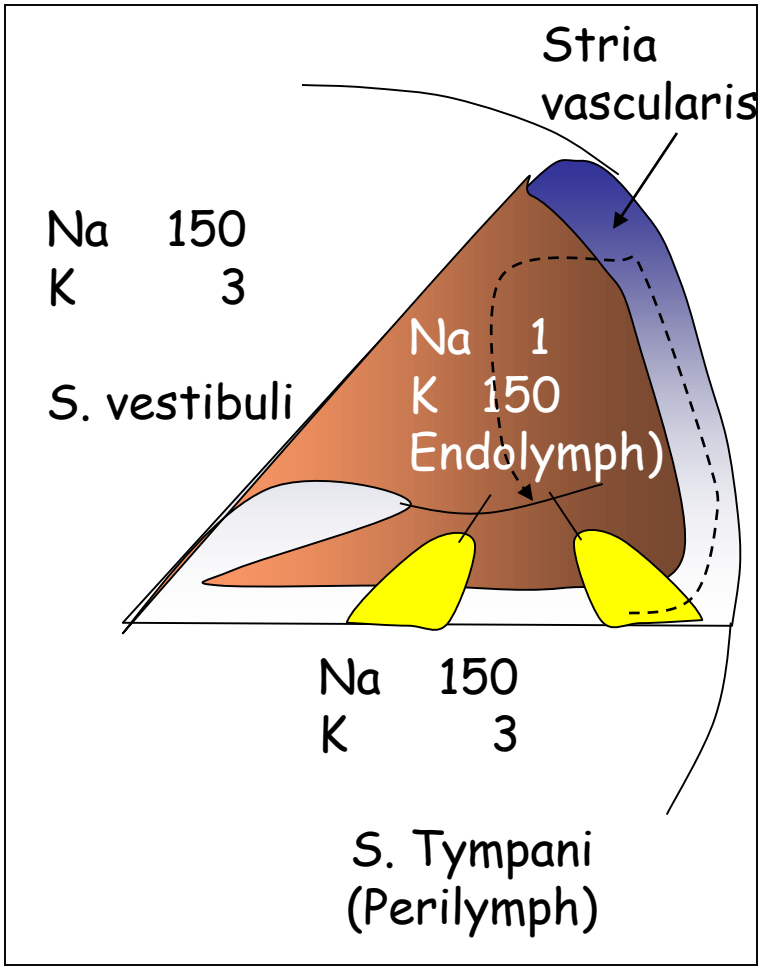
- Cilia connected by tip links
- When cilia move, tip links pull & open up cation channels
- K+ or Ca++ moves in to cell causing depolarisation
- Release of excitatory neurotransmitter (glutamate) & Afferent nerve impulse



The Endocochlear Potential

Tips of stereocilia in endolymph & bases in perilymph

- RMP -60mV
- Much larger gradient at tips
  - Scala media +ve compared with scala tympani
  - High K+ (secreted by stria vascularis)



True or false?

1. The stapes pushes in to the scala media.
2. The Reissner membrane separates the scala media from the scala tympani.
3. The scala media contains a fluid with a high potassium content.
4. The Reissner membrane prevents pressure wave transmission from the scala vestibuli to the organ of Corti
5. Hair cells are depolarisation by the pulling of tip links of hair cells

Auditory pathway

Spiral ganglion of Corti

↓

Medulla — Cochlear nuclei

↓

Pons — Contralateral superior olivary nucleus
[few fibres to ipsilateral olivary nucleus]

↓ Via lateral lemniscus

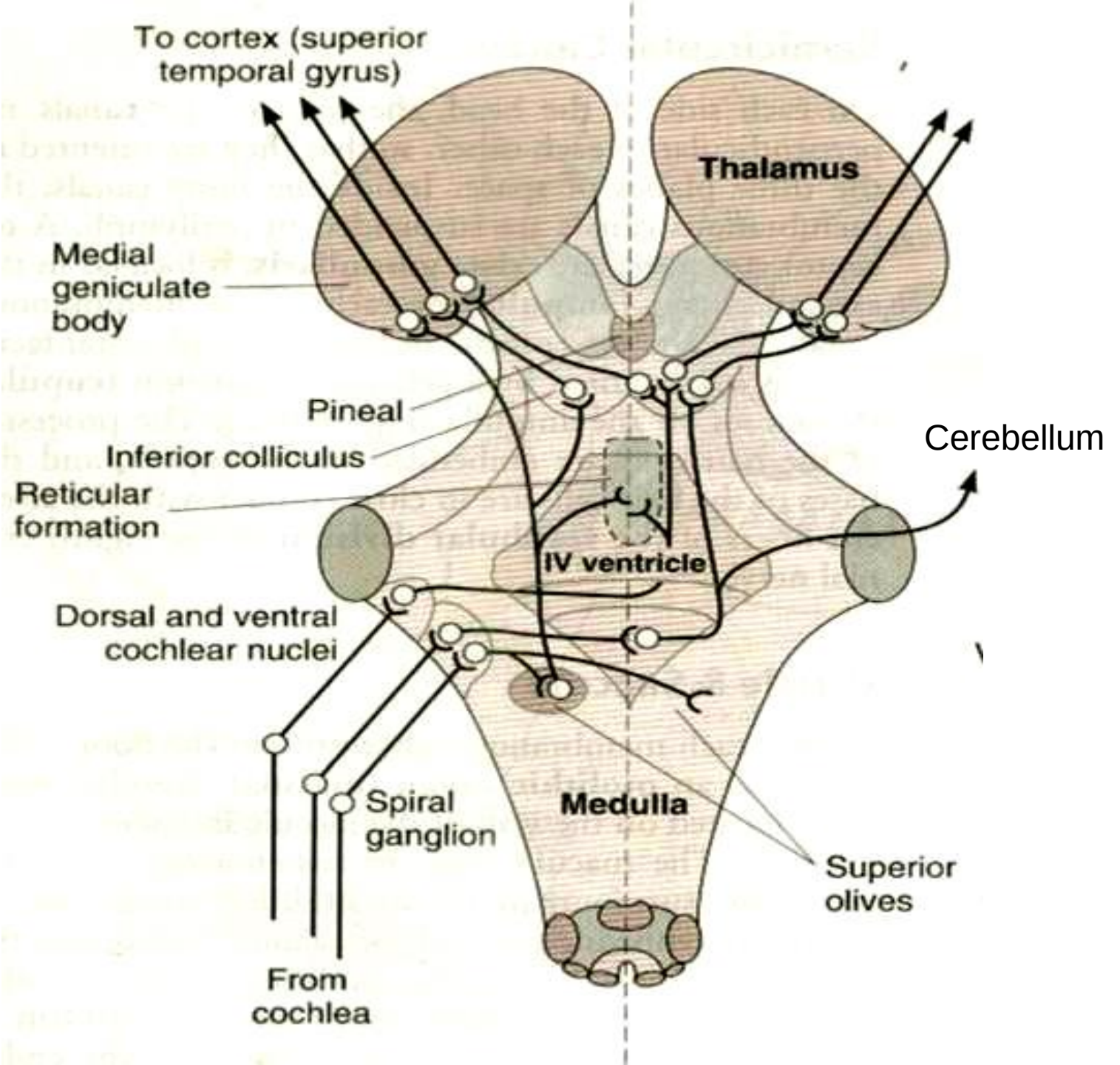
Mid brain — Inferior colliculus (ipsi & contralateral)

↓

Thalamus — Medial geniculate body (ipsi & contralateral)

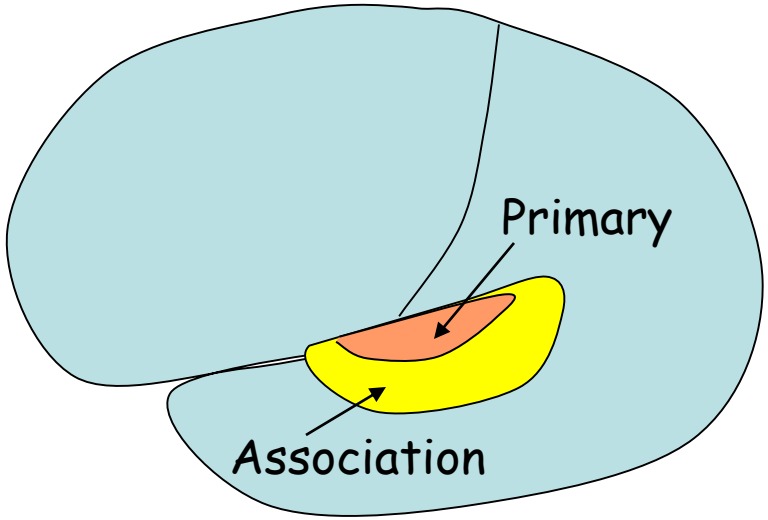
↓ Via auditory radiation

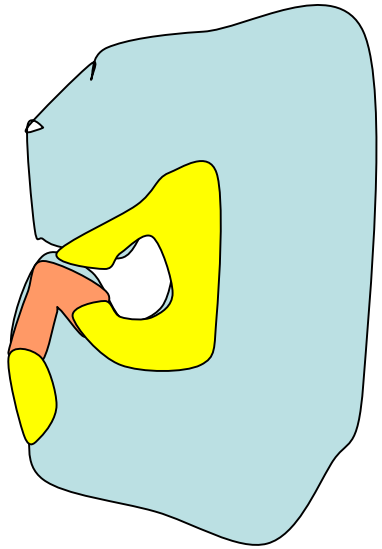
Temporal lobe — Auditory cortex (ipsi & contralateral)


To cortex (superior temporal gyrus)
Thalamus
Medial geniculate body
Pineal
Inferior colliculus
Reticular formation
Cerebellum
IV ventricle
Dorsal and ventral cochlear nuclei
Spiral ganglion
Medulla
Superior olives
From cochlea

Auditory Cortex

- Temporal lobe
- Primary cortex
  - Stimuli via medial geniculate body
- Association area
  - Primary cortex and thalamic areas



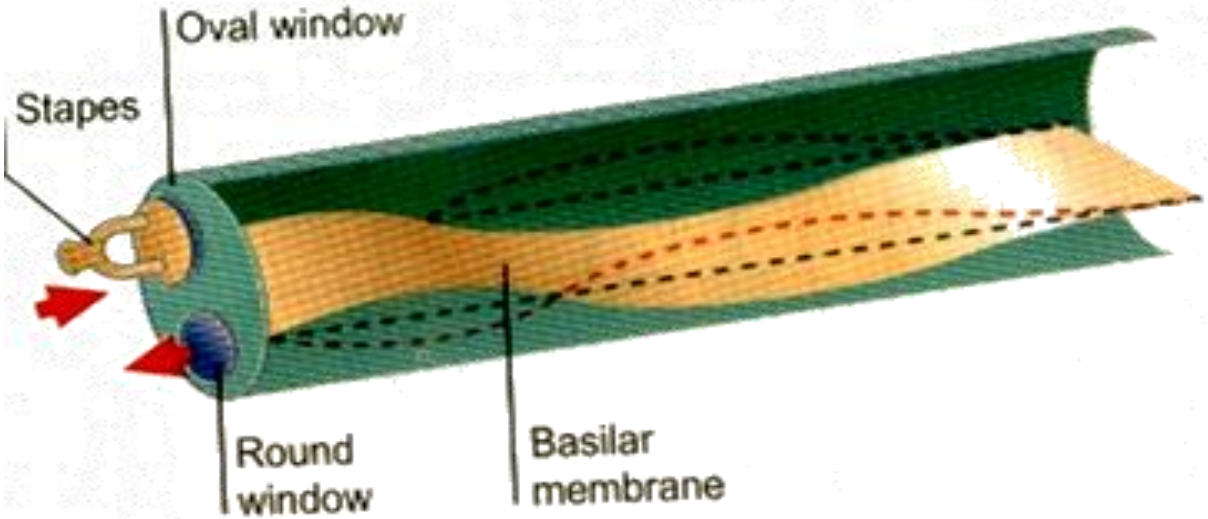


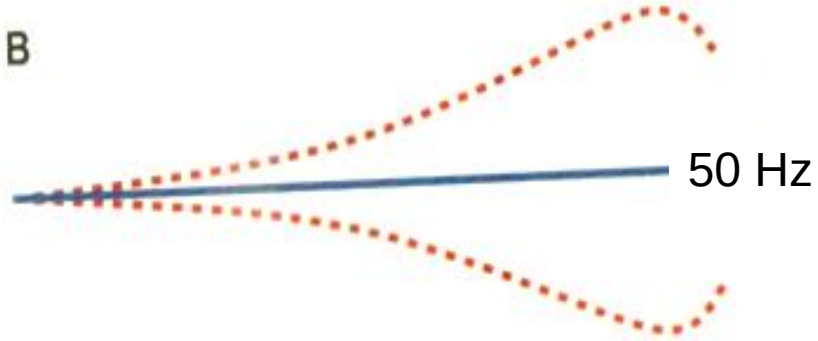
True or false?

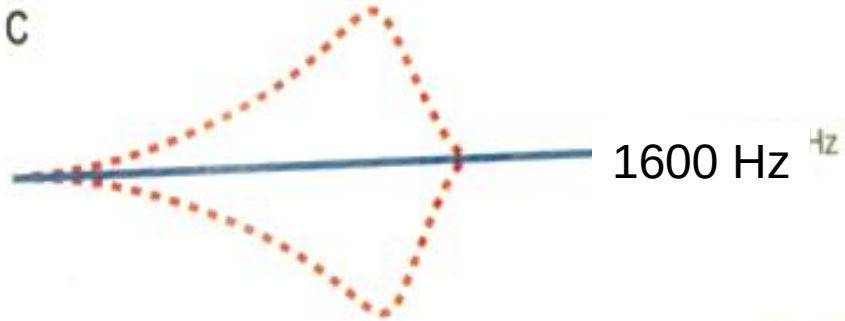
1. The inner hair cells send afferent information to the VIIIth nerve.
2. Shearing of hair cells causes opening ion channels.
3. Sodium ions are involved in depolarisation of hair cells in the cochlea.
4. Movement of the hair cells toward the tallest causes a depolarisation.
5. The auditory cortex only gets afferent information from the contralateral cochlea.

Determining sound frequency

- High frequency sounds
  - activate basilar membrane near oval window
- Low frequency sounds
  - activate basilar membrane near helicotrema
- "Place principle"- brain detects sound frequency by the position of basilar membrane stimulation
- Low frequency sound (20-2000Hz) cause synchronised discharges of afferent nerves


Oval window
Stapes
Round window
Basilar membrane


B
50 Hz


C
1600 Hz

Determination of Loudness

- Increasing amplitude of basilar membrane vibration
  - increasing frequency of impulses in afferent neuron
- Spatial summation- more near by hair cells stimulated
  - more afferent neurons stimulated
- *Stimulation of outer hair cells*

Localisation of sound

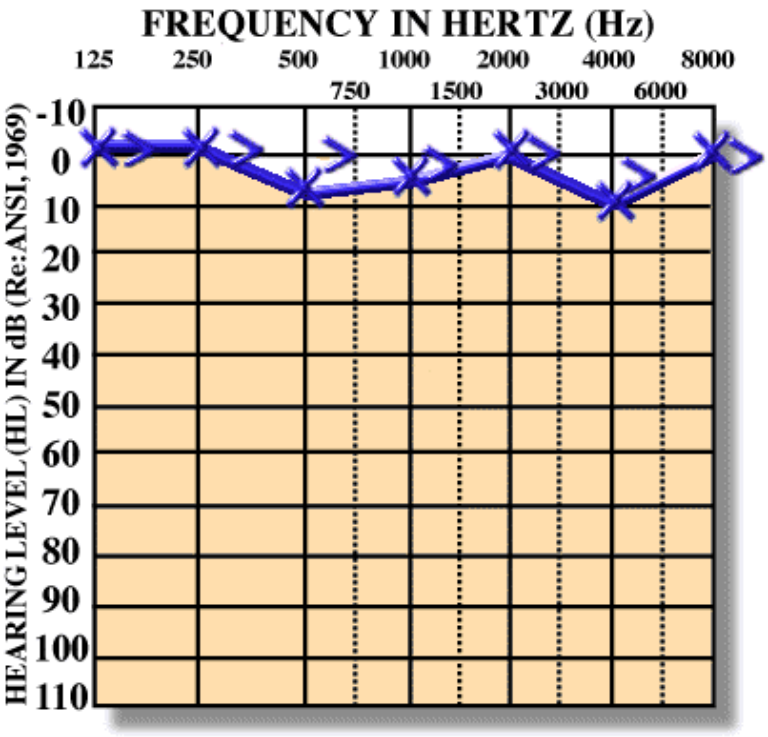
- Time difference between sound in the two ears
  - Frequencies below 3000Hz
- Difference in intensity between two ears
  - Frequencies more than 3000Hz
- Require pinnae
- Damage to one auditory cortex can reduce localisation of sounds

Deafness- reduced hearing

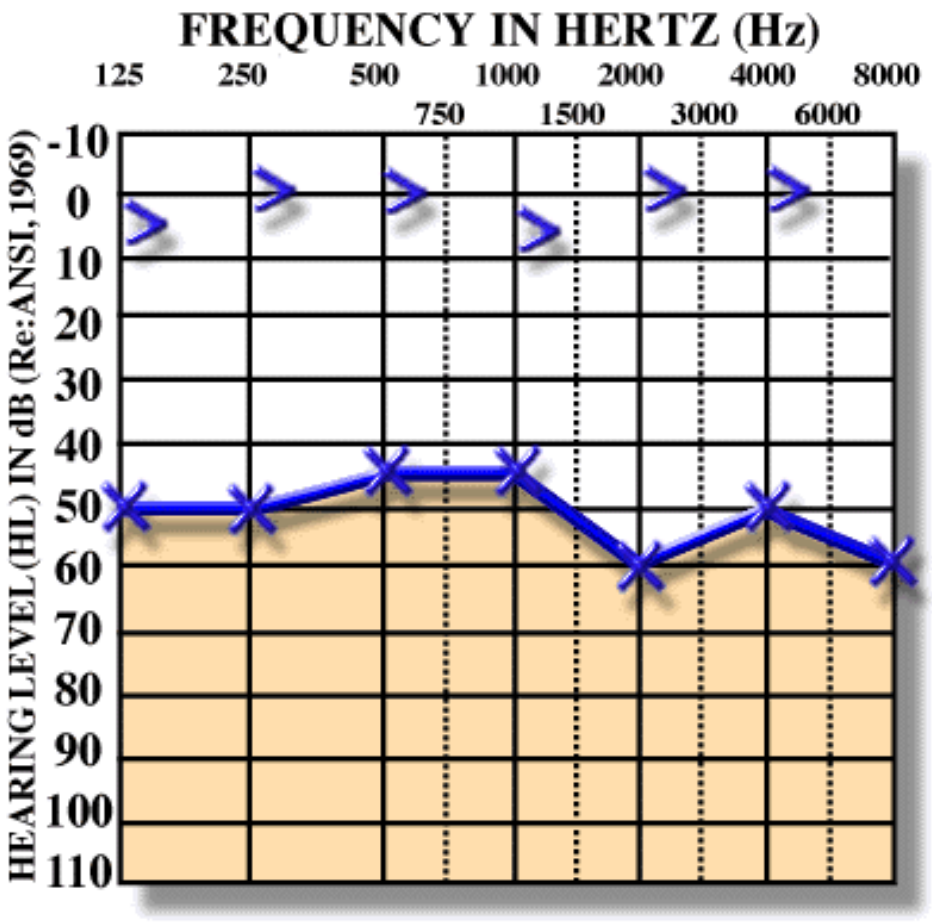
- Normal hearing
  - sounds go through middle ear to inner ear
- Sound can go through bone or via round window less efficiently
- Nerve deafness
  - Damage to inner ear or auditory nerves
- Conductive deafness
  - Damage/ obstruction to external or middle ear

Testing for deafness

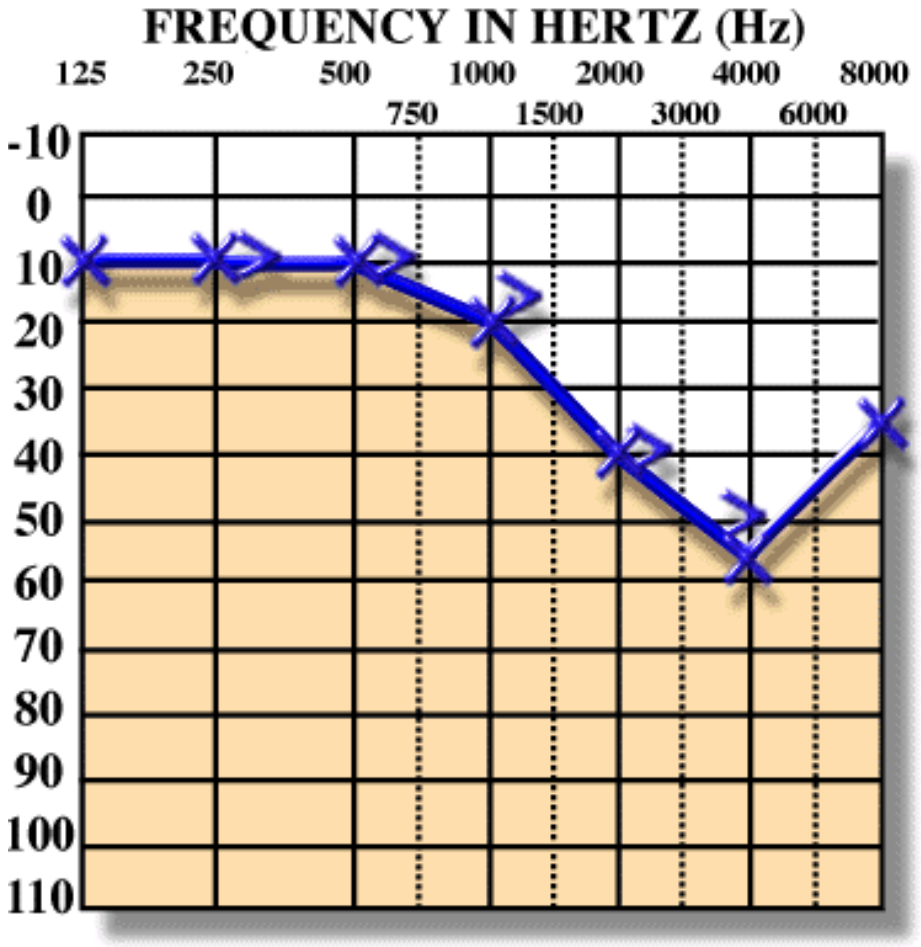
- Clinical (bed side)
  - Include tuning fork based Rinne/ Weber
- Audiometry
  - Machine emits sounds of a specific frequency and amplitude
  - Can separate between nerve and conduction deafness
  - Identify specific frequency losses



Conduction Deafness



Sensorineural Deafness



Correcting hearing loss

- Amplify sounds using conventional hearing aid
- Conduction deafness- stimulate the mastoid
- Cochlear damage with normal VIII nerve
  - Cochlear implant

True or false?

1. Sounds of low frequency are detected by the organ of Corti close to the helicotrema.
2. Sound waves that cause basilar membrane movement also stimulates the membrane at a more distal location.
3. Loud noise causes more action potentials in the afferent neurones.
4. Sound localisation is aided by having two ears.
5. Bedside testing of VIII th nerve function utilises a tuning fork.

True or false?

1. Ear wax obstructing the external auditory meatus is likely to cause sensorineural deafness.
2. Exposure to loud noise contributes to high frequency hearing loss.
3. Sound stimulation of the mastoid process is a treatment for hearing loss in middle ear disease.
4. Old age is associated with hearing loss.
5. Cochlear implants are beneficial in patients with VIIIth nerve lesions.