

Sense of Hearing

Sense of Balance

Auditory system

Auditory system

- capturing and transmission of mechanical energy to the receptor organ, transduction into electrical signal (ear)
- transmission to CNS
- processing of the transmitted information
 - interpretation of the sound
 - interpretation of its importance for the organism

Auditory system

- capturing and transmission of mechanical energy to the receptor organ, transduction into electrical signal (ear)

- transmission

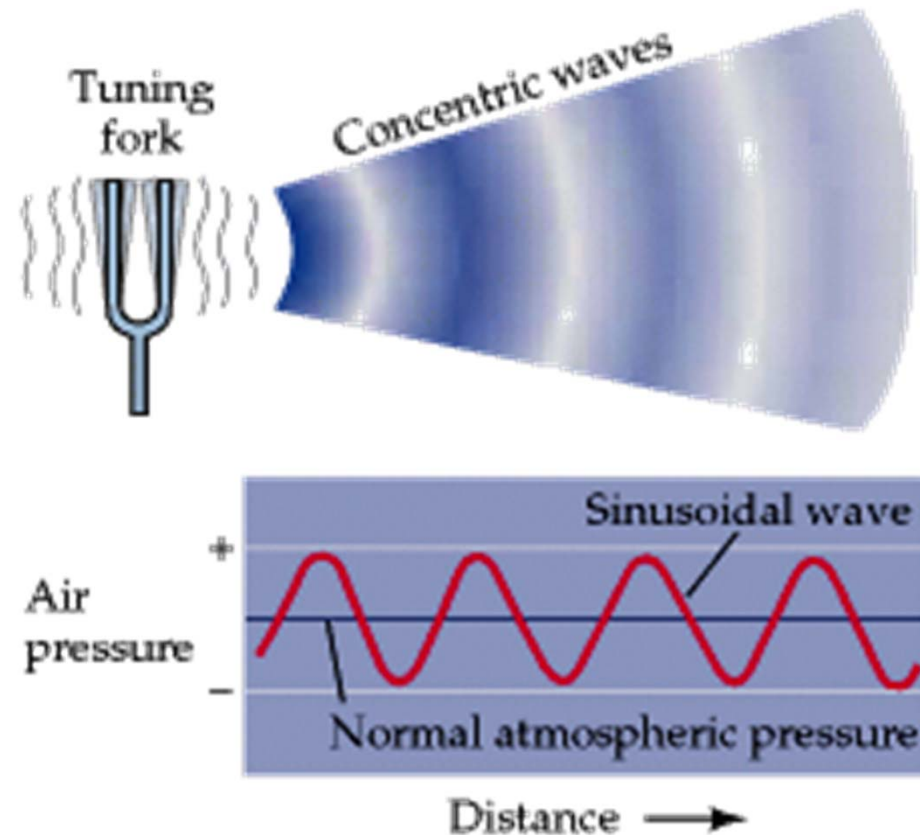
Sound is a mechanical undulation of flexible environment with frequency in audible spectrum.

- transmitted information
- interpretation of the sound

- interpretation of its importance for the organism

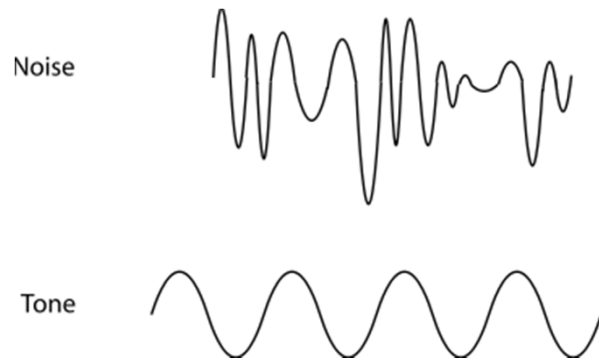
Sound

- rises by vibration of a solid object in the air or water
- characteristics:
 - frequency – pitch of the tone
 - amplitude – intensity
 - timbre – given by representation of harmonic frequencies of the oscillation



Sound

- simple (clear)
- composite
 - harmonic
 - periodic
 - non-harmonic (noise)
 - non-periodic



<http://www.earmaster.com/music-theory-online/ch03/chapter-3-2.html>

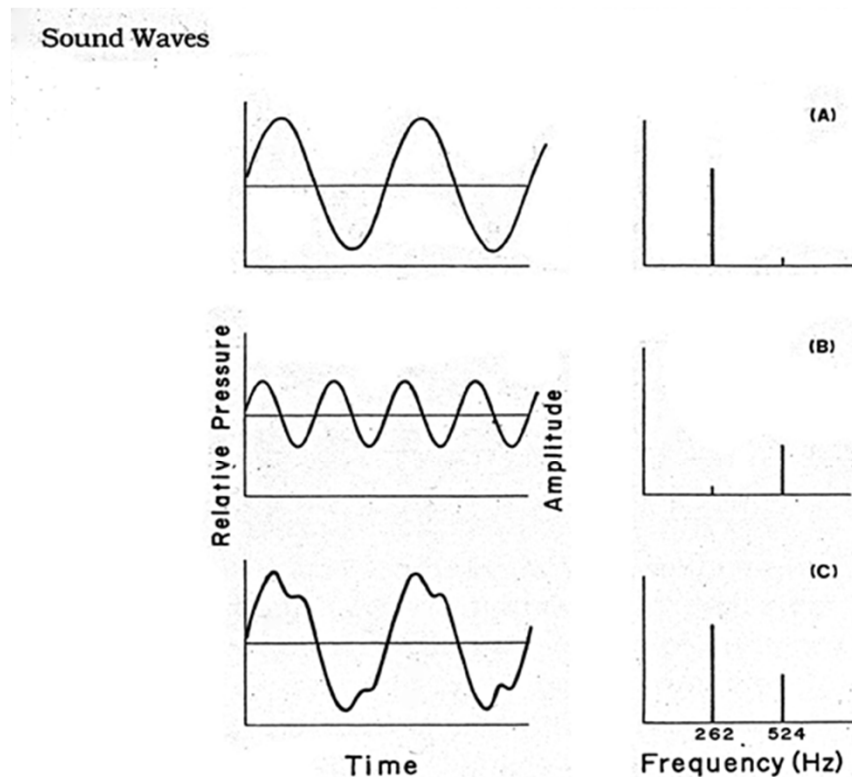
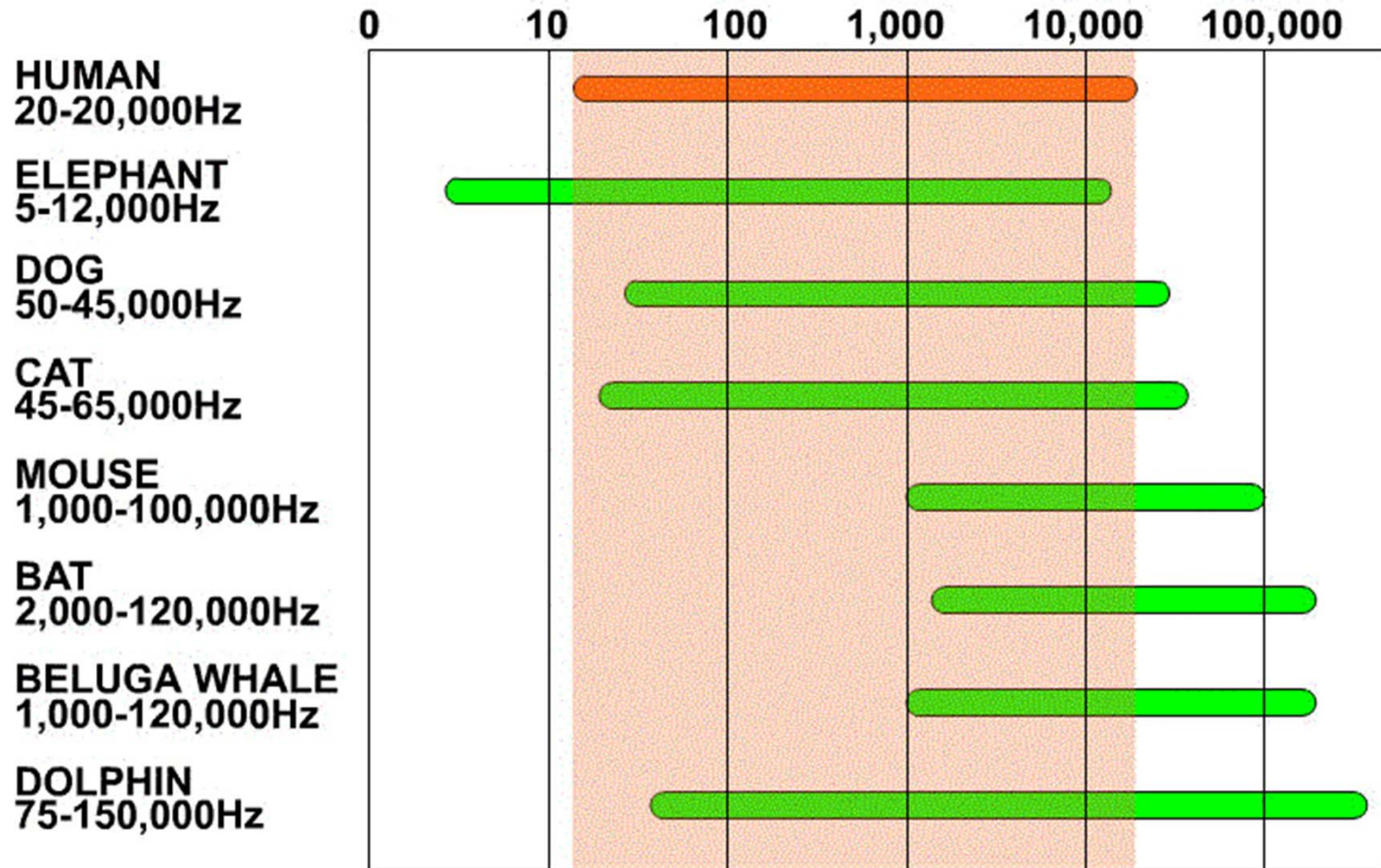


Figure 2.7 Waveform (left) and spectra (right) of two sine waves (A and B), combining into a complex wave (C).

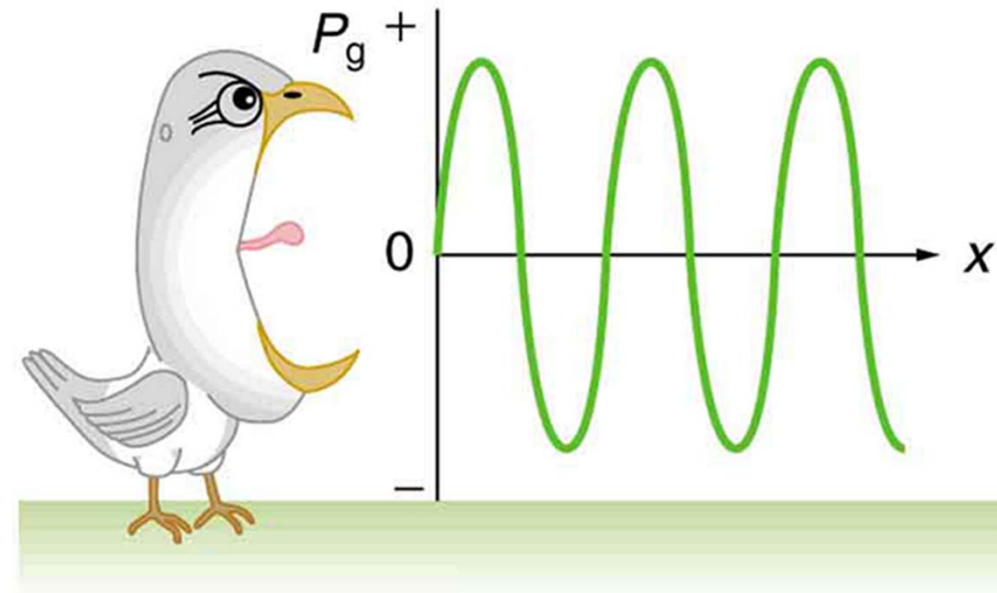
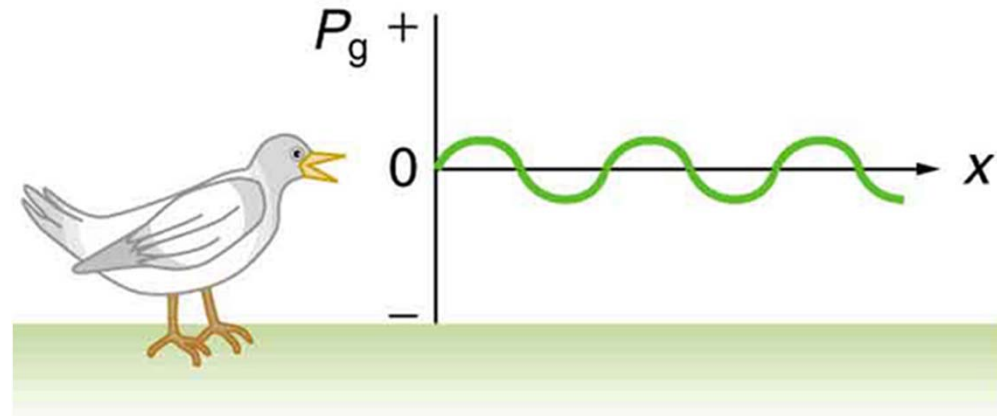
<http://physics.bowlderderby.com/soundwaves.html>

Audible spectrum



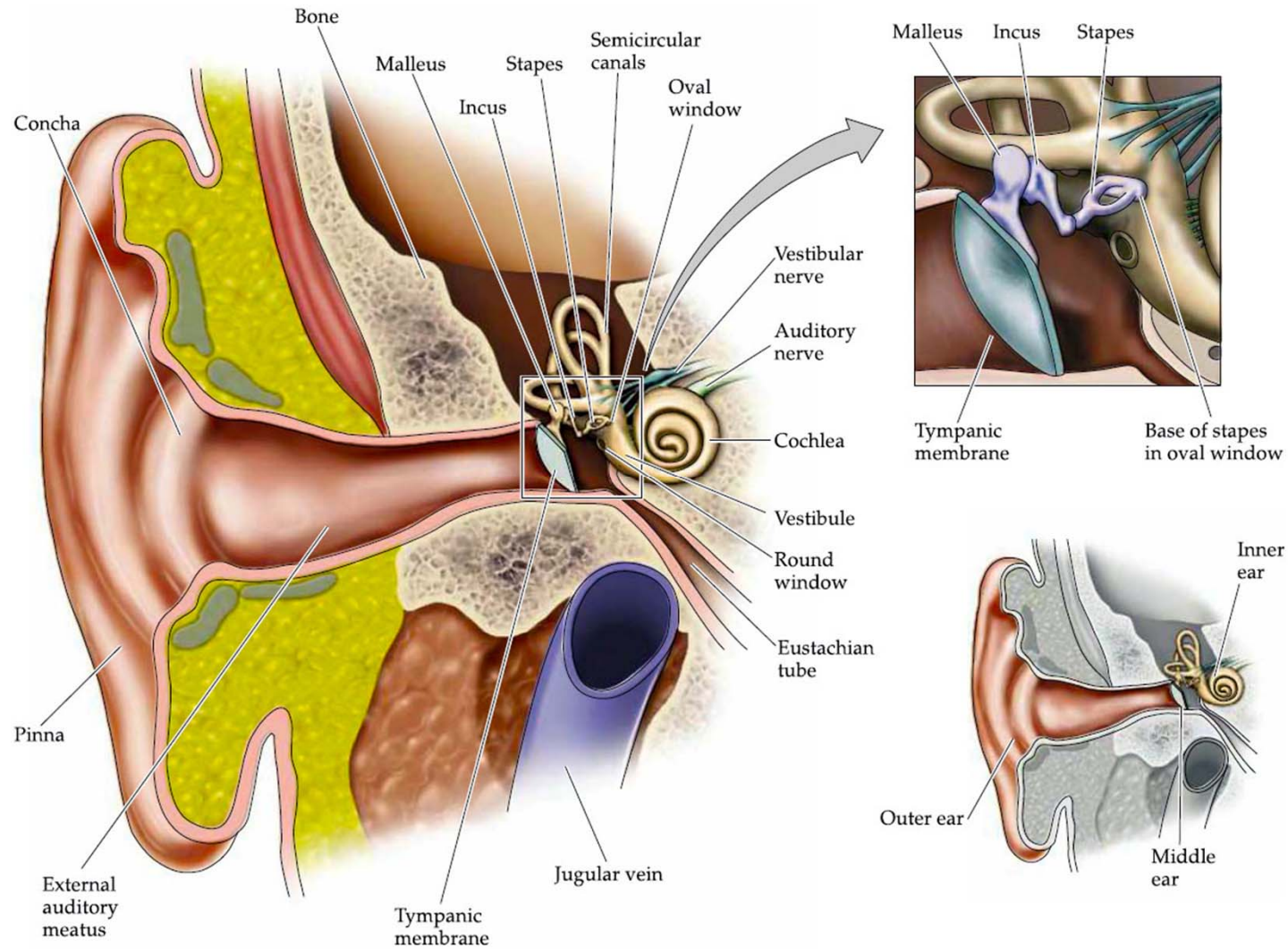
Intensity of the sound

- given by the amplitude of signal
 - whisper – 20 dB
 - common speech - 65 dB
 - jet engine – 100 dB
 - pain threshold – 120 dB
- volume (loudness) - subjectively perceived intensity of the sound



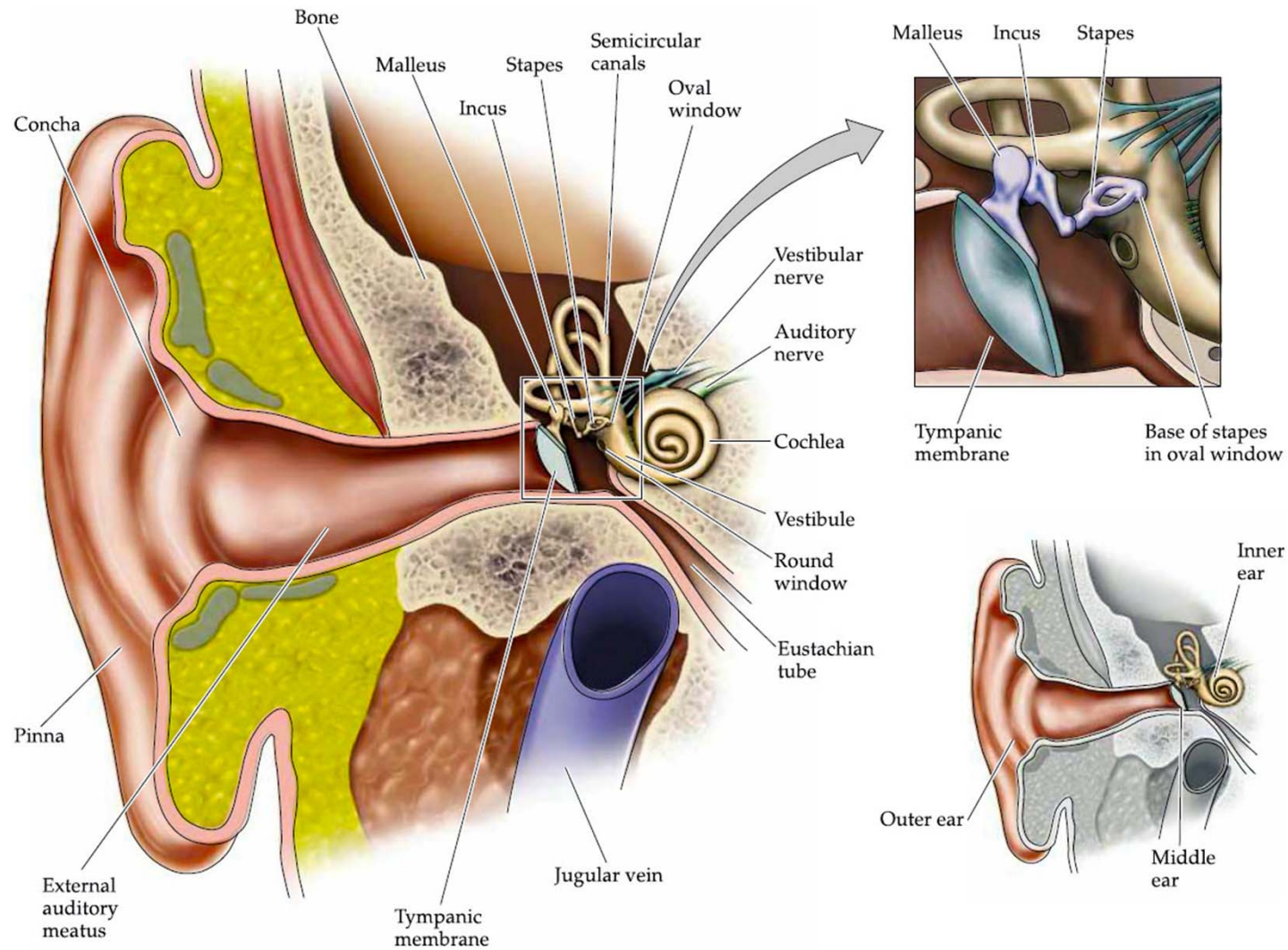
External ear

transmission of the acoustic signal from the external environment to the tympanic membrane



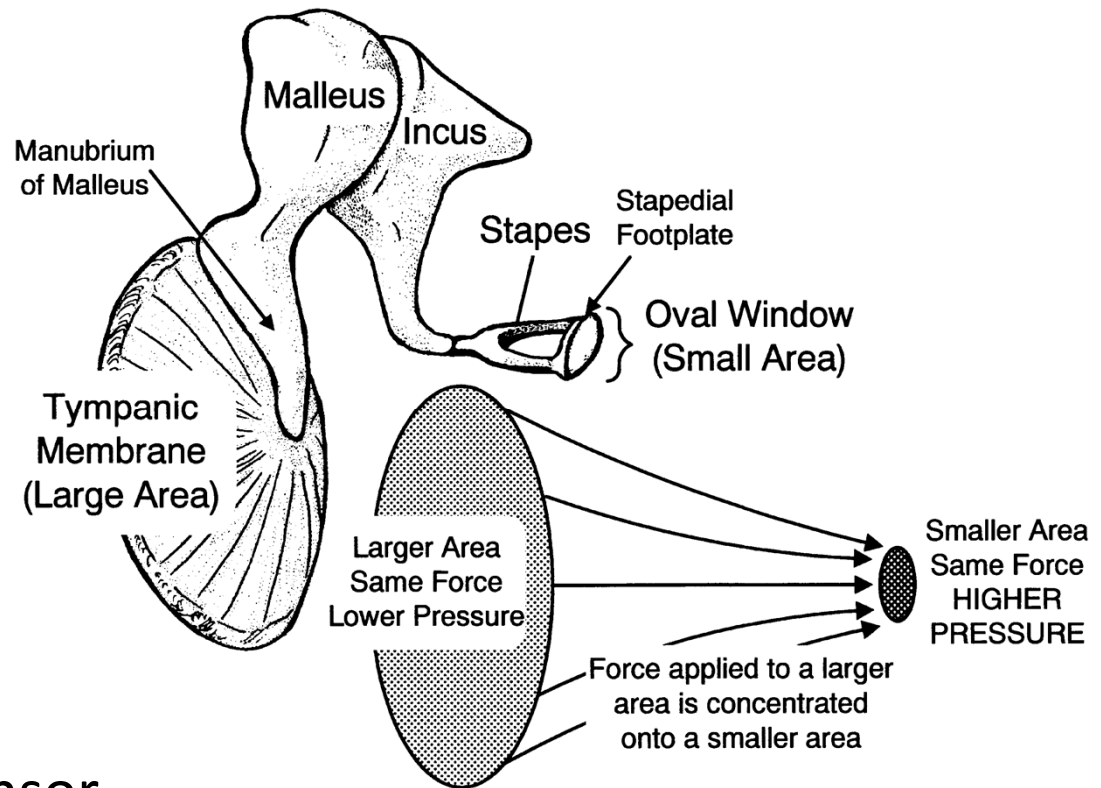
Middle ear

transmission of the signal from the tympanic membrane to the oval window and perilymph

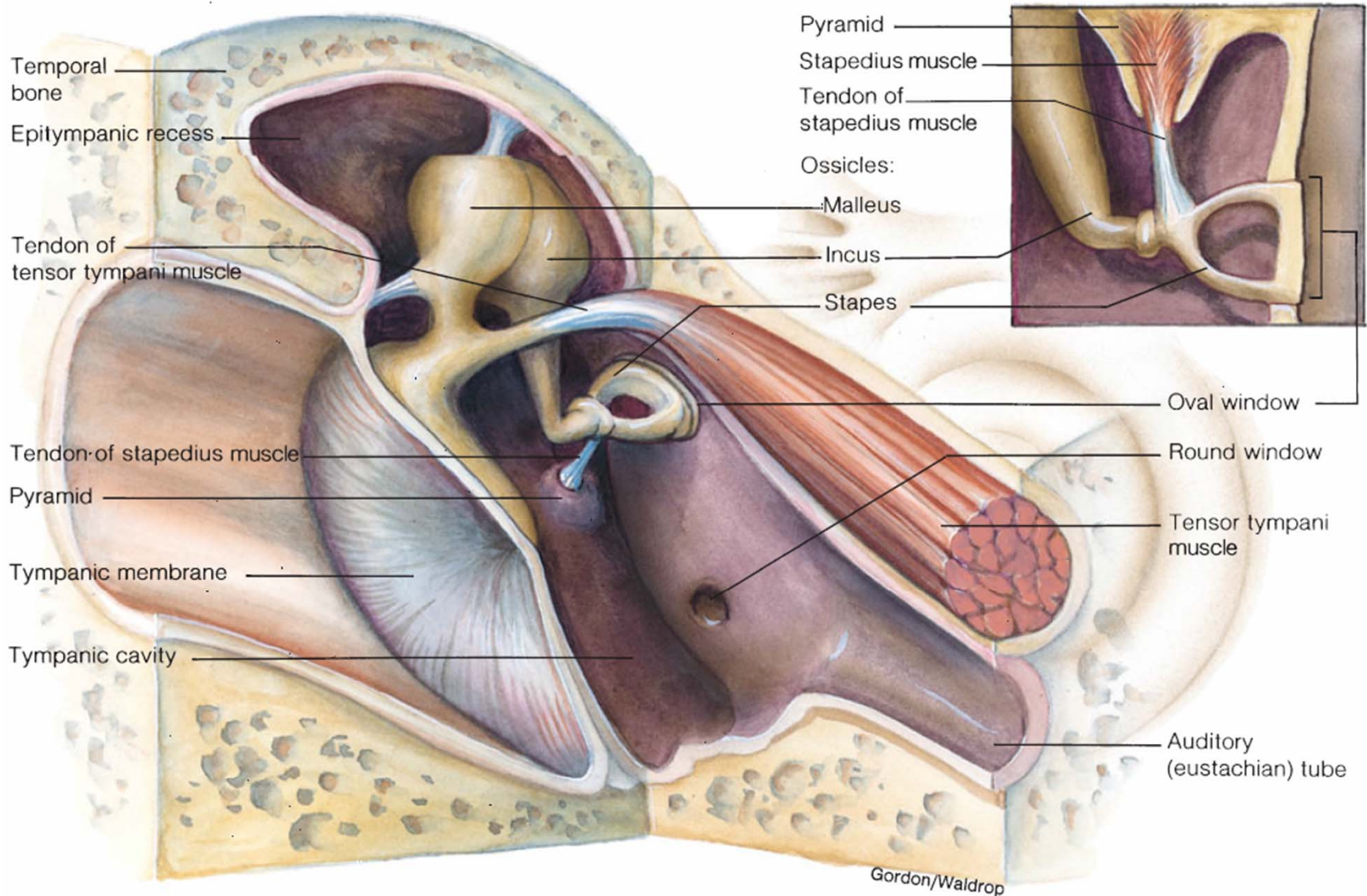


Middle ear

- Reinforcement of the signal
 - area of the tympanic membrane/ area of the oval window
 - leverage mechanism of the middle ear ossicles
- Protective function
 - m. stapedius, m. tensor tympani
 - Eustachian tube

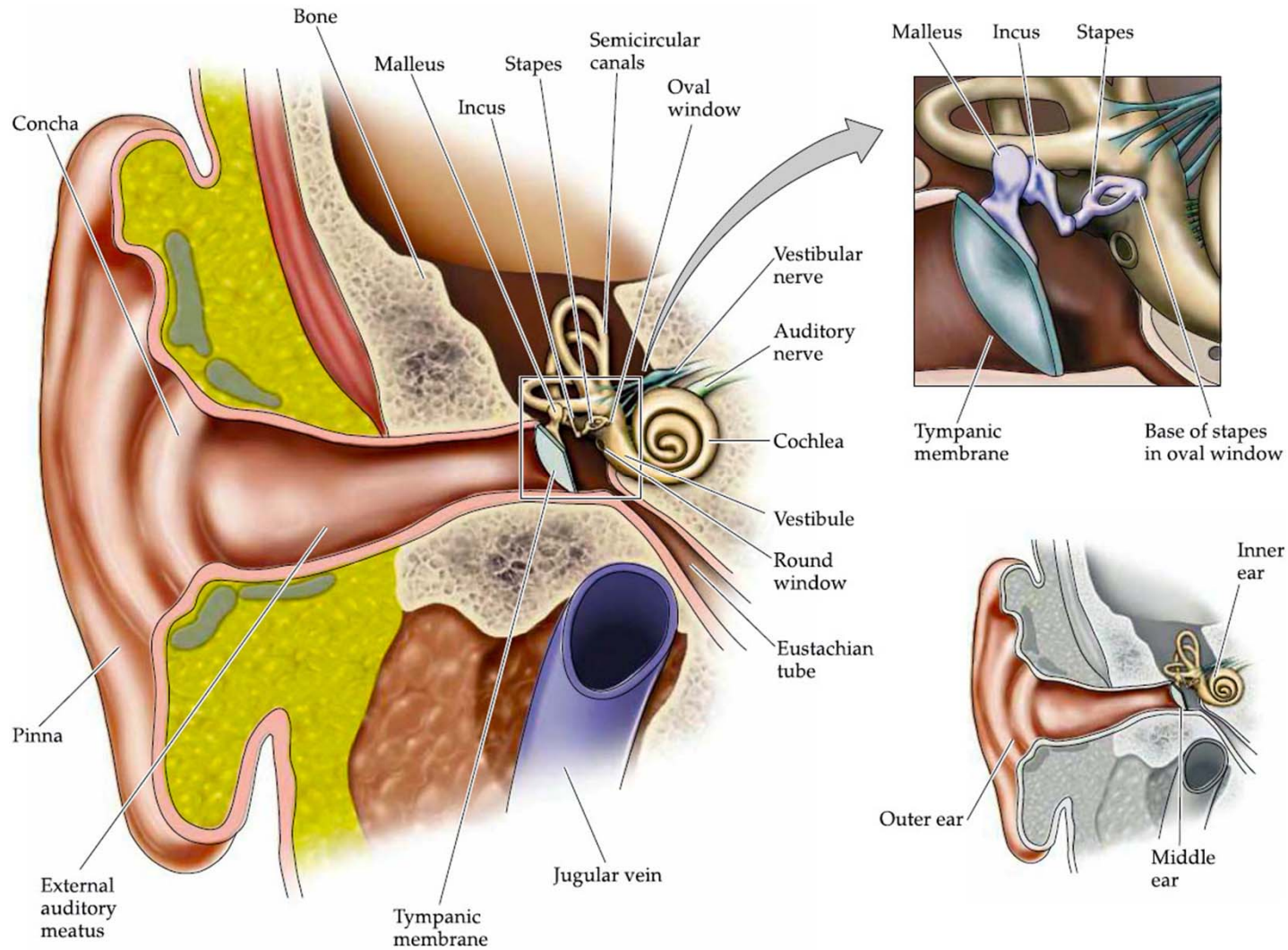


Middle ear



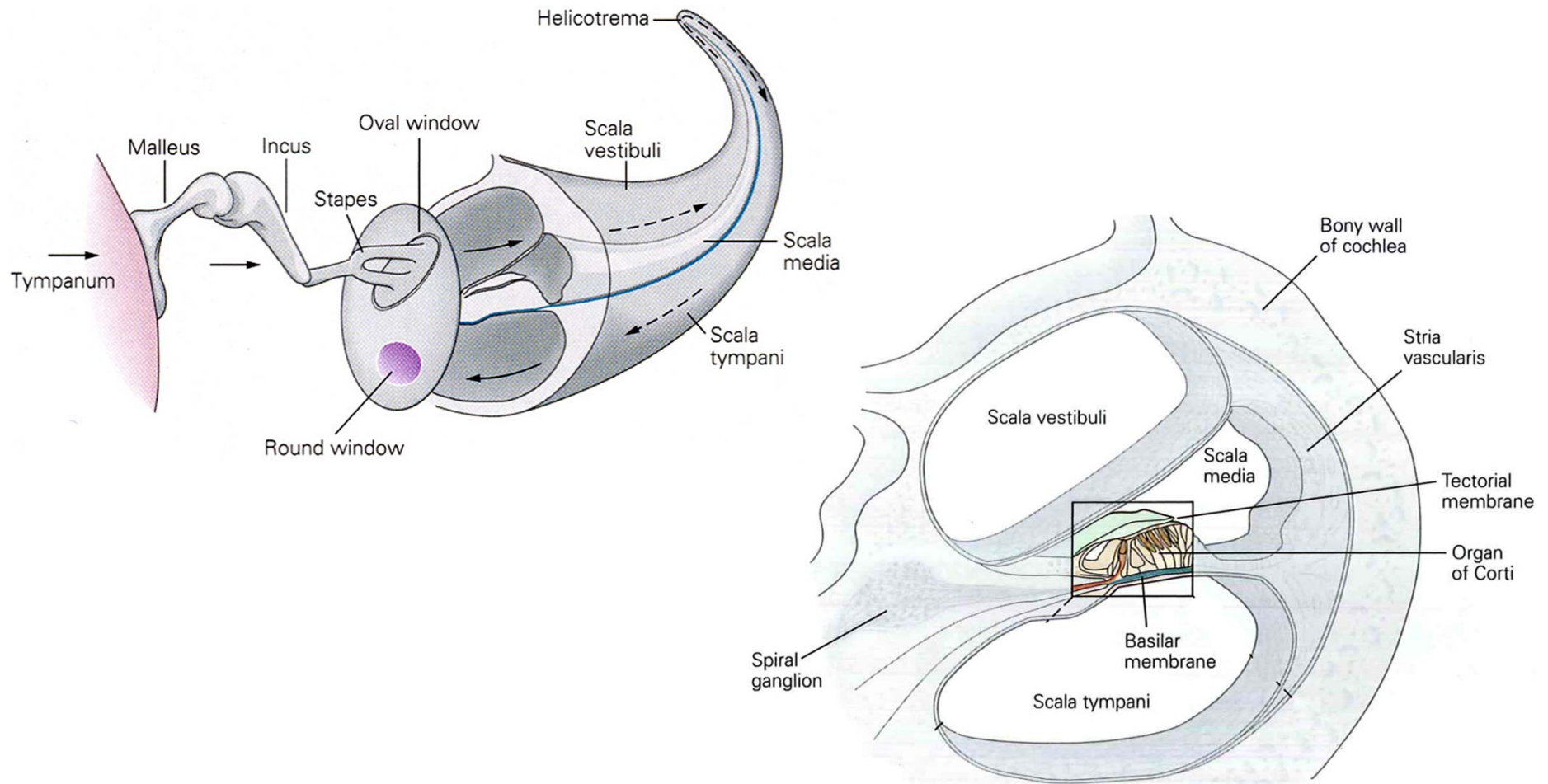
Inner ear

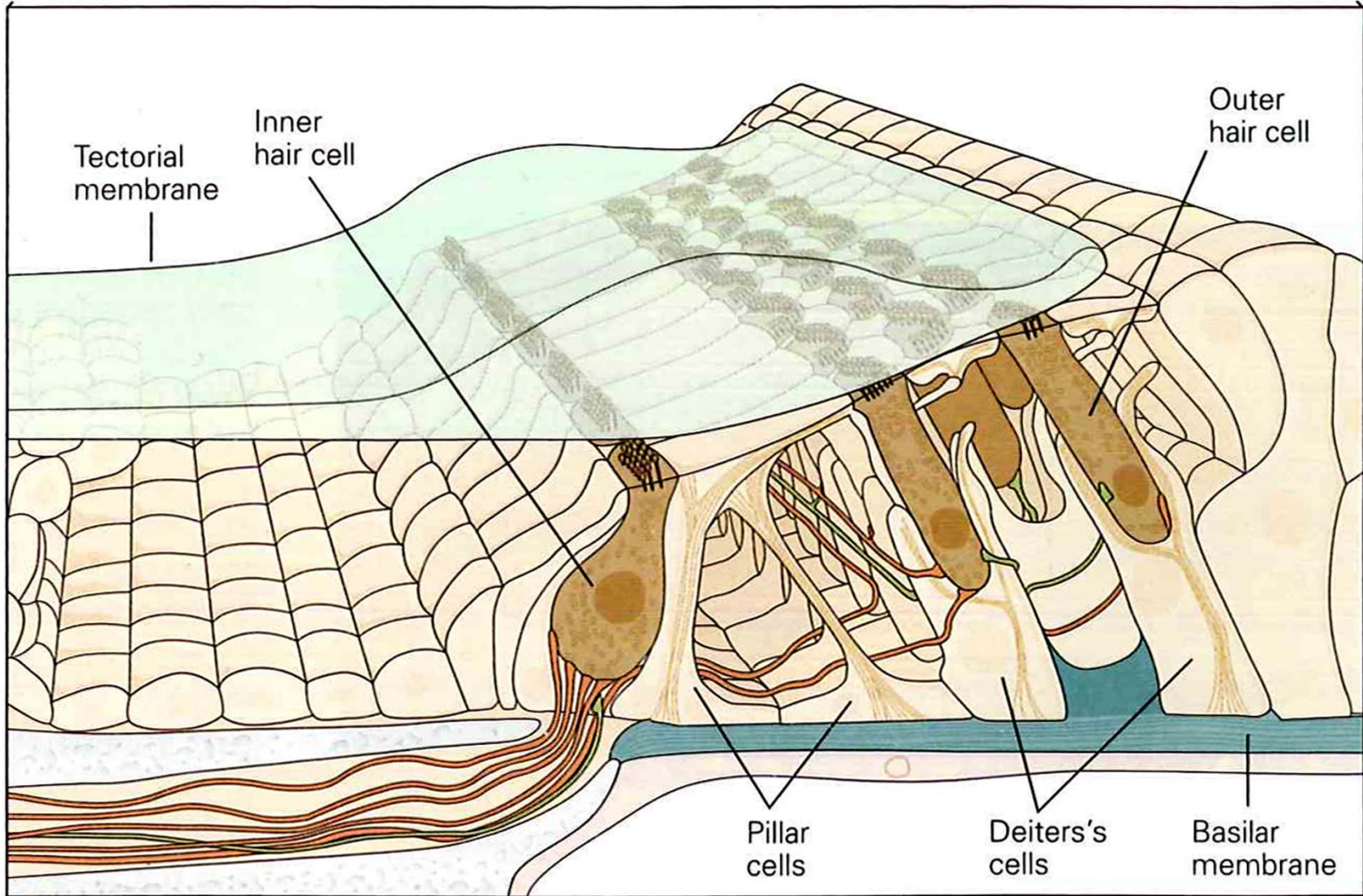
transmission of mechanical undulations of the perilymph to the neural (electric) signal

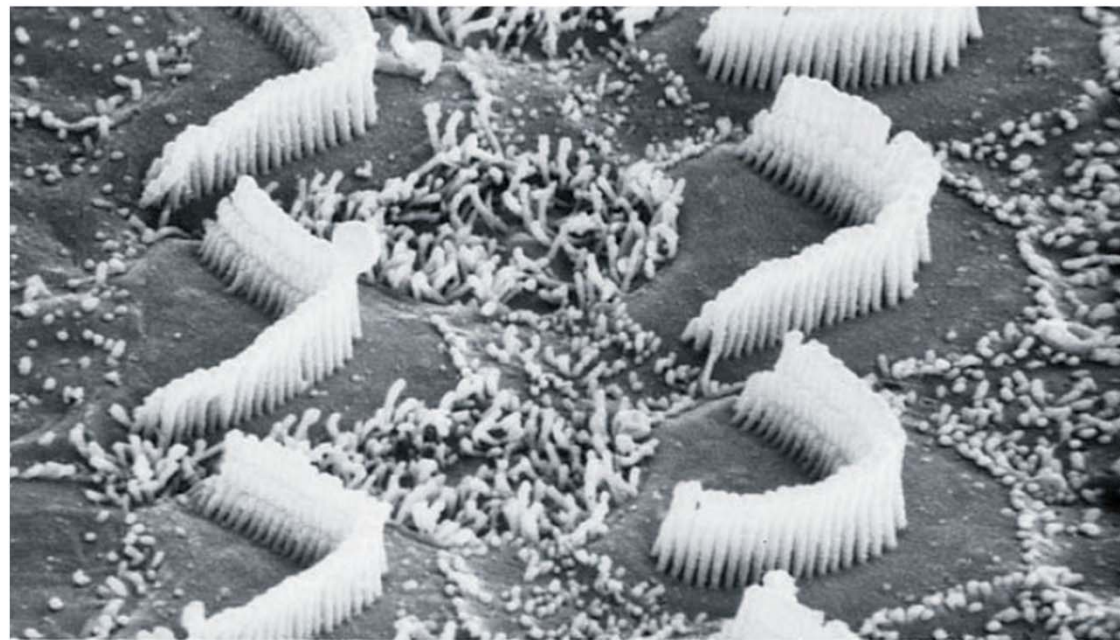
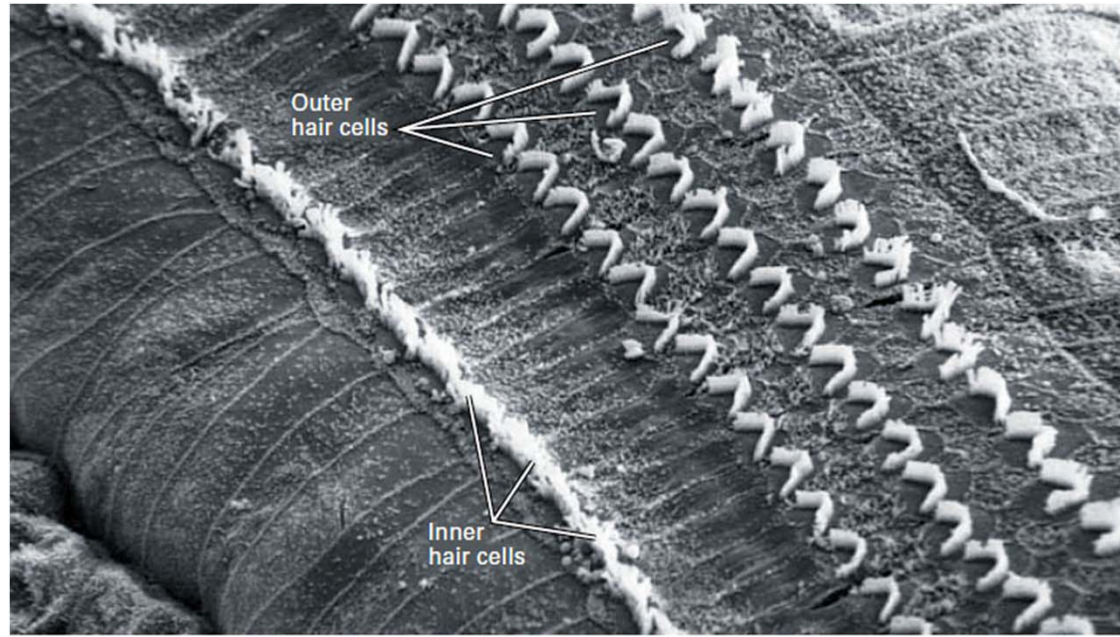


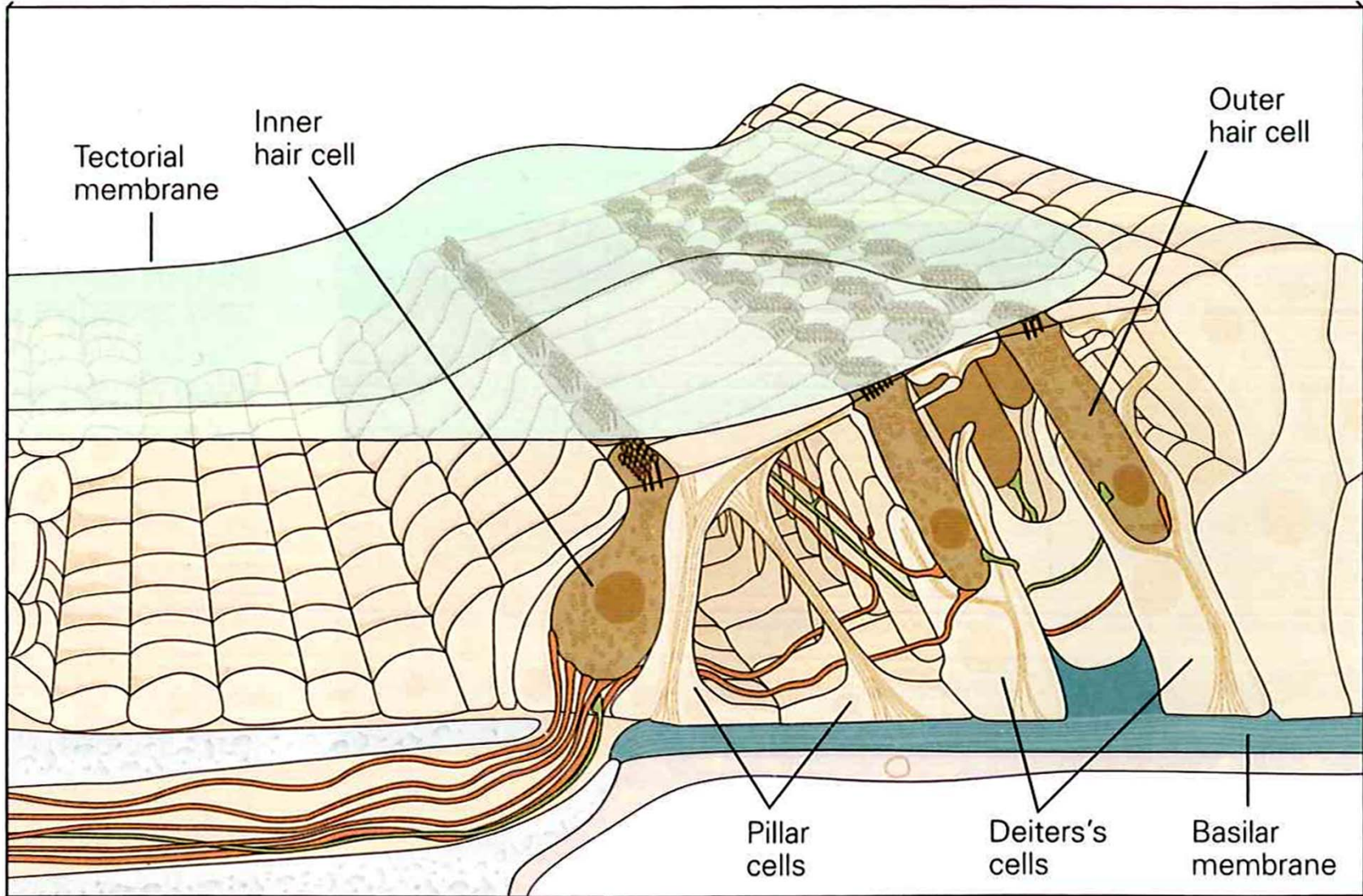
Inner ear

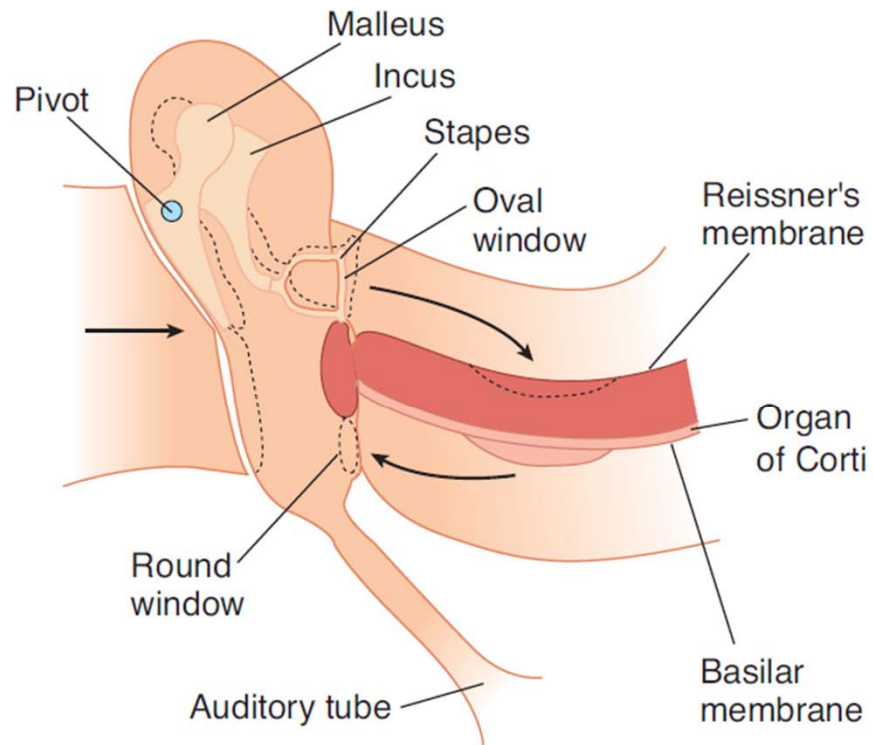
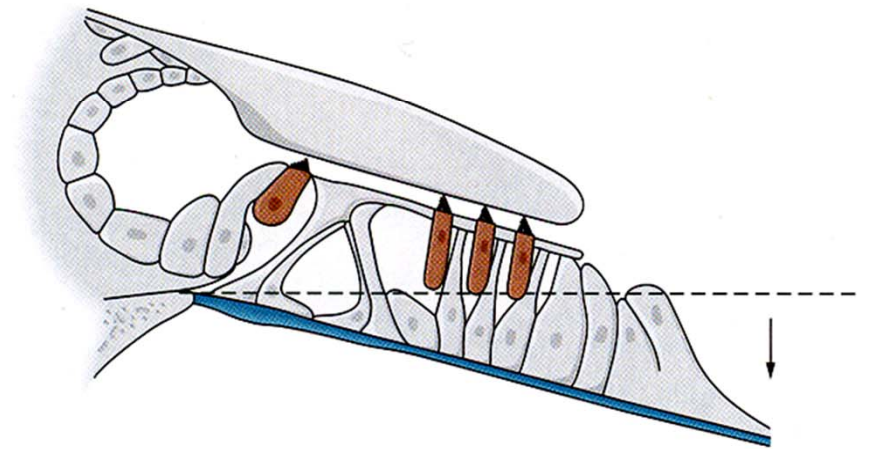
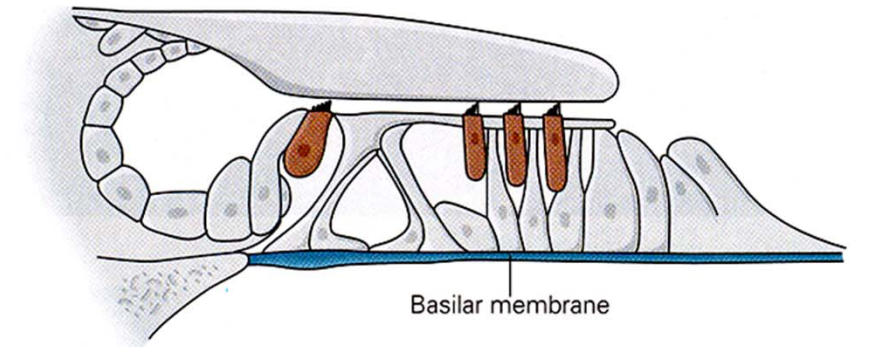
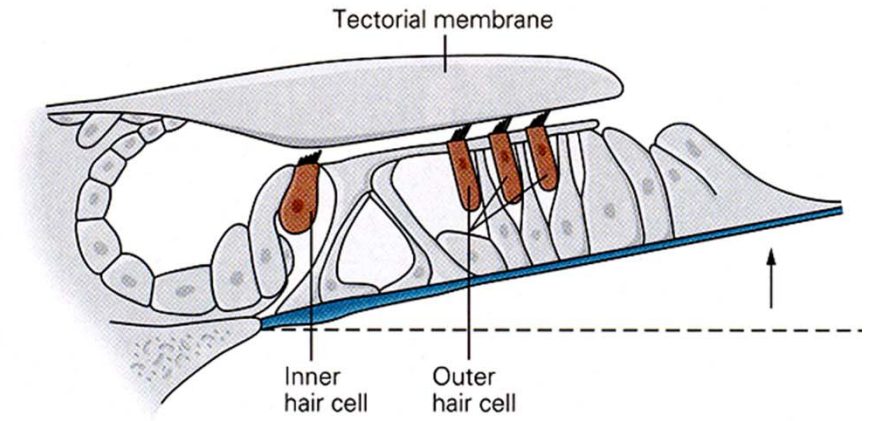
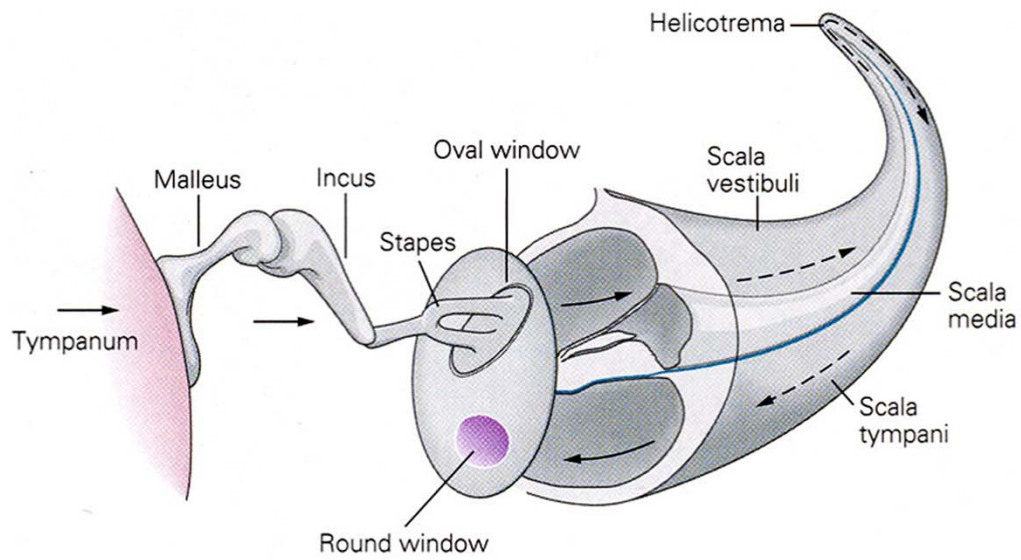
transmission of mechanical undulations of the perilymph to the neural (electric) signal

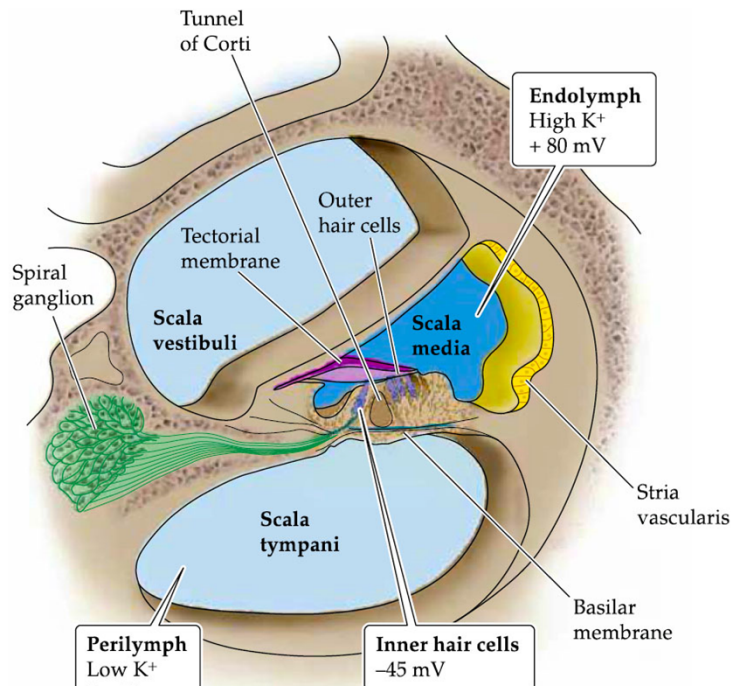




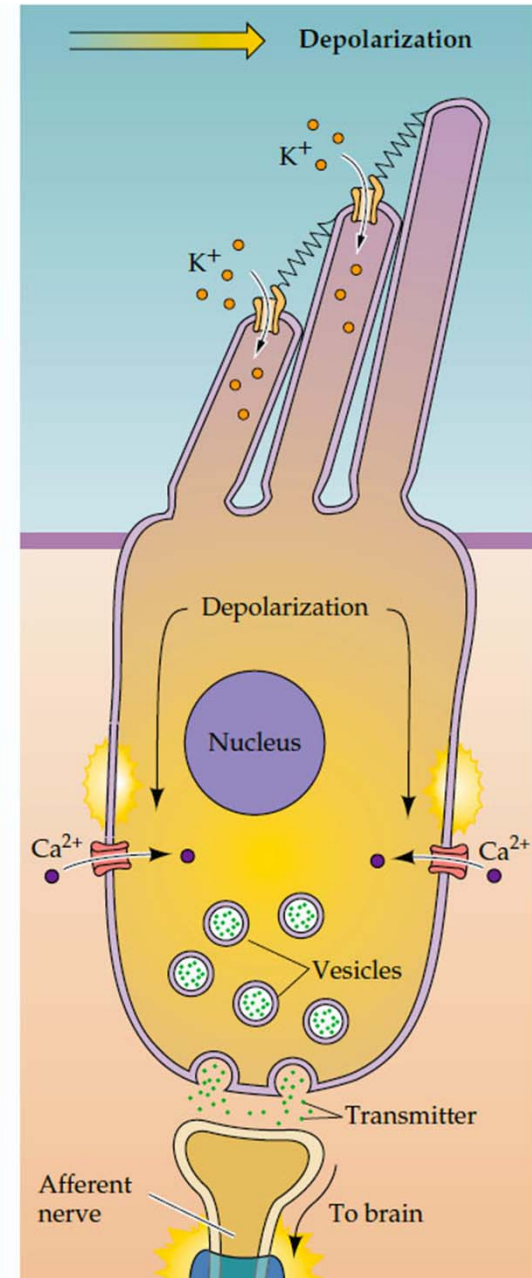
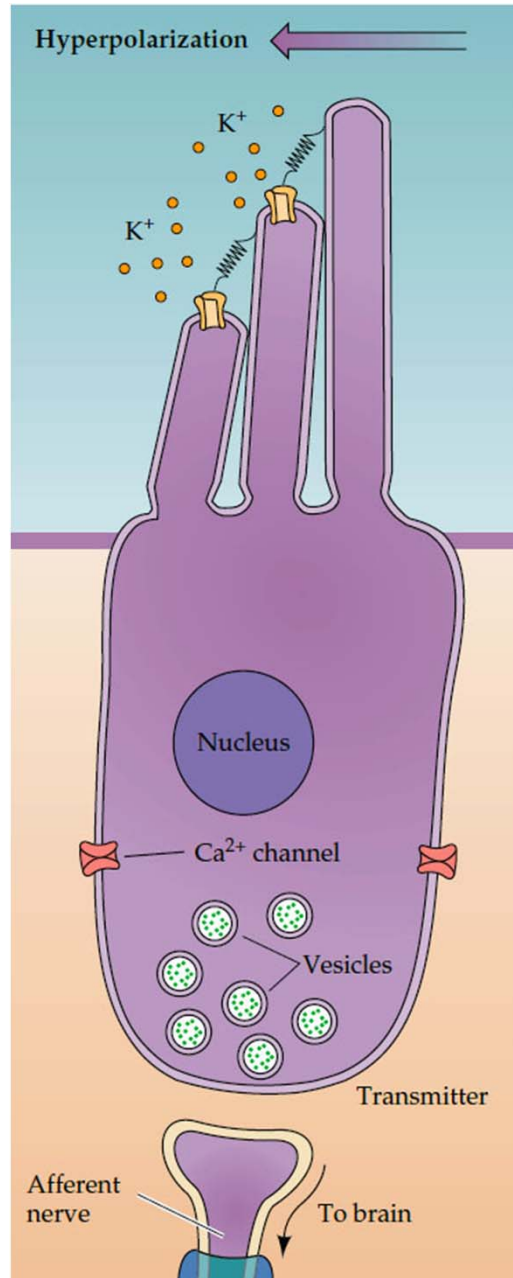
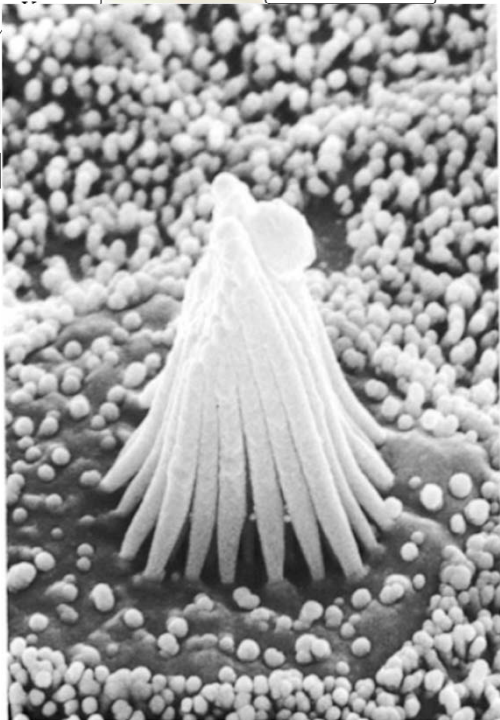


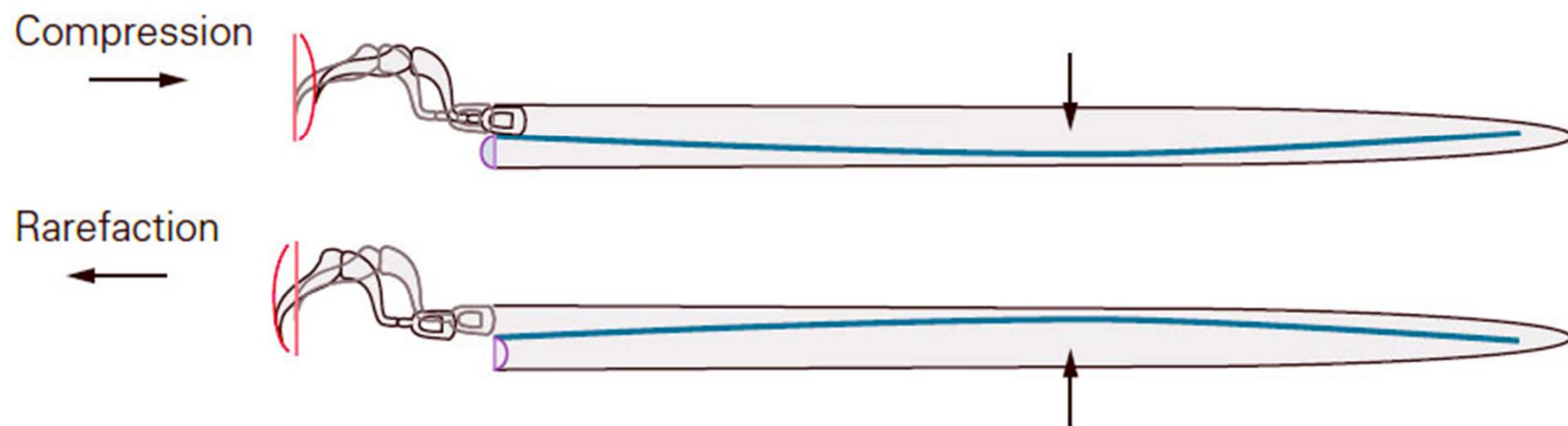
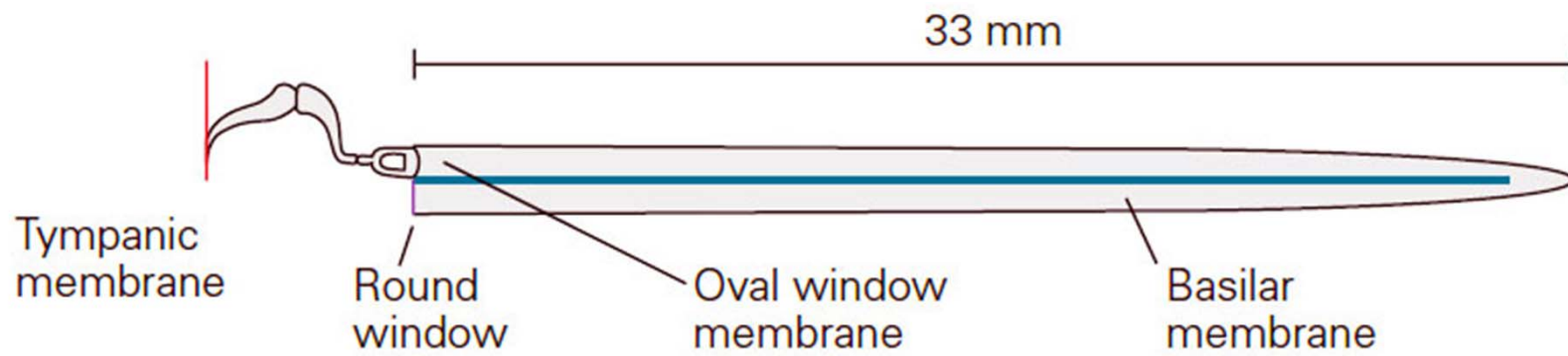




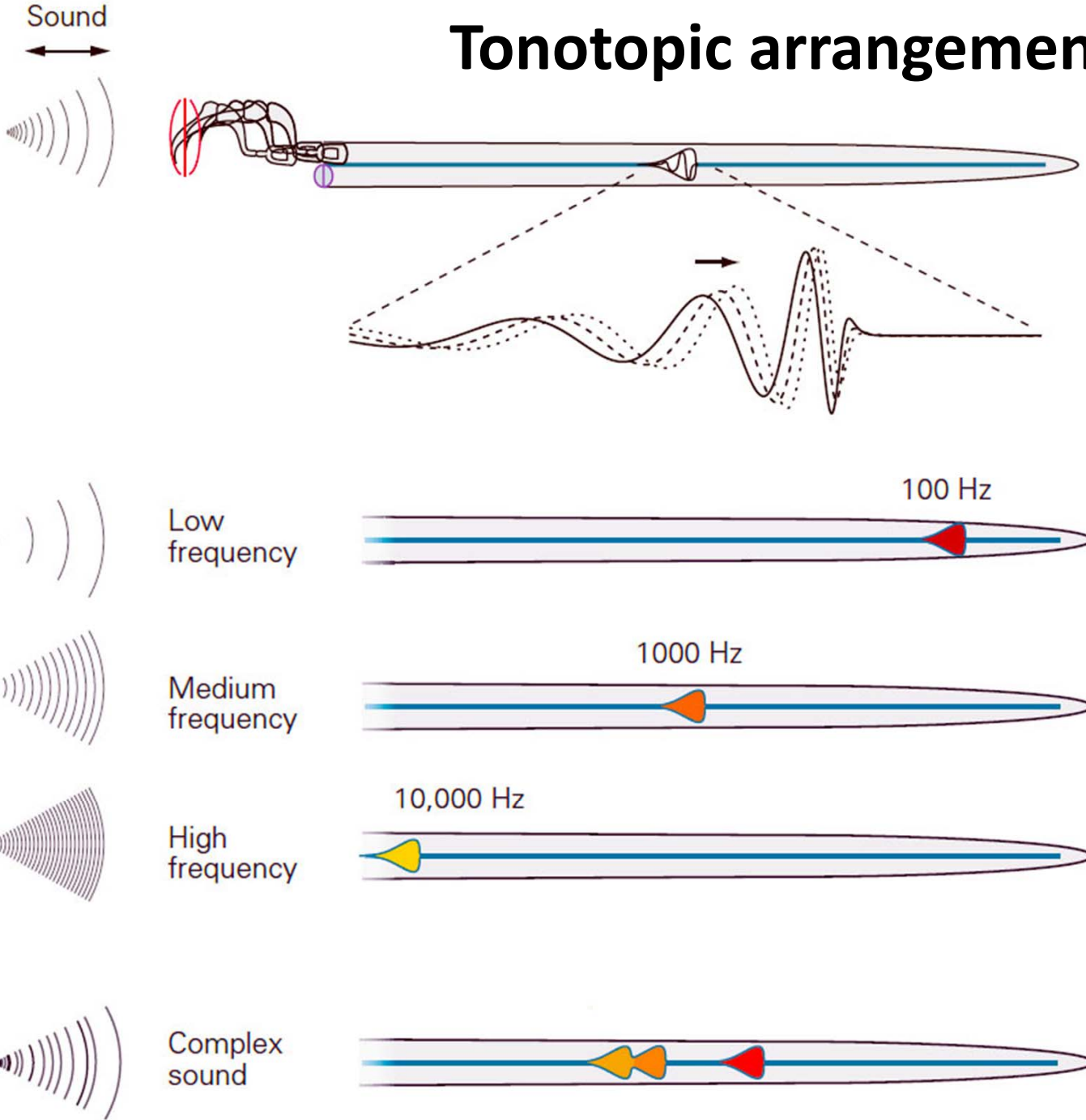


End
end
0mV





Tonotopic arrangement



Low frequency

100 Hz

Medium frequency

1000 Hz

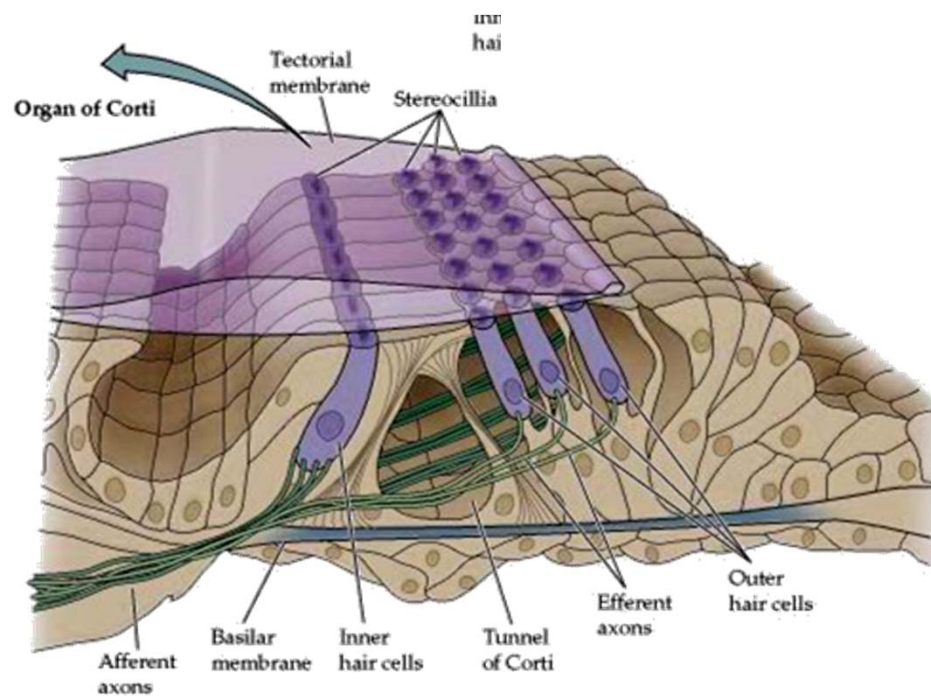
High frequency

10,000 Hz

Complex sound

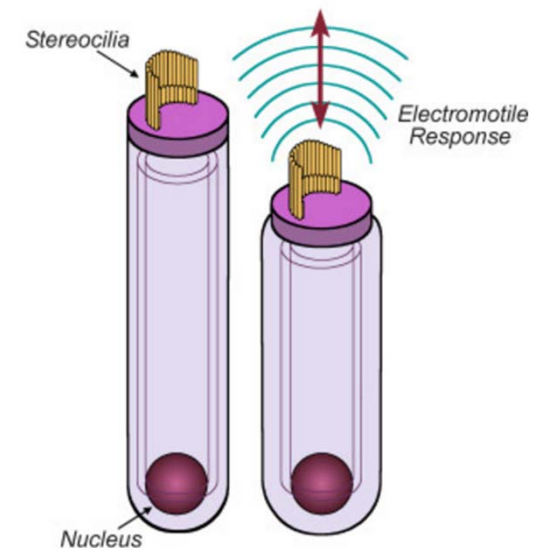
Outer hair cells

- modulation of the signal
 - ✓ amplification of the signal of required frequencies



<http://www.slideshare.net/drpsdeb/presentations>

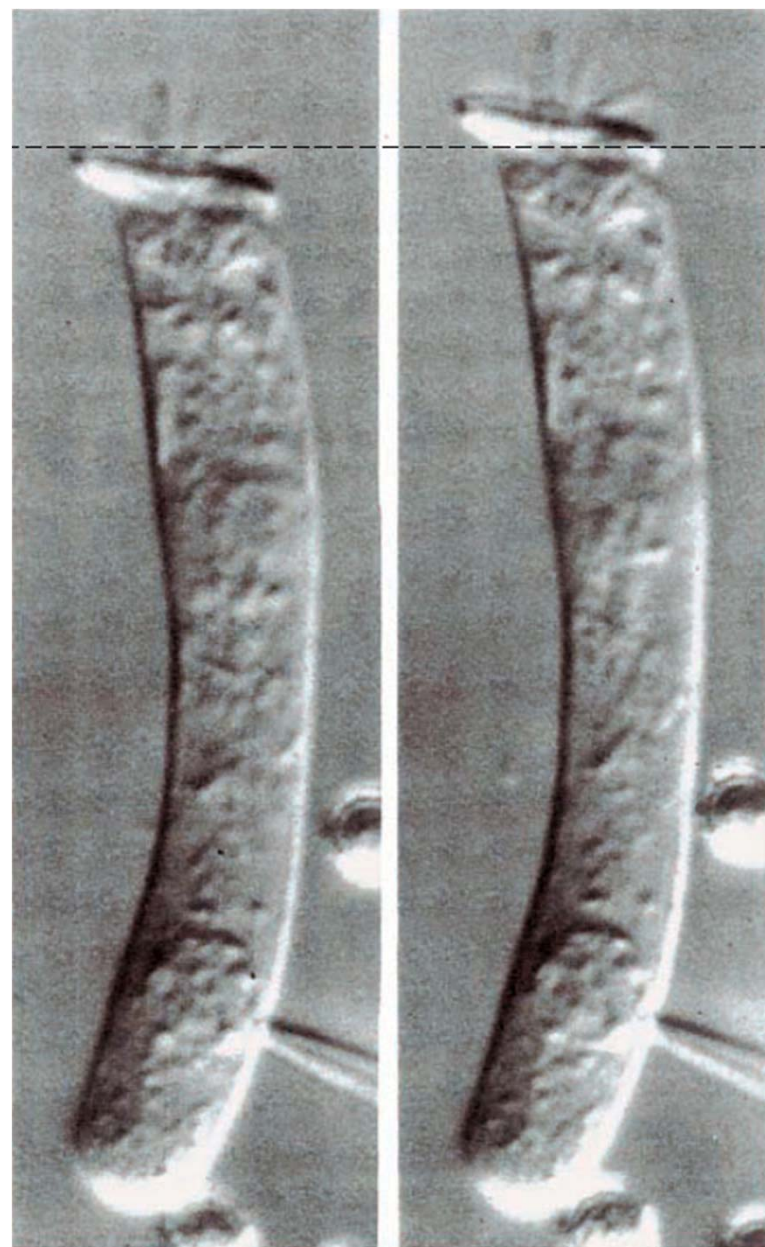
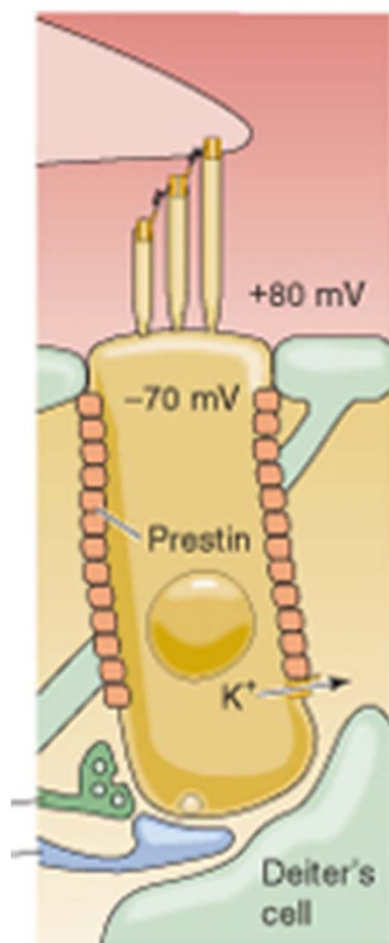
depolarization → shortening



The Outer Hair Cell

<http://www.neurophys.wisc.edu/auditory/johc.html>

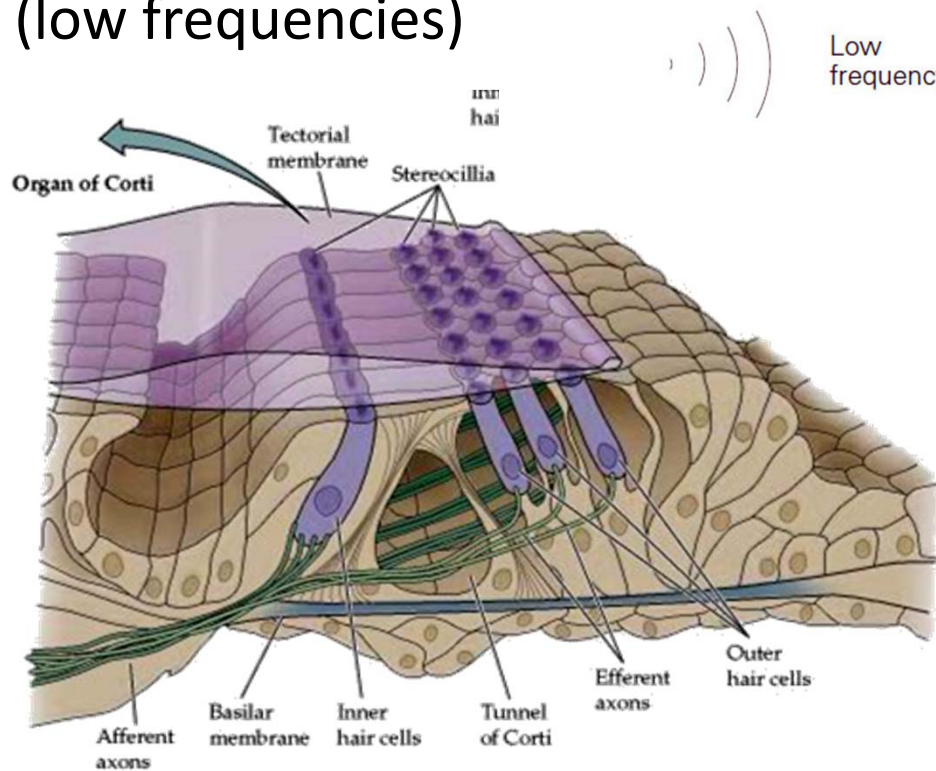
C OUTER HAIR CELL



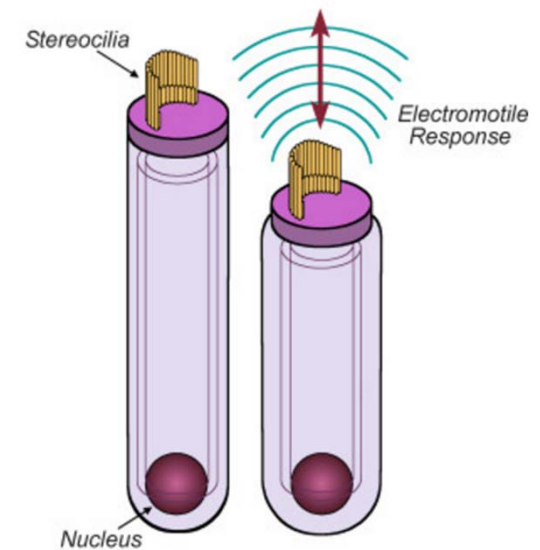
Outer hair cells

- modulation of the signal
 - ✓ amplification of the signal of required frequency
- their number increases in the direction of the apex (low frequencies)

Their action may be detected (otoacoustic emissions)

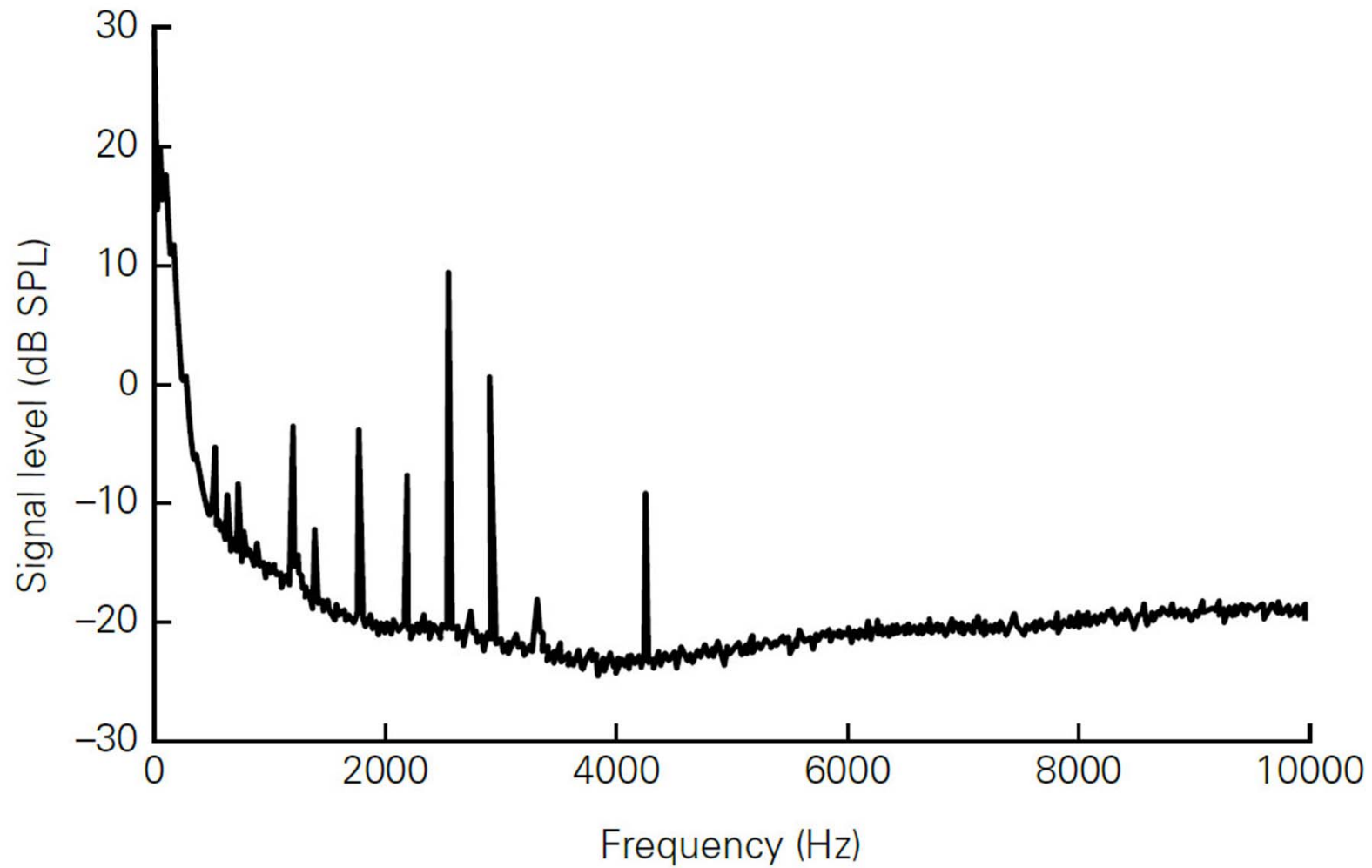


depolarization → shortening

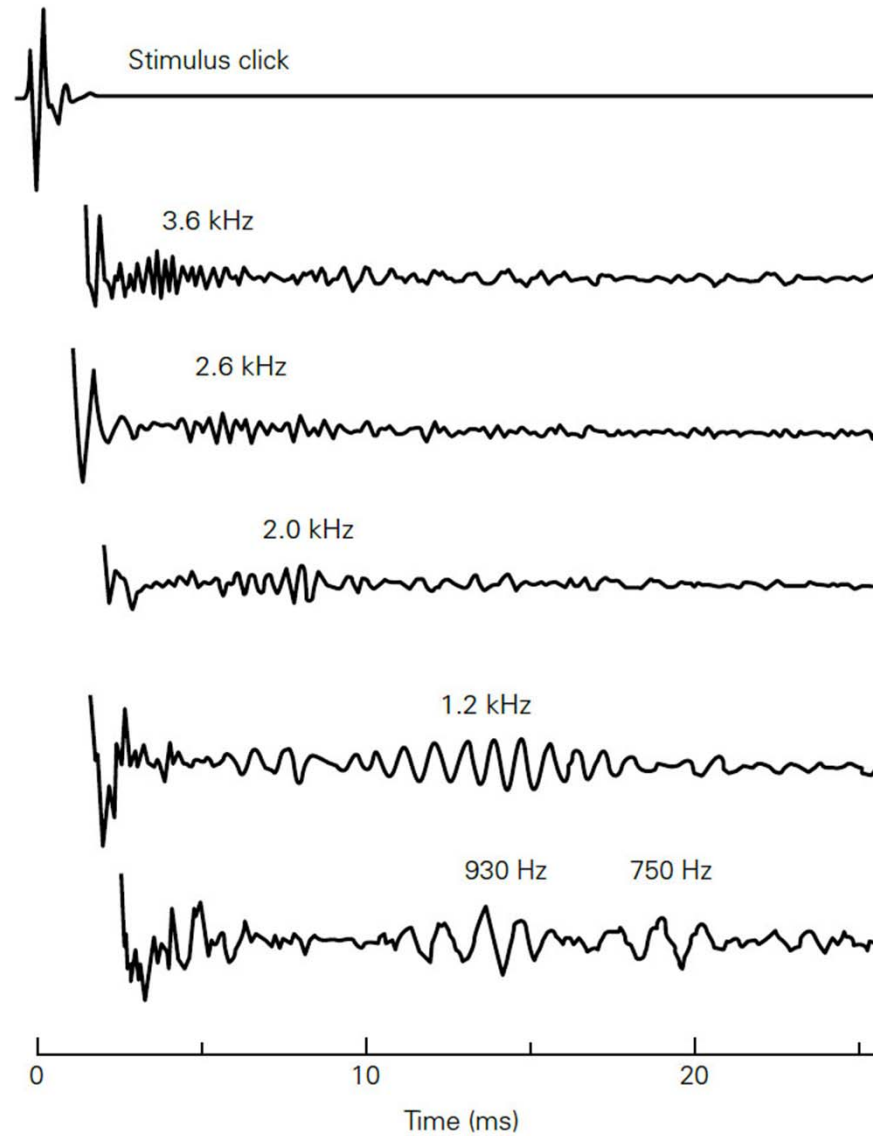


The Outer Hair Cell

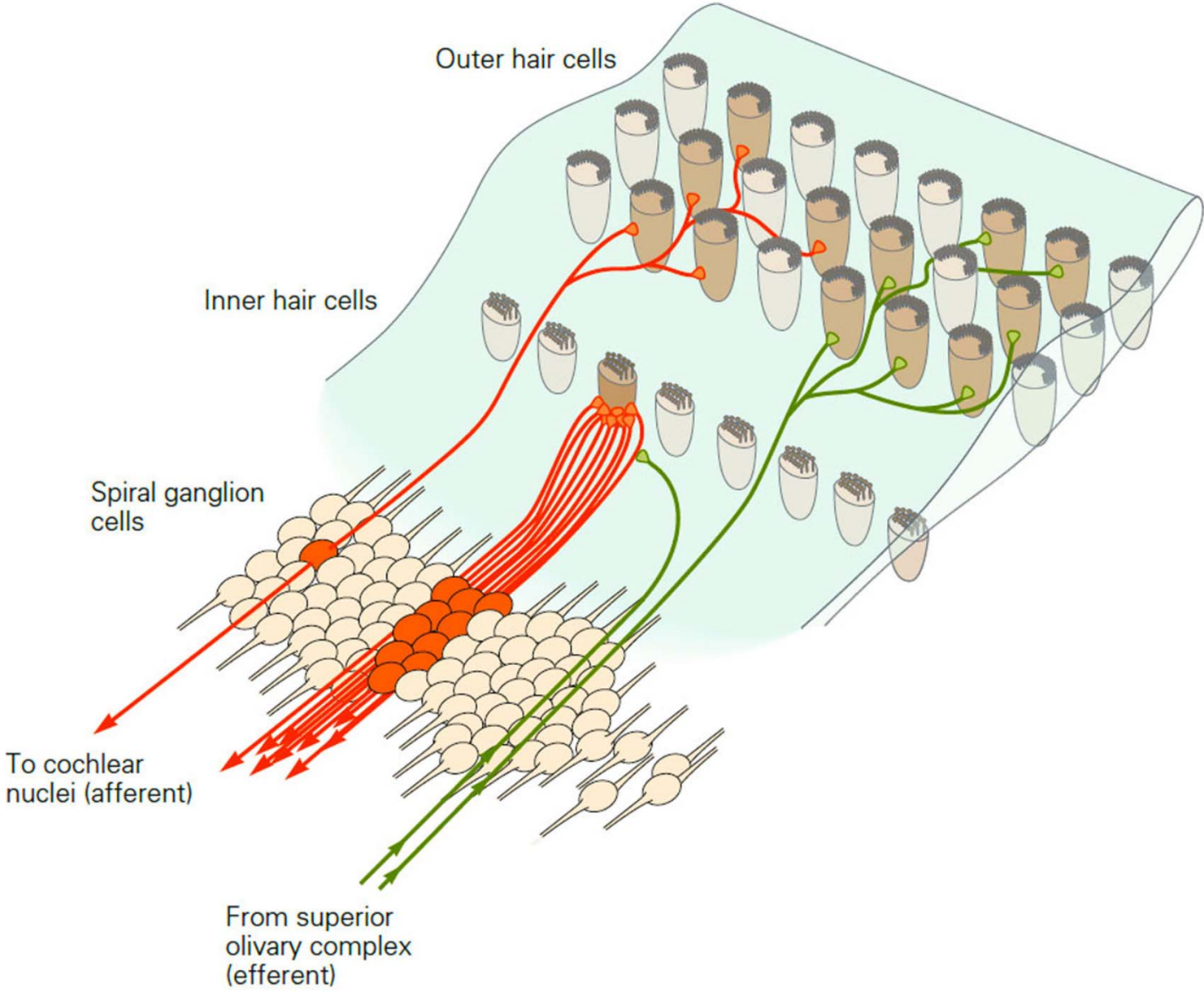
Otoacoustic emissions - spontaneous



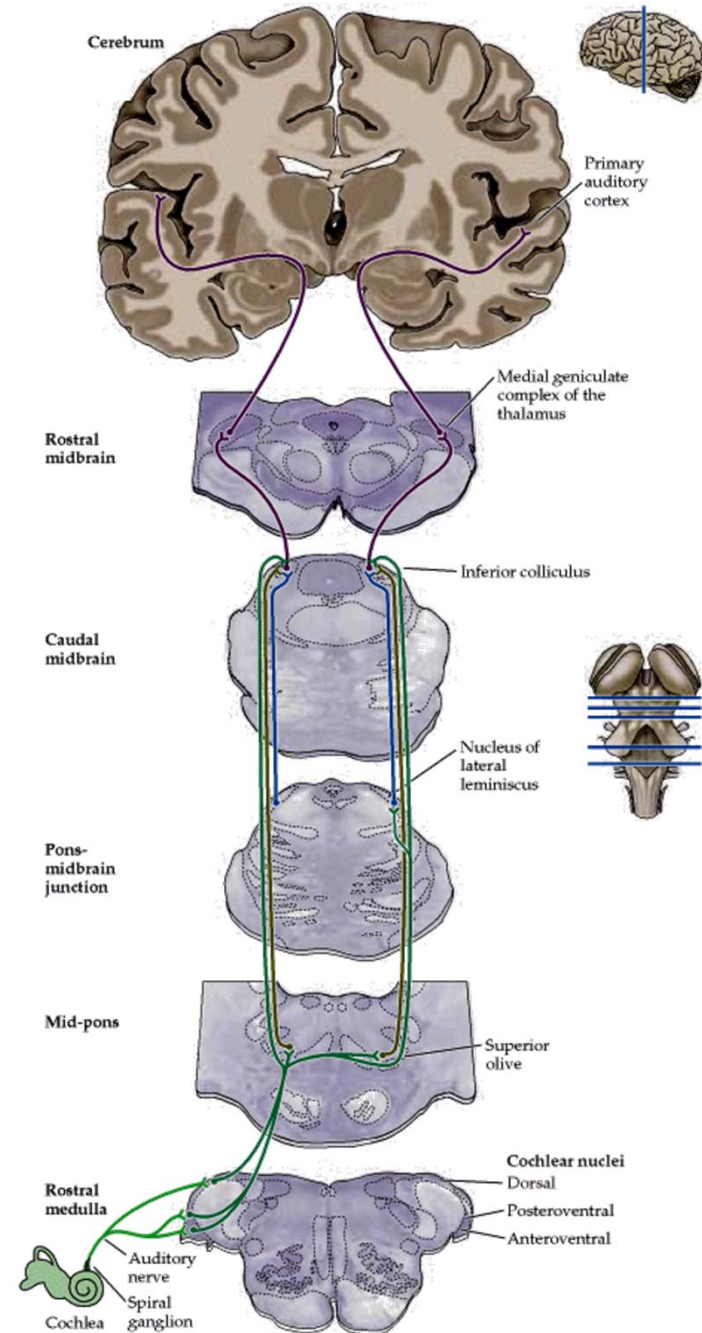
Otoacoustic emissions - evoked



Innervation of the Corti organ



- Nucleus spiralis cochleae
- Nucleus cochlearis ventralis
 - information about the intensity
 - time delay - the sound direction
- Nucleus cochlearis dorsalis
 - information about the frequency
- Olivary nuclei
 - analysis of the direction
 - modulation (increase) of sensitivity of the outer hair cells

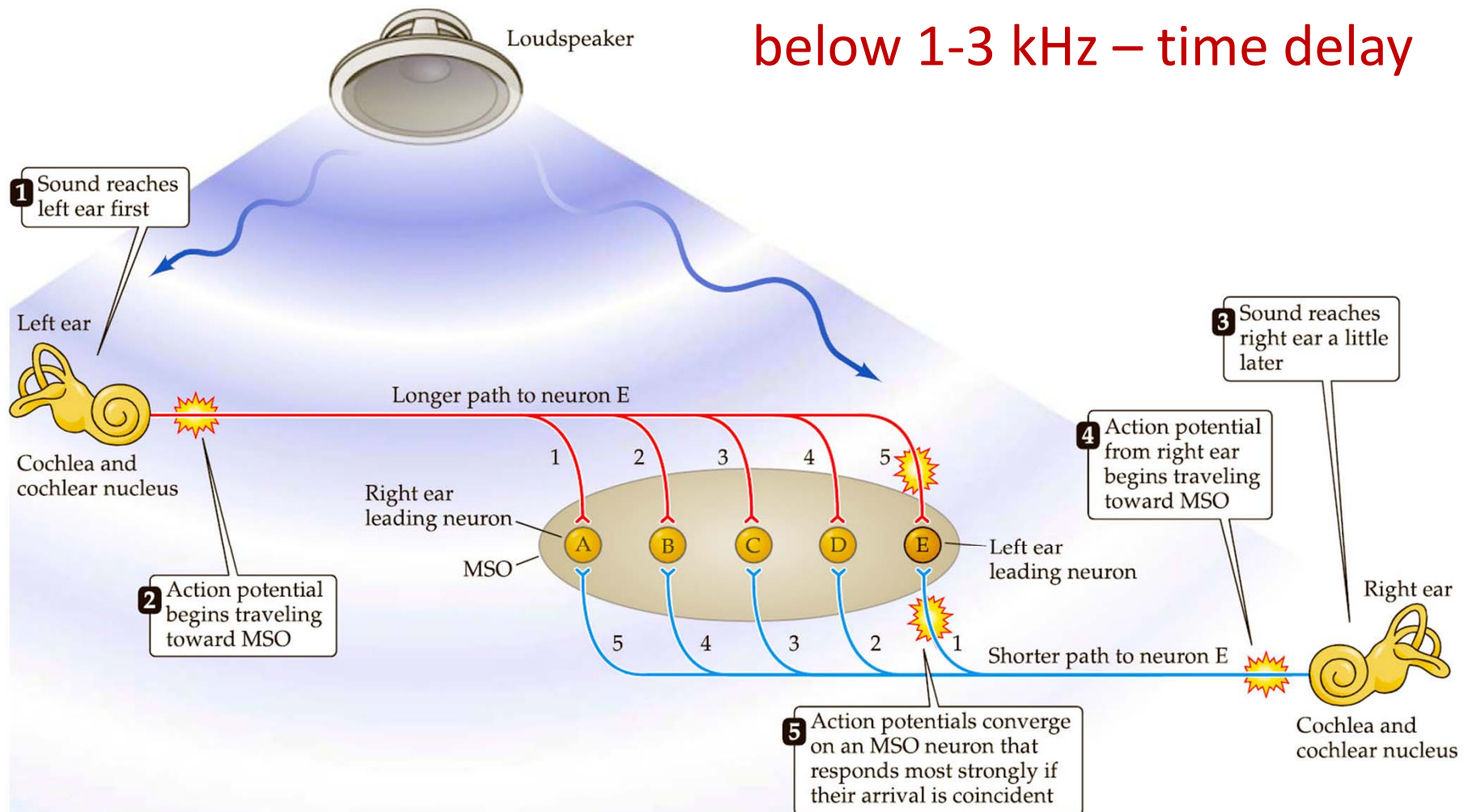


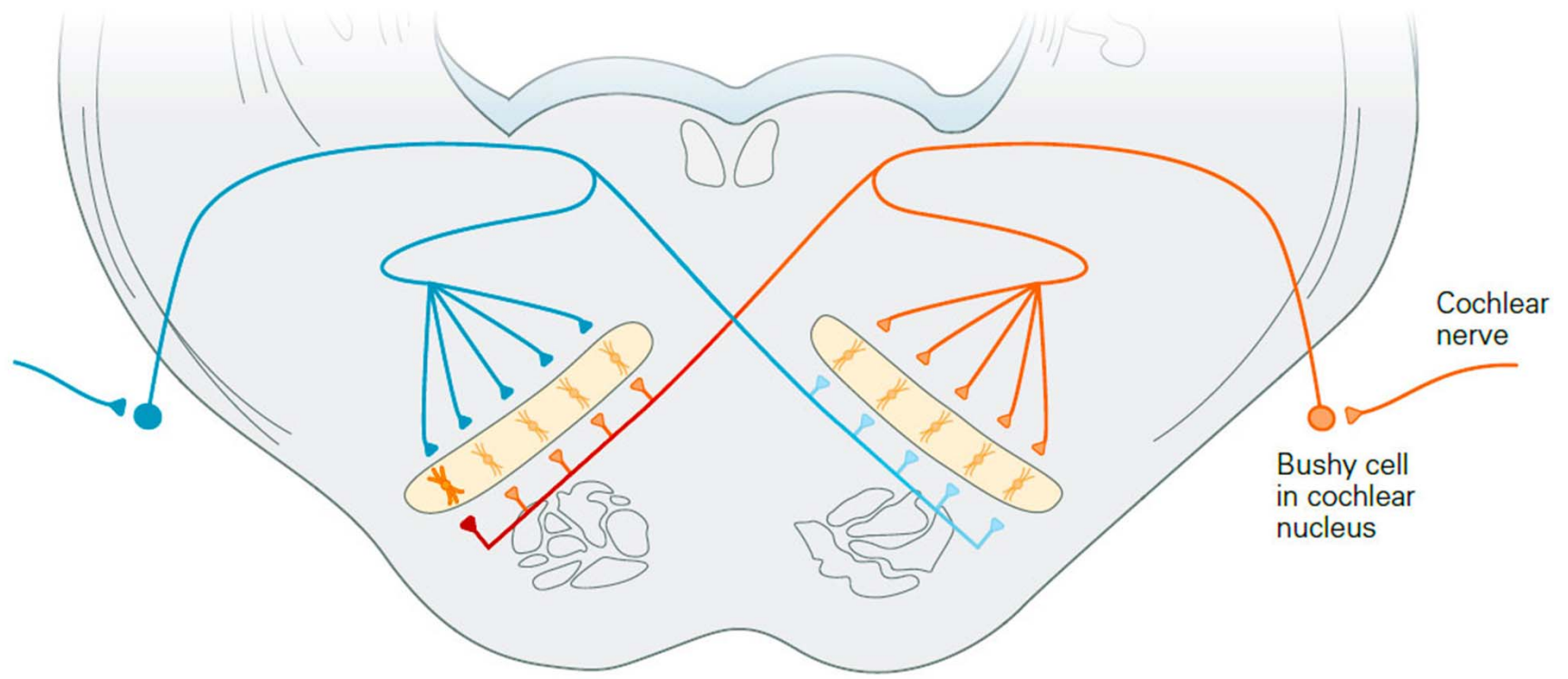
Sound localization

1. **below 3 kHz:** based on analysis of the time delay
2. **above 3 kHz:** based non the analysis of loudness

Nucleus olivaris superior medialis

localization of the sound based on analysis of the time delay

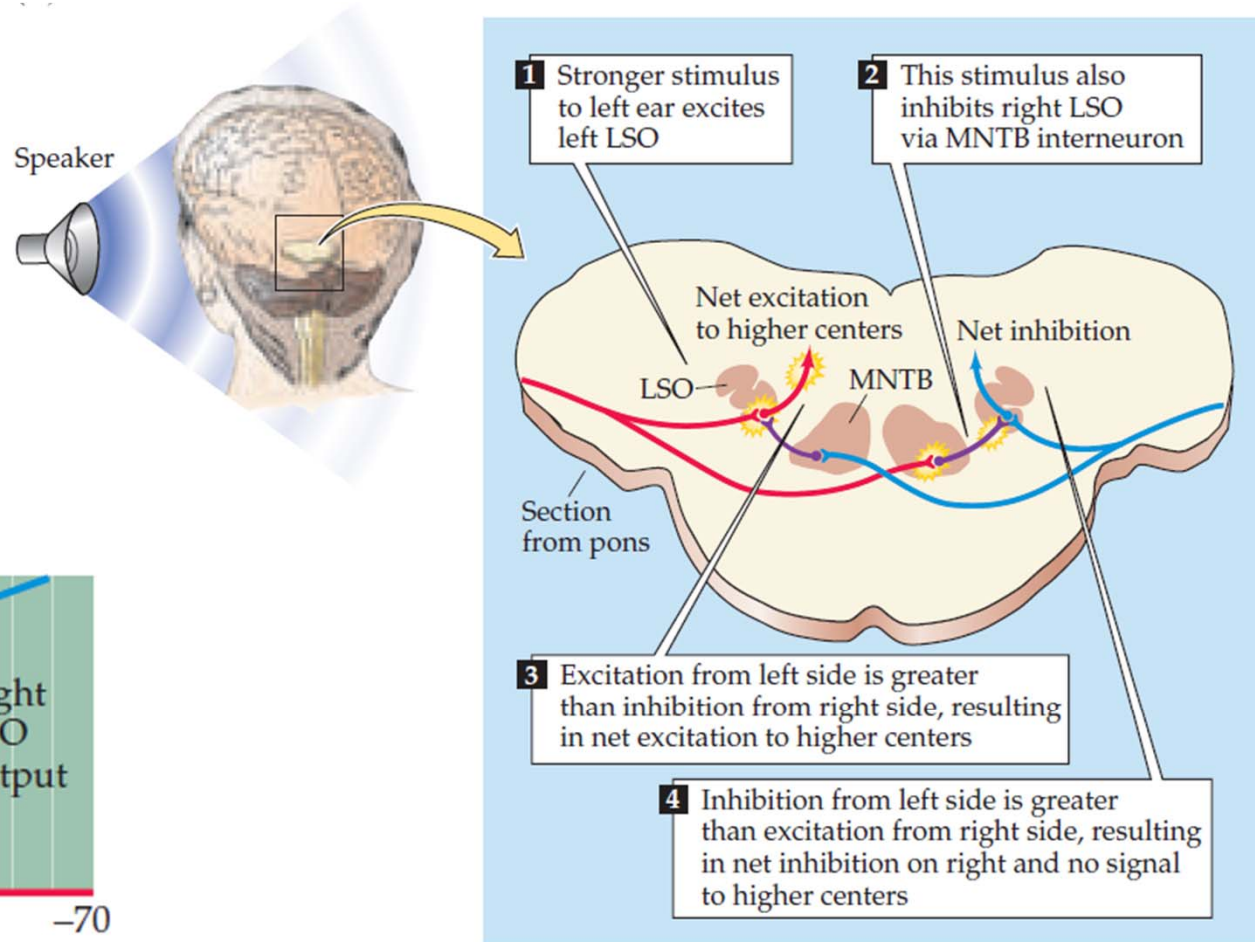
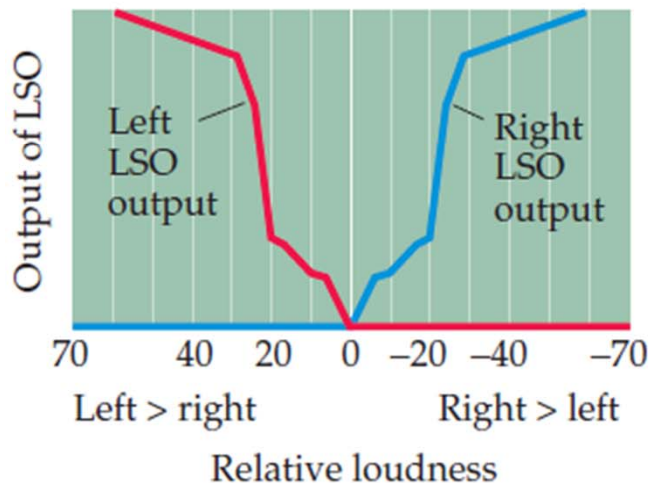




Nucleus olivaris superior lateralis

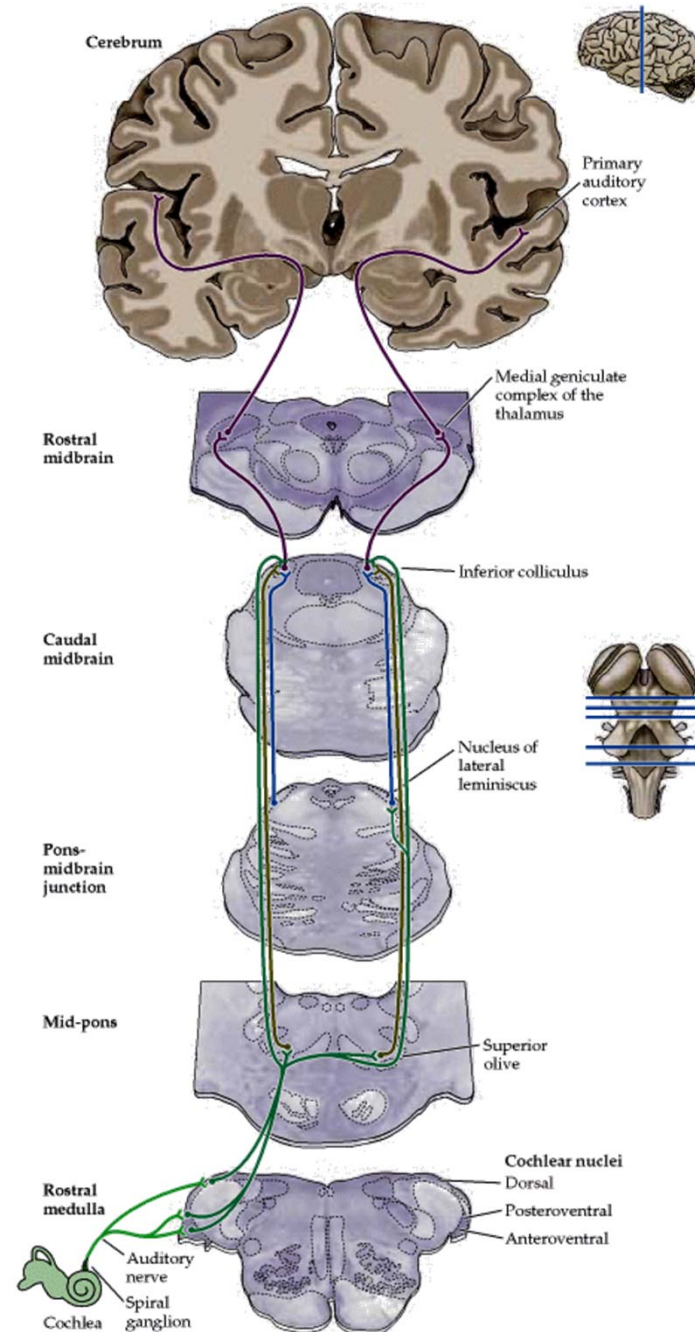
localization of the sound based on analysis of the intensity

from 1-2 kHz –
intensity

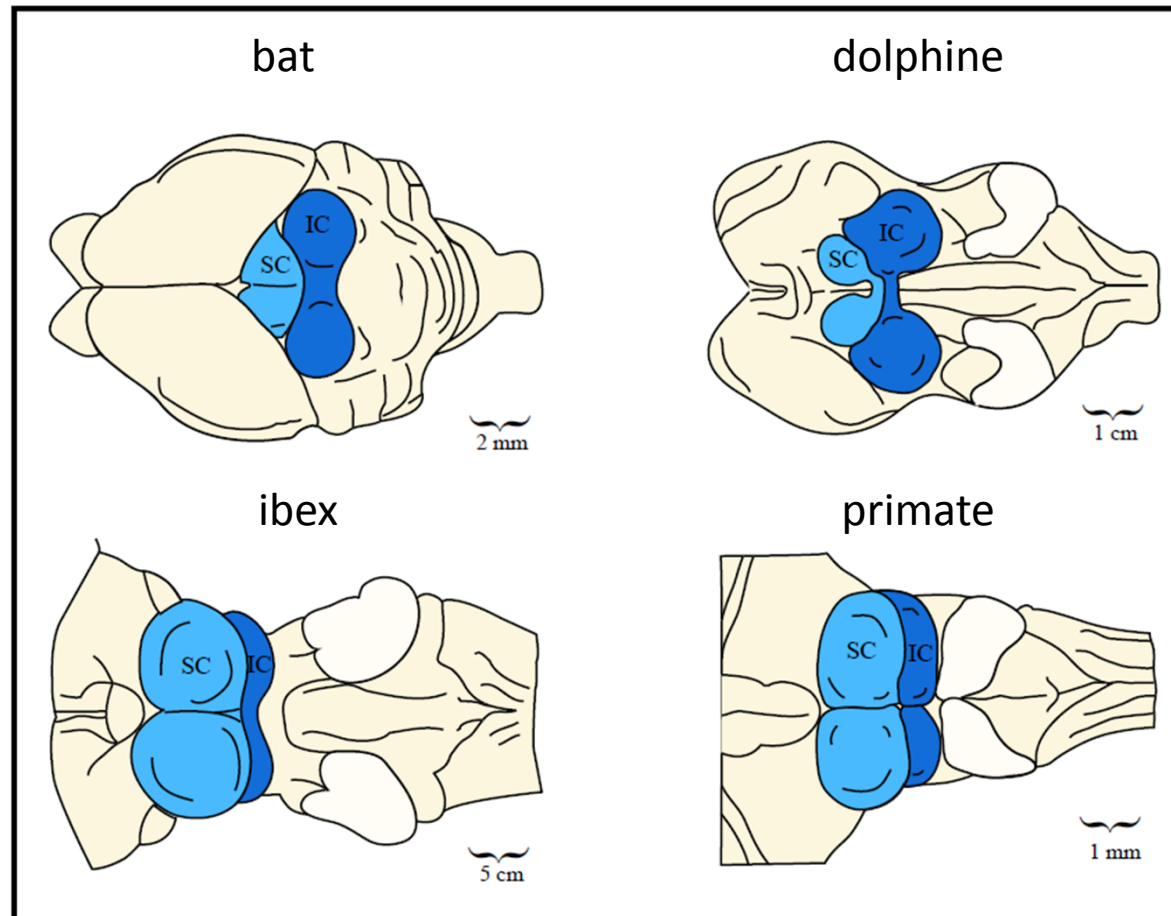


MNTB – medial nucleus of the trapezoid body

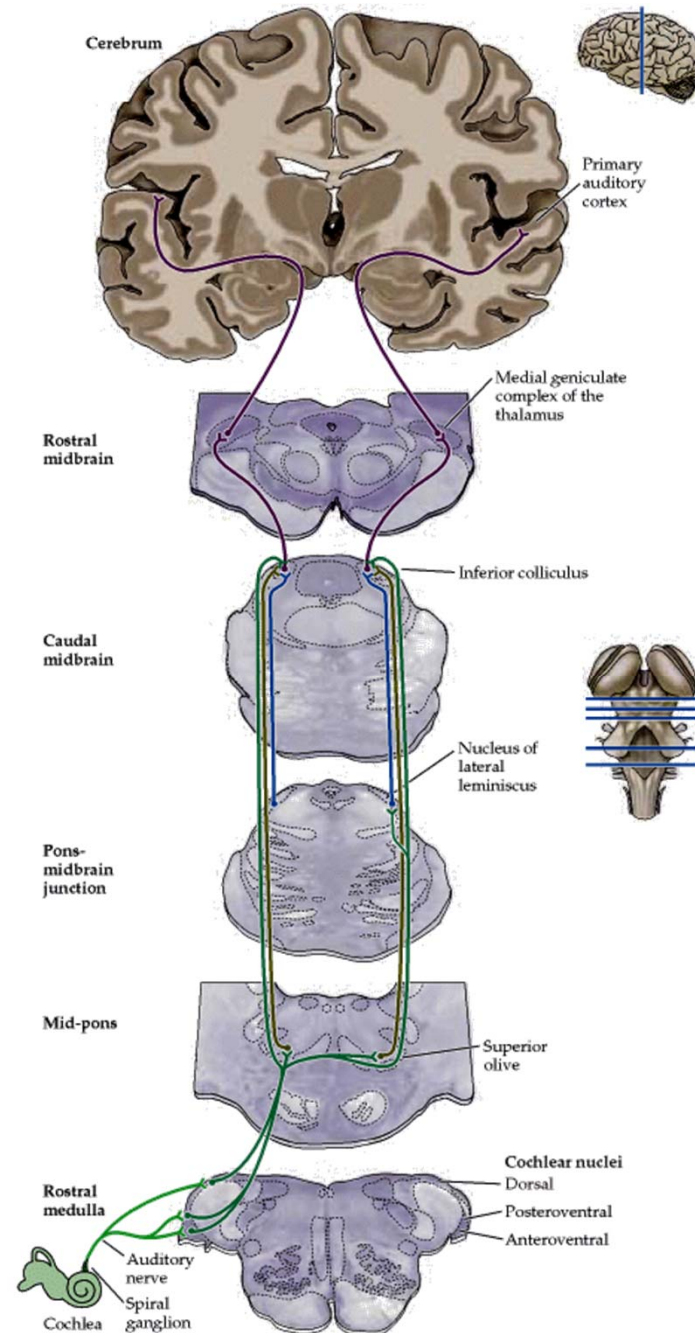
- Nucleus spiralis cochleae
- Nucleus cochlearis ventralis
 - information about the intensity
 - time delay - the sound direction
- Nucleus cochlearis dorsalis
 - information about the frequency
- Olivary nuclei
 - analysis of the direction
 - modulation (increase) of sensitivity of the outer hair cells
- Colliculi inferiores
 - integration of information from the lower structures
 - centre of the acoustic reflexes



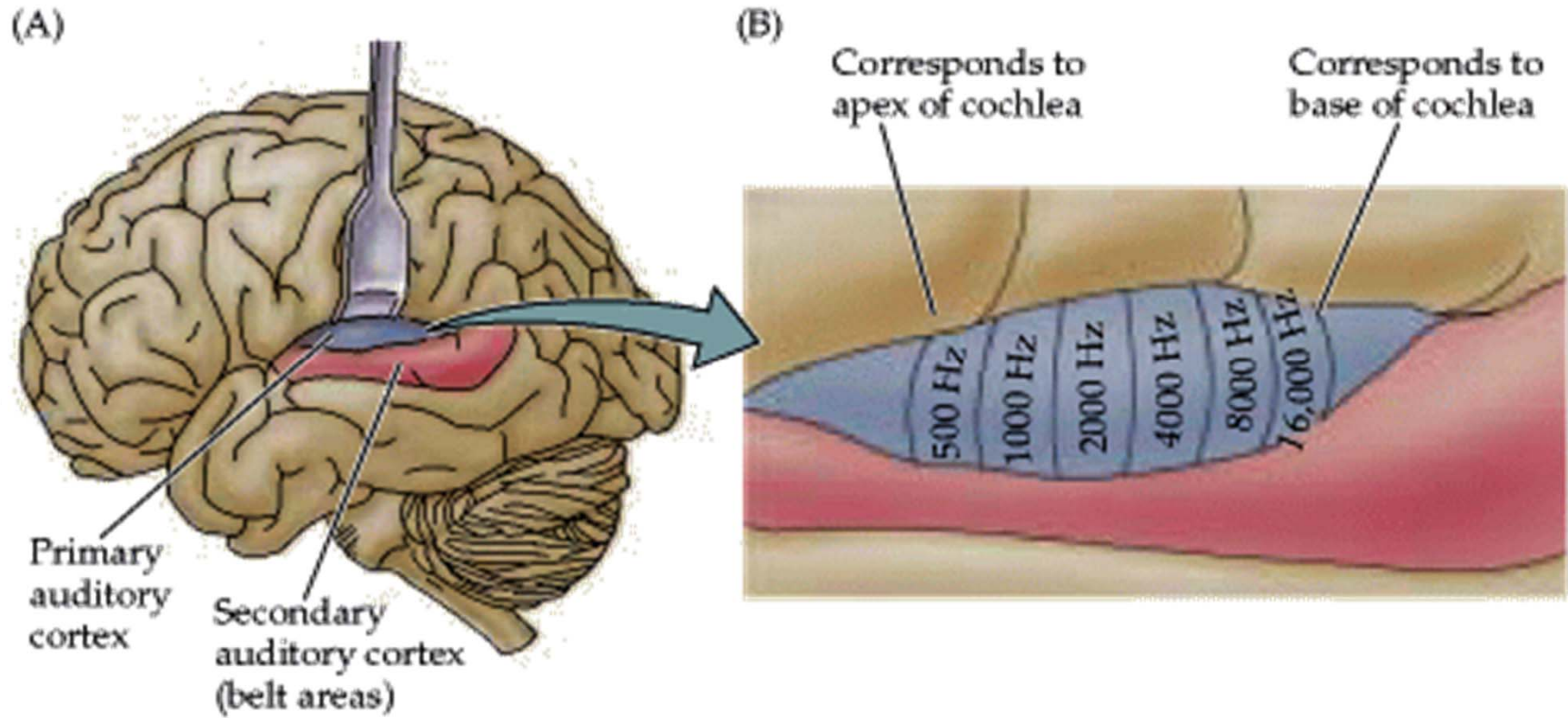
Colliculi inferiores in various animal species



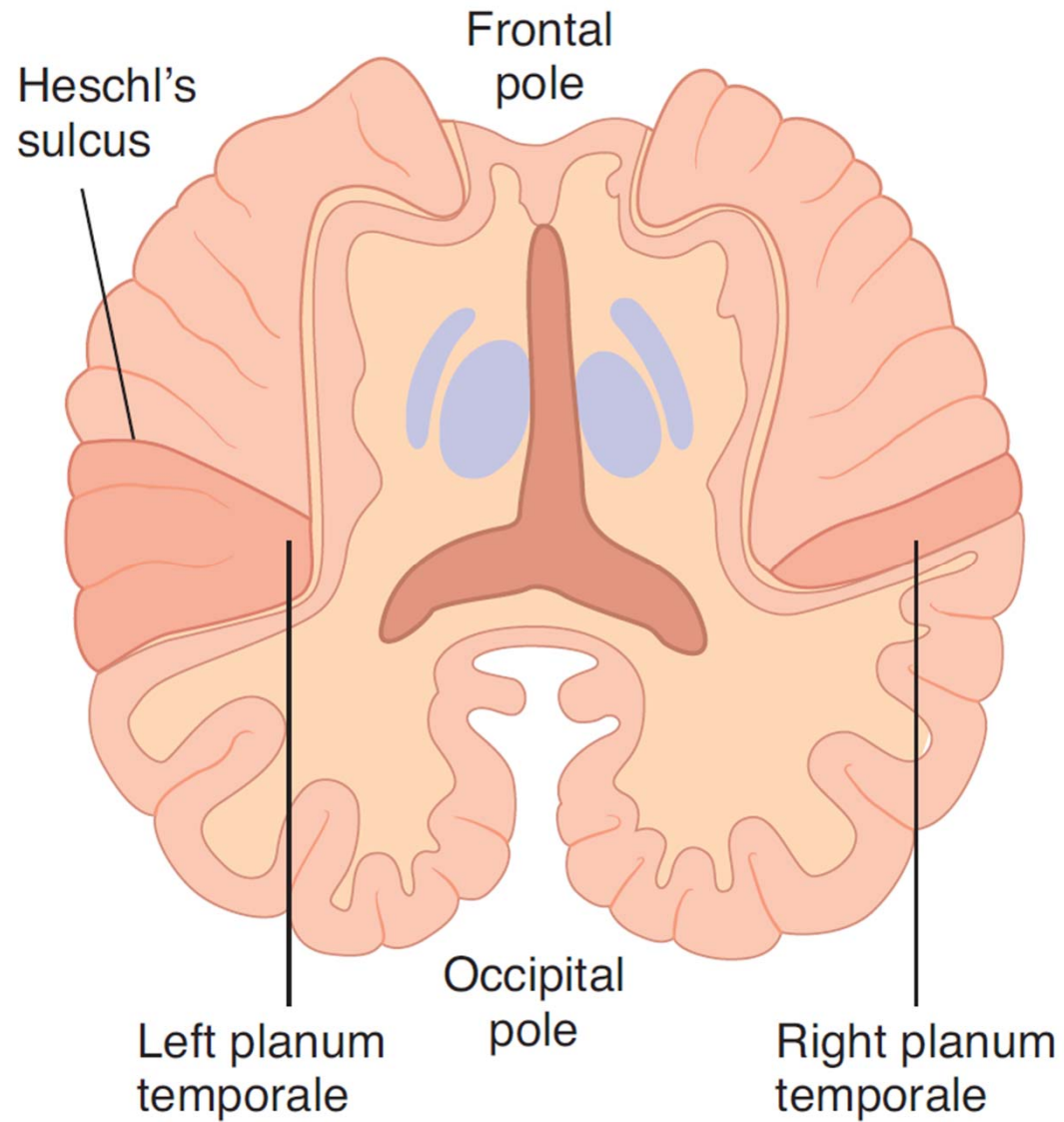
- Nucleus spiralis cochleae
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 - analysis of the direction
 - modulation (increase) of sensitivity of the outer hair cells
- Colliculi inferiores
 - integration of information from the lower structures
 - centre of the acoustic reflexes
- Nucleus corporis geniculati medialis (thalamus)
- Auditory cortex



Auditory cortex



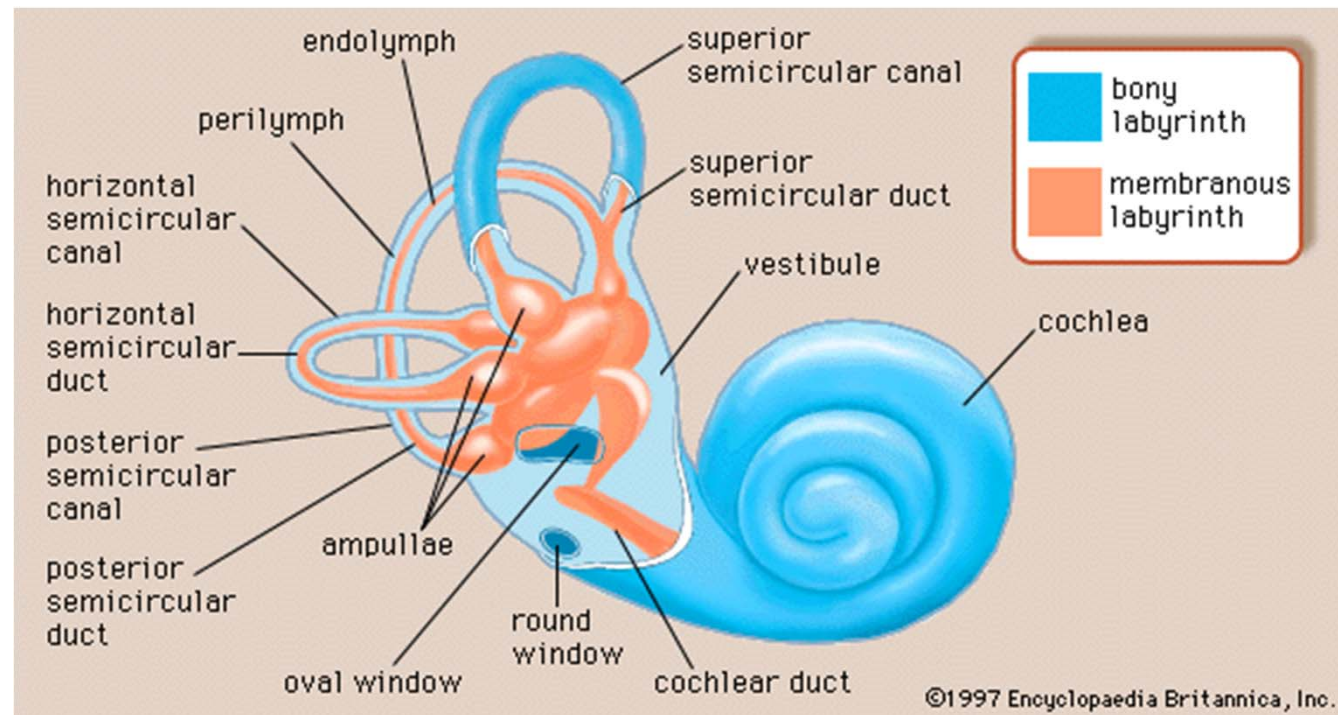
Auditory cortex



Vestibular system

Vestibular system

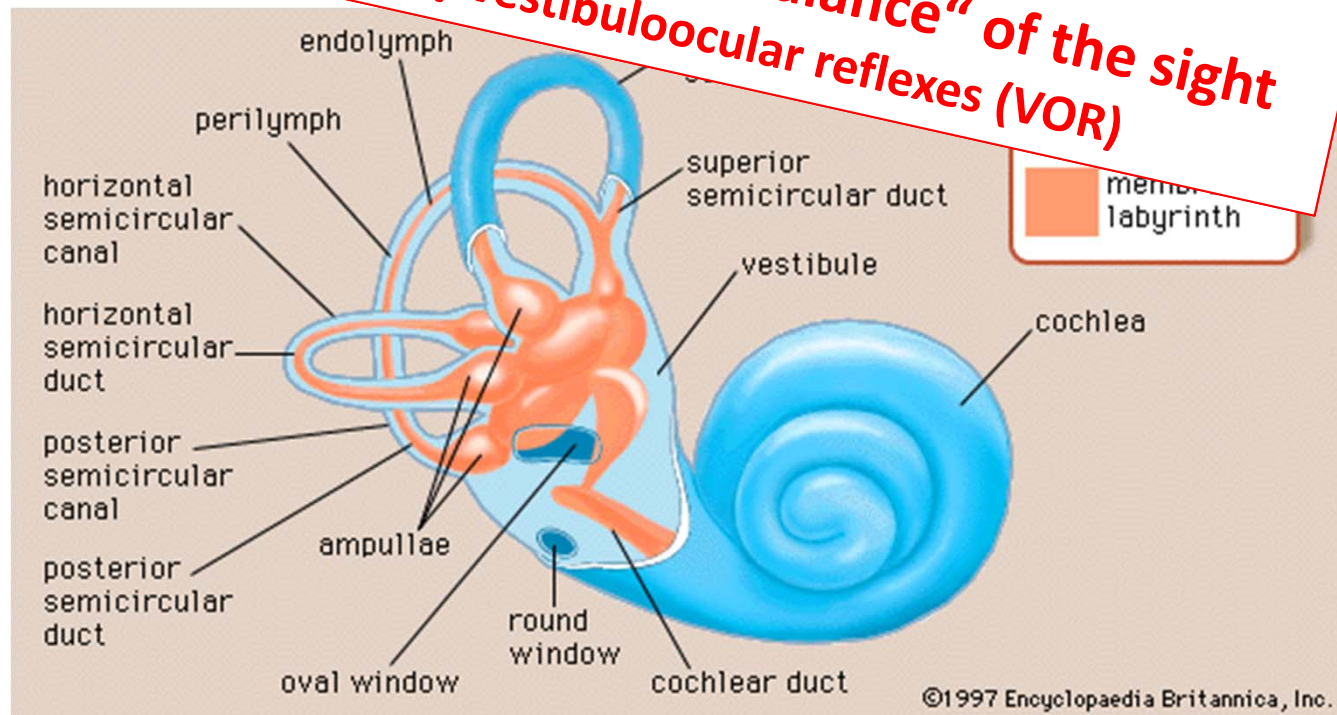
- anatomic localization, hair cells
- information about the position
- information about the acceleration
 - Linear
 - Angular



Vestibular system

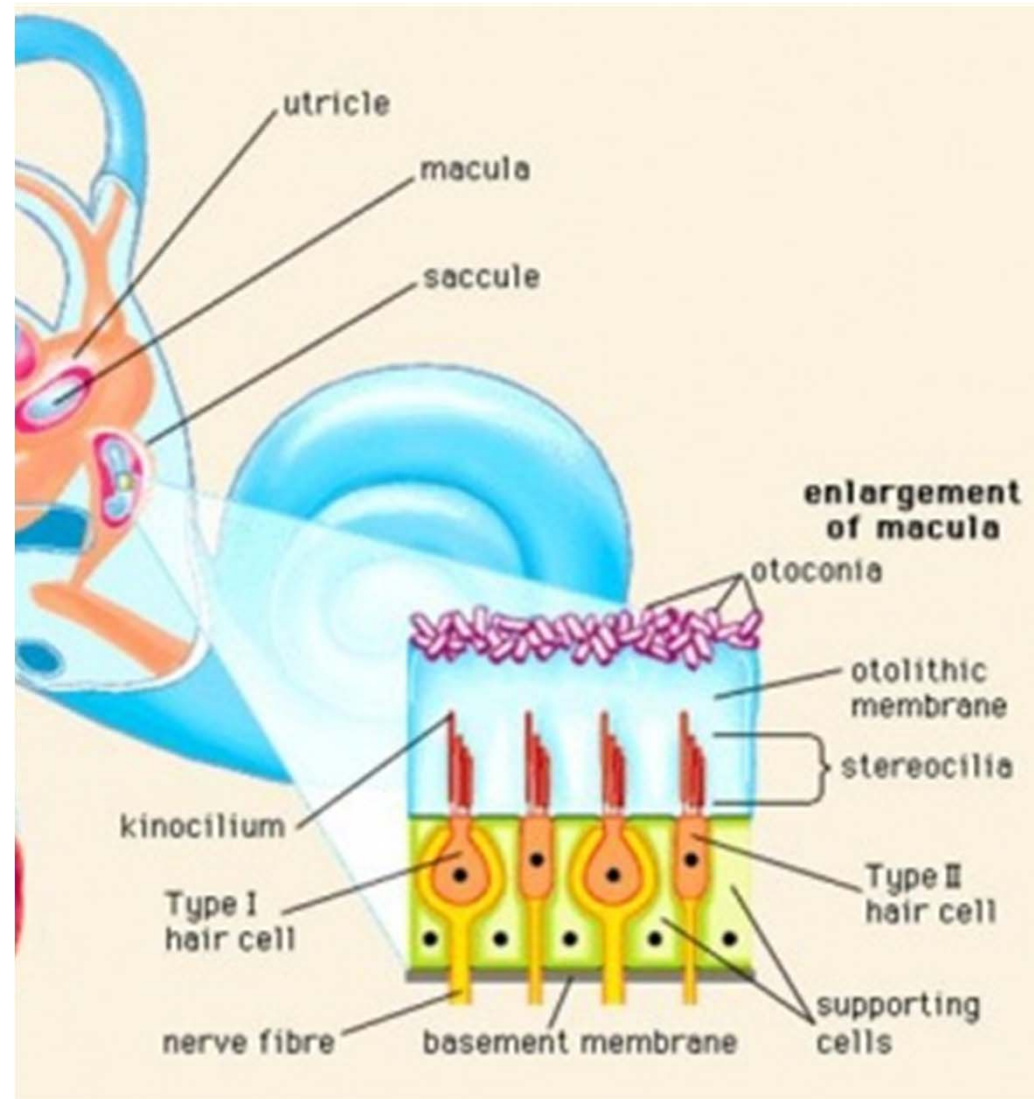
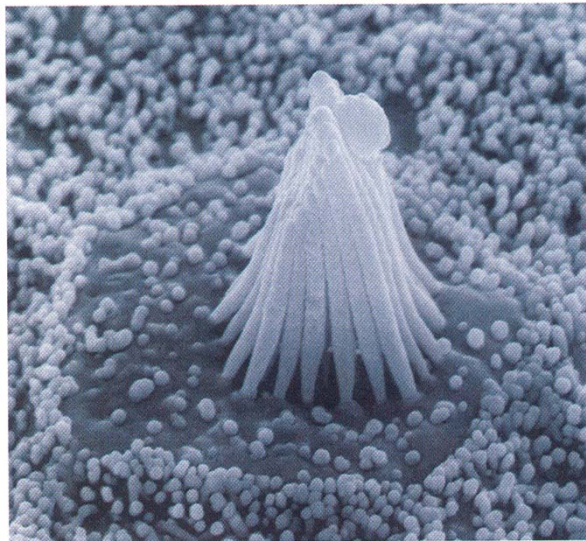
- anatomic localization
- information about
- information about
 - Linear
 - Angular

Maintenance of the balance
by modification of the muscle tone
„Maintenance of the balance“ of the sight
by vestibuloocular reflexes (VOR)



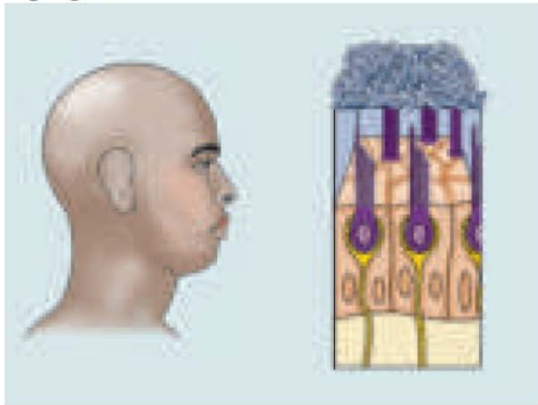
Information about position and linear acceleration

- Macula
 - Crystals of CaCO_3
- Utriculus
 - Macula horizontally
- Sacculus
 - Macula vertically

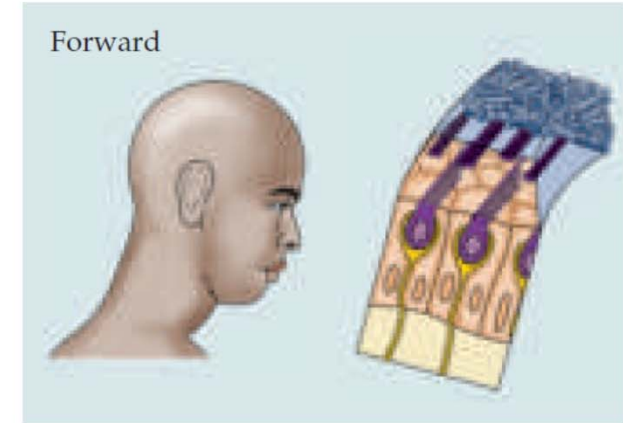
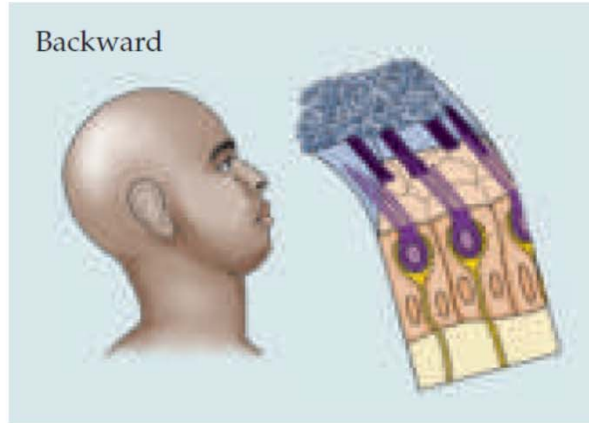


Information about position and linear acceleration

Upright



Head tilt; sustained



No head tilt; transient

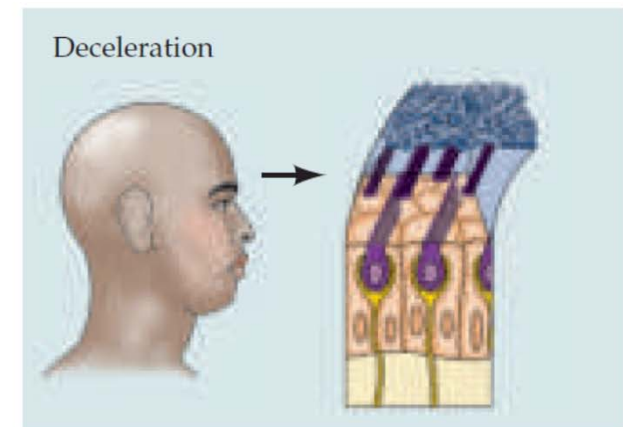
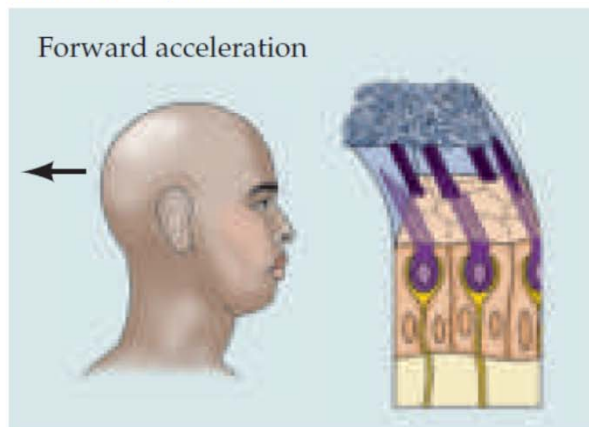
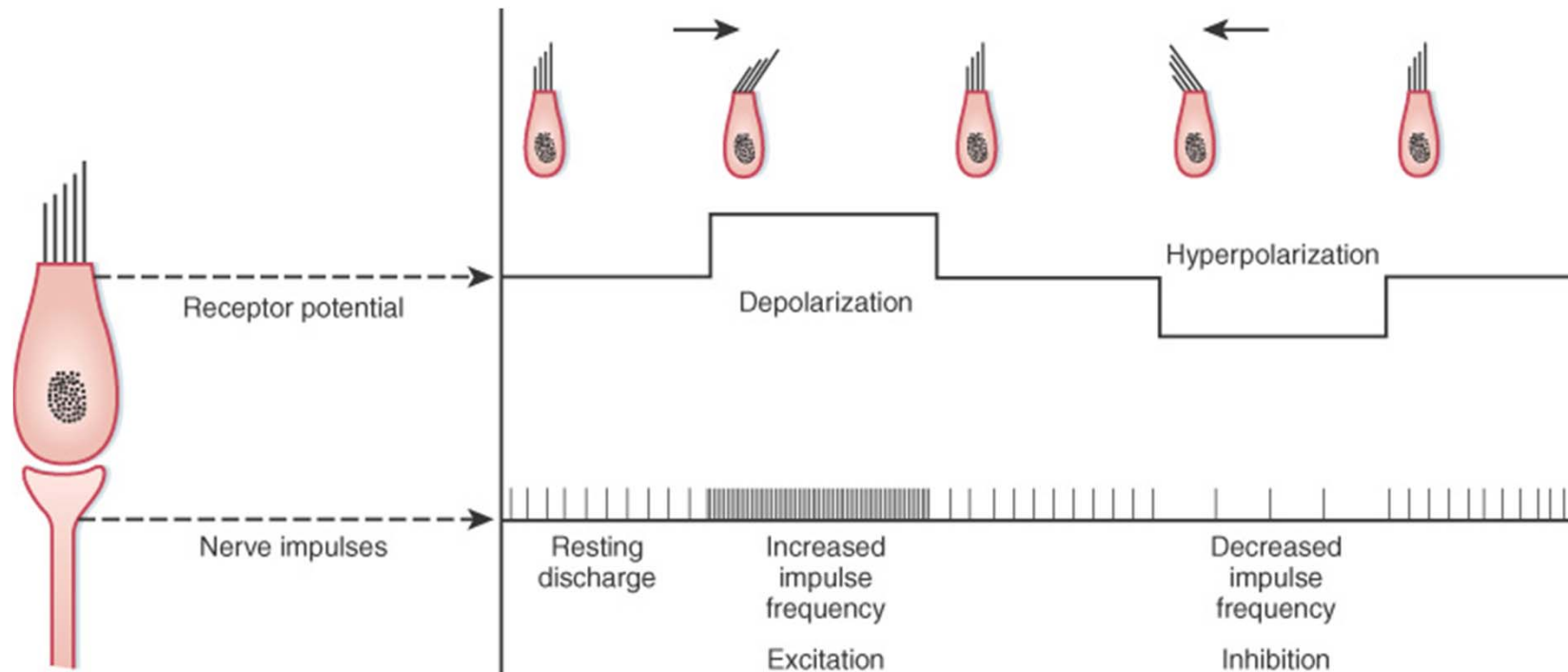
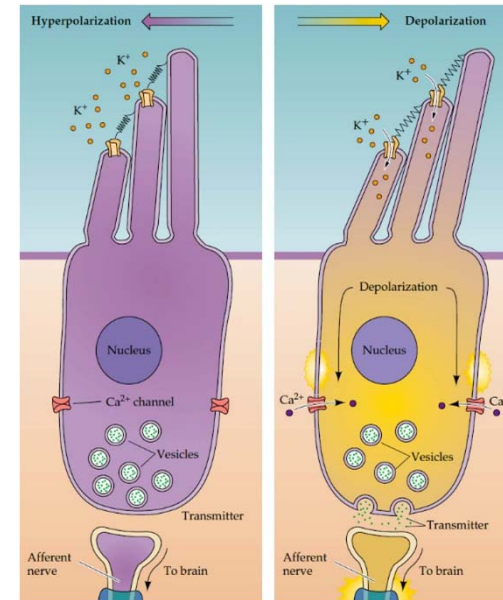


Figure 13.5 Forces acting on the head and the resulting displacement of the otolithic membrane of the utricular macula. For each of the positions and accelerations due to translational movements, some set of hair cells will be maximally excited, whereas another set will be maximally inhibited. Note that head tilts produce displacements similar to certain accelerations.

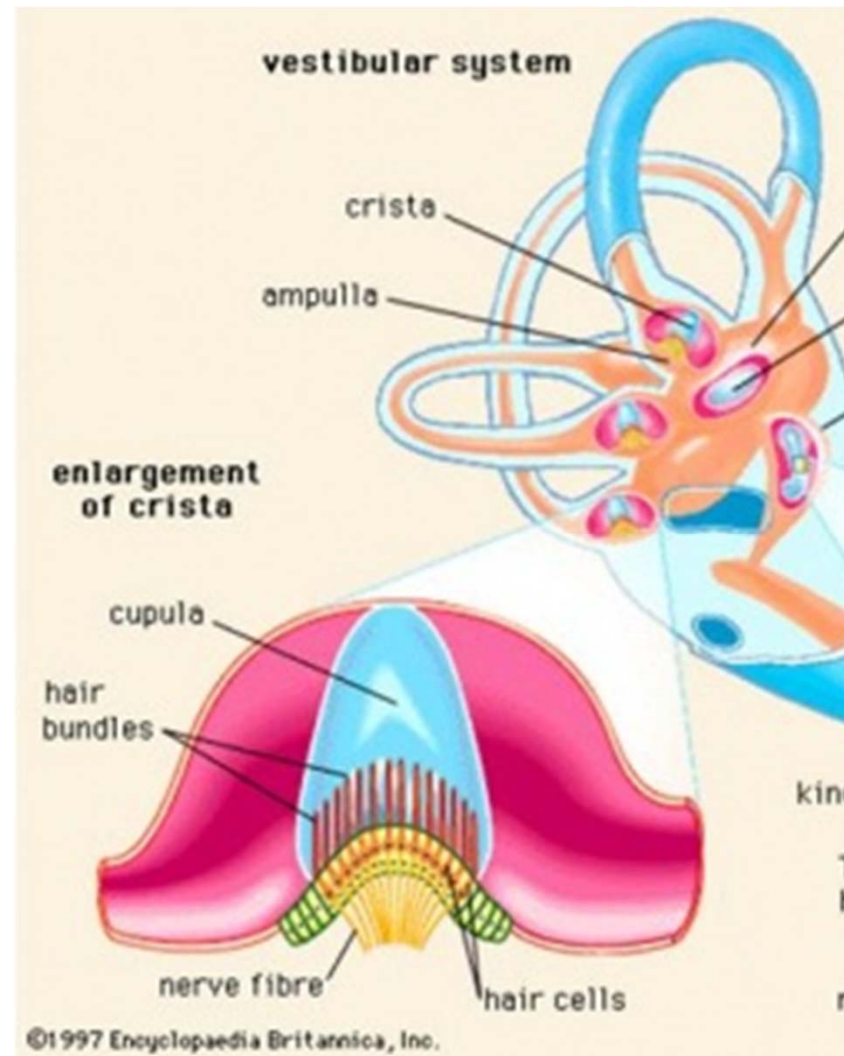
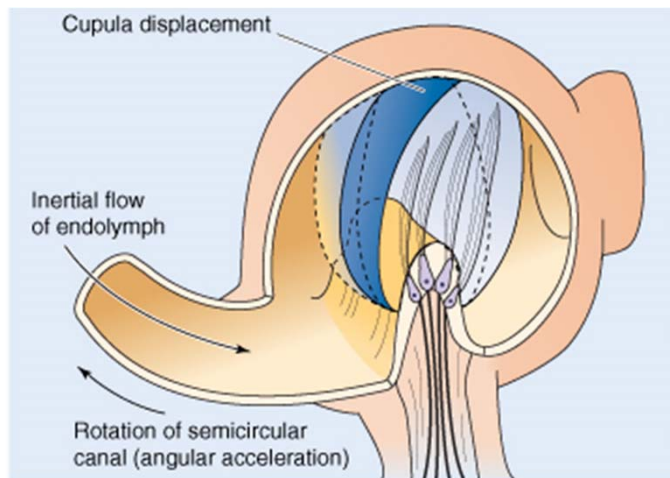
Mechanism

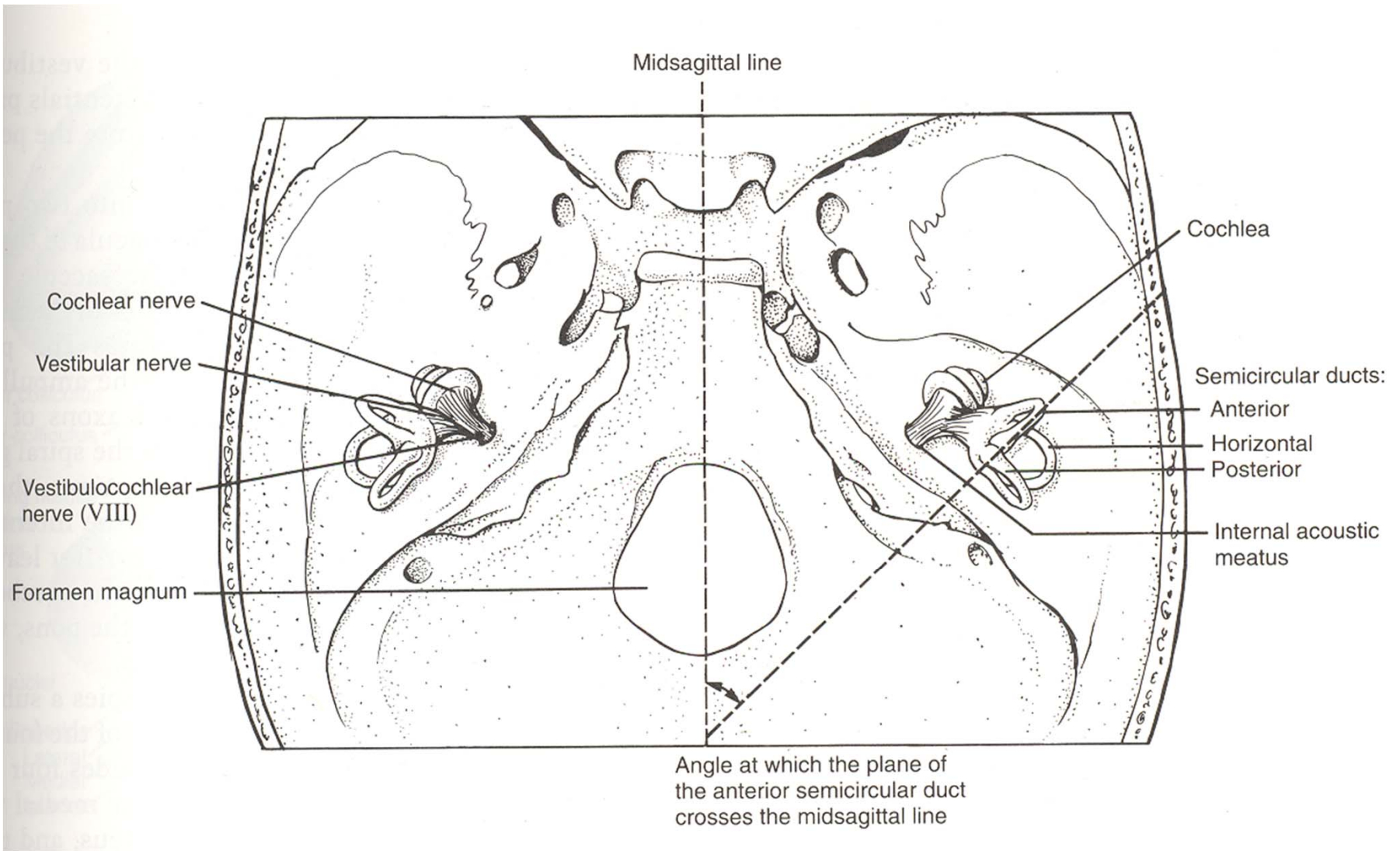
- Flexion towards stereocilia
 - opening of mechanically activated K^+ channels – depolarization
- Flexion away from stereocilia
 - closing of the channels - hyperpolarization

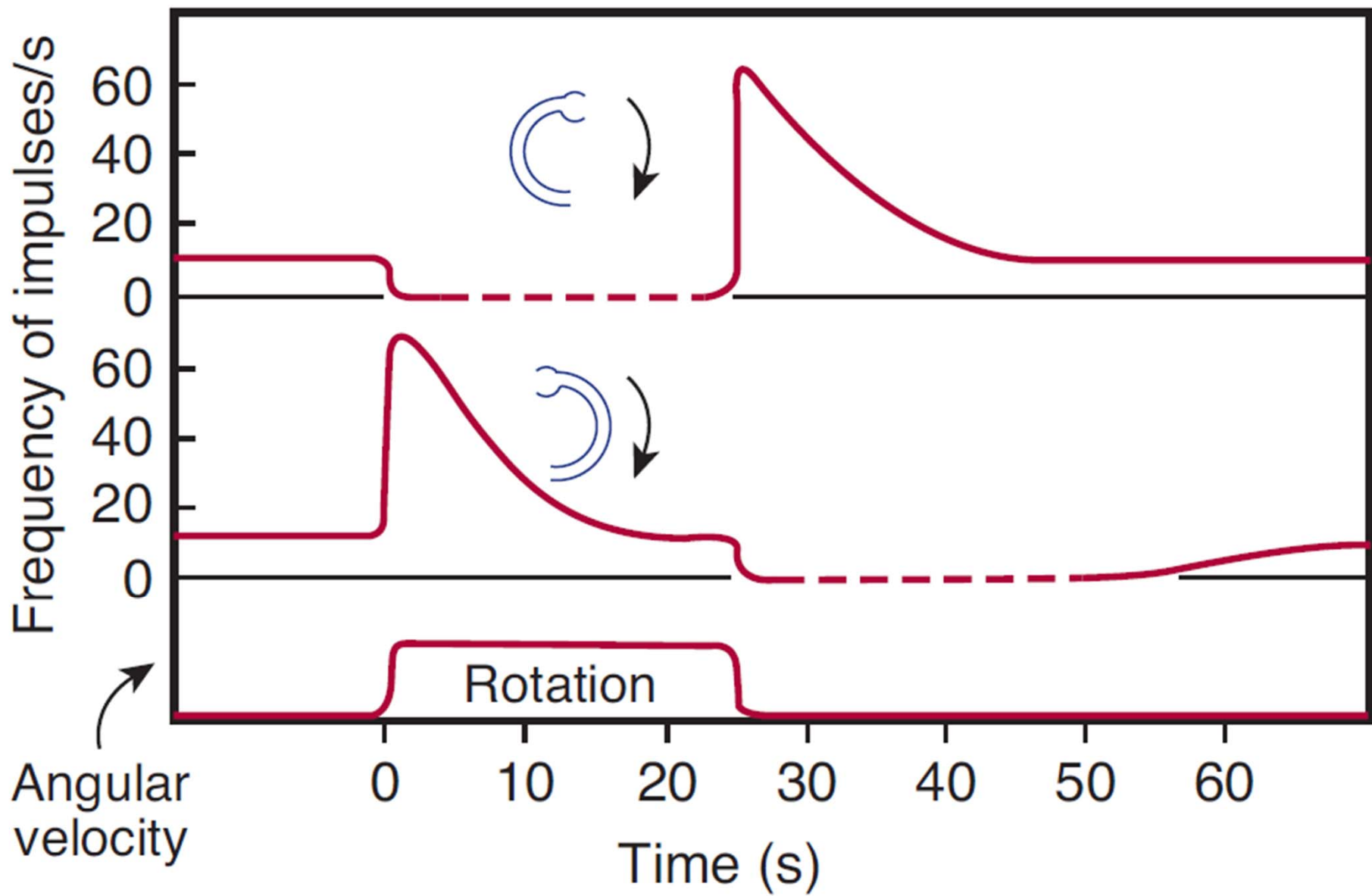


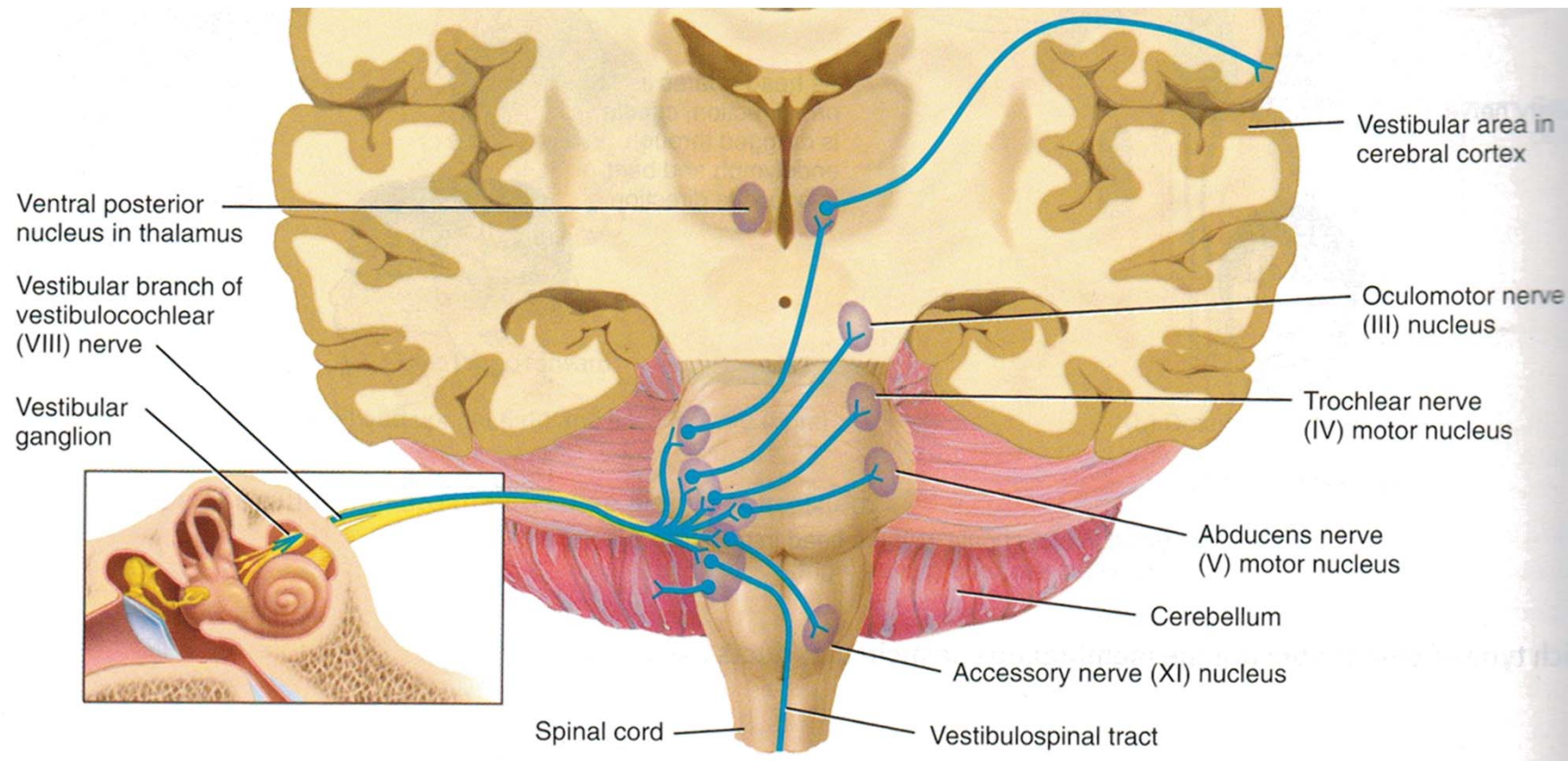
Information about angular acceleration

- Ampullae
- Semicircular canals
 - upper
 - horizontal
 - posterior









Vestibular nuclei

- integration of vestibular, visual and somatosensory information
- projections:
 - cerebellum
 - oculomotoric nuclei
 - nucleus of n. accessorius (neck muscles)
 - thalamus - cortex