Νευροφυσιολογία και Αισθήσεις

Διάλεξη 11

Ακουστικό και Αιθουσιαίο Σύστημα

(Auditory and Vestibular Systems)

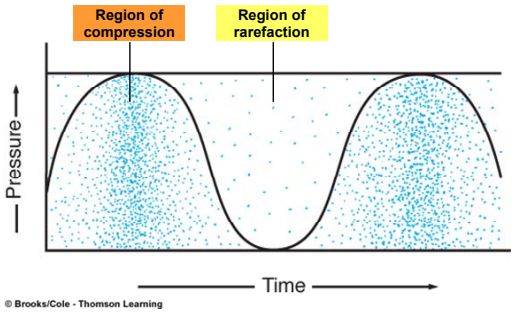
Biomedical Imaging & Applied Optics
University of Cyprus

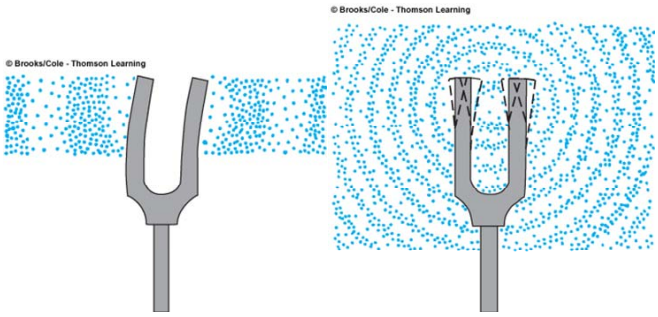
Introduction

- **Sensory Systems**
  - Sense of hearing, audition
    - Detect sound
    - Perceive and interpret nuances
  - Sense of balance, vestibular system
    - Head and body location
    - Head and body movements

Hearing

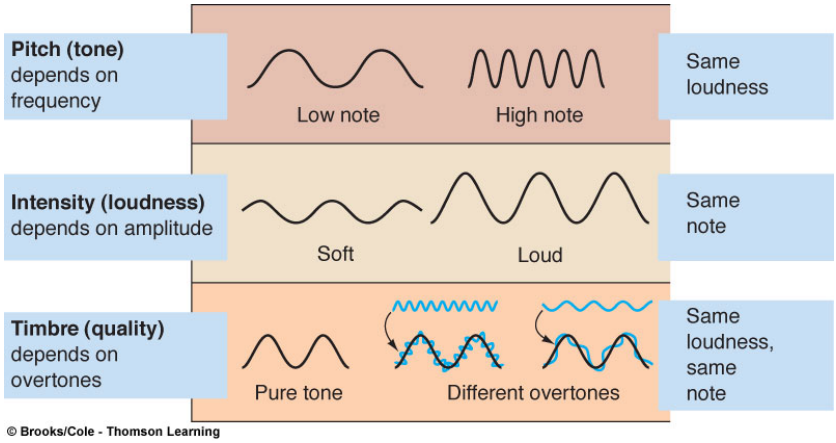
- **Hearing**
  - Neural perception of sound energy
  - Involves two aspects
    - Identification of the sounds (“what”)
    - Localization of the sounds (“where”)
- **Sound**
  - Audible variations in air pressure
    - Consist of alternate regions of compression and rarefaction of air molecules
  - Sound frequency: Number of cycles per second expressed in Hertz (Hz)
  - Cycle: Distance between successive compressed patches
  - Range: 20 Hz to 20,000 Hz
  - Intensity: Difference in pressure between compressed and rarefied patches of air



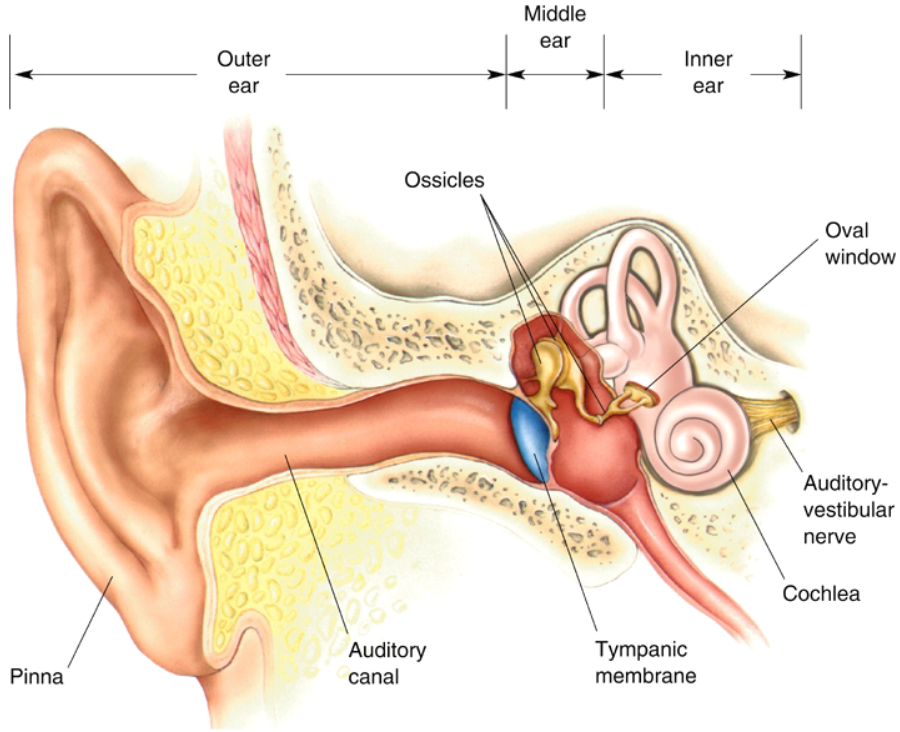


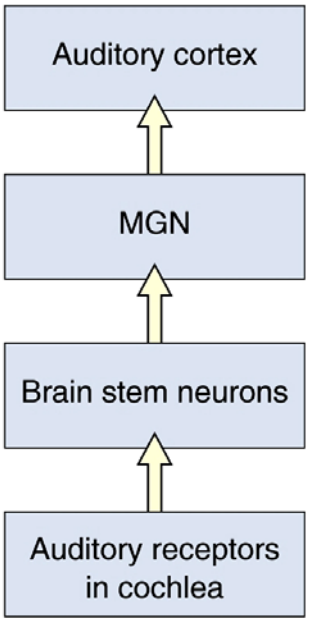
Hearing

- **Characteristics of sound**
  - Pitch (tone) of sound
    - Depends on frequency of air waves
  - Intensity (loudness)
    - Depends on amplitude of air waves
  - Timbre (quality)
    - Determined by overtones



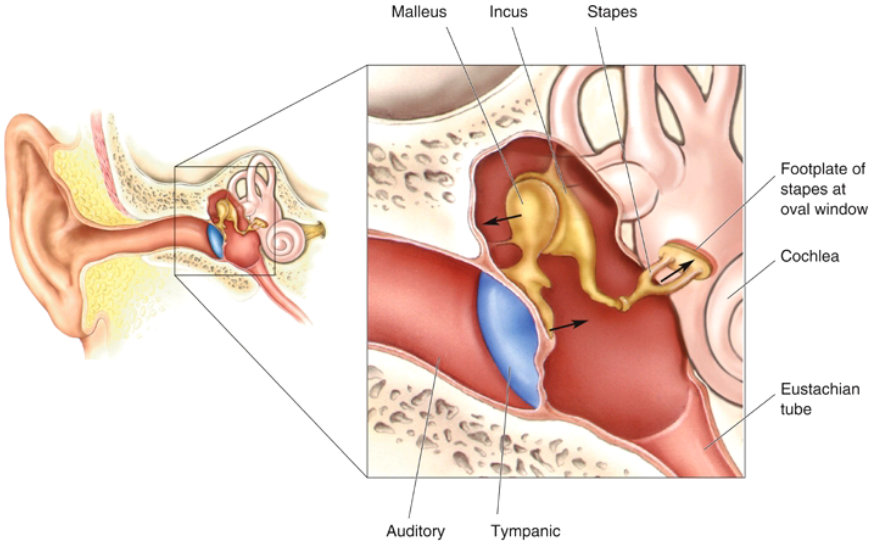
Auditory System





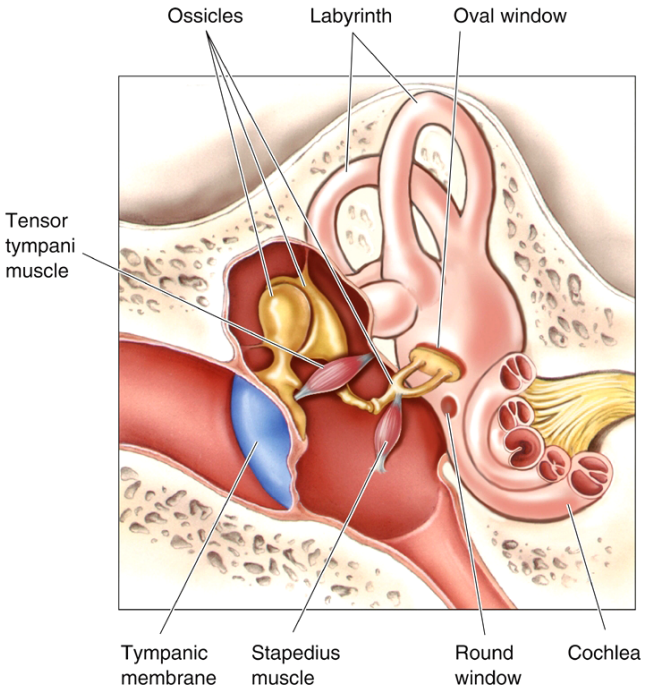
Middle Ear

- **Sound Force Amplification by the Ossicles**
  - Greater pressure at oval window than tympanic membrane (20x) → moves fluids
    - Pressure: Force by surface area
    - Ossicles → System of levers

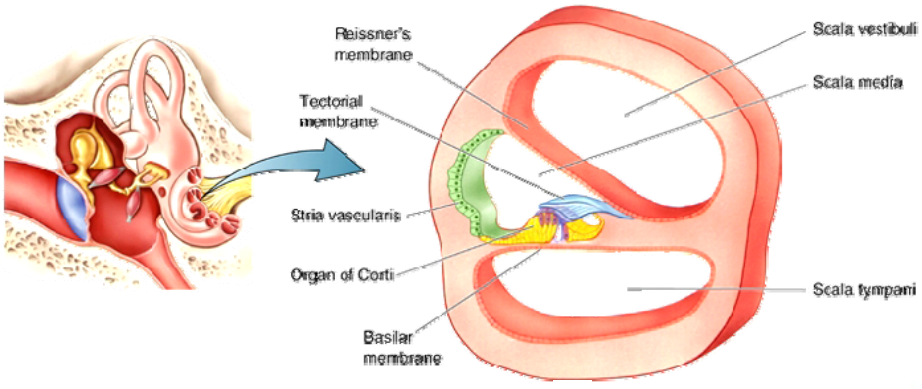


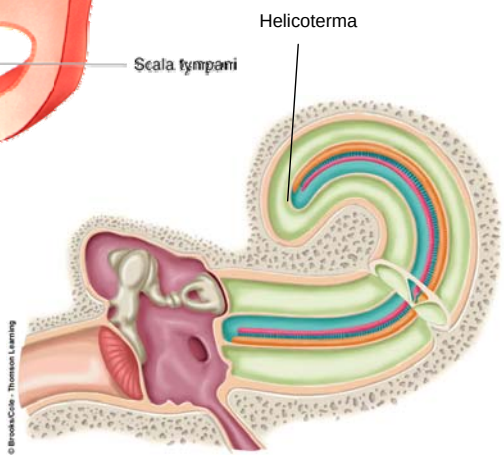
Middle Ear

- **The Attenuation Reflex**
  - Response where onset of loud sound causes tensor tympani and stapedius muscle contraction
    - Diminish low frequencies more than high
  - Function
    - Protection but with a delay
    - Adapt ear to loud sounds
    - Understand speech better
    - Not hear own speech



Inner Ear

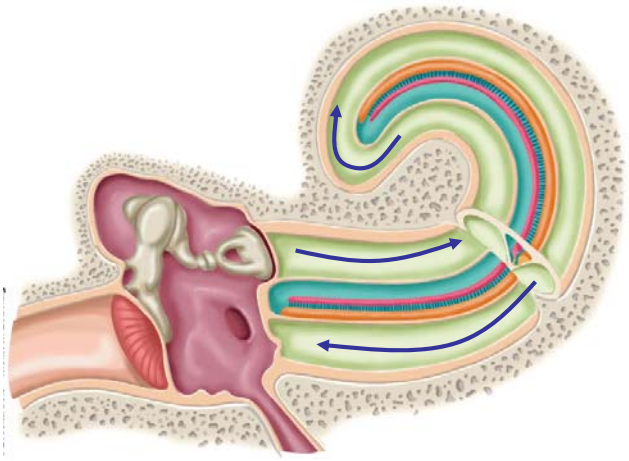




- **Perilymph**
  - Fluid in scala vestibuli and scala tympani
  - Similar to CSF (K+=7mM, Na+=140mM)
- **Endolymph**
  - Fluid in scala media
  - Unusual (K+=150mM, Na+=1mM)
- **Endocochlear potential**
  - Endolymph electric potential 80 mV more positive than perilymph

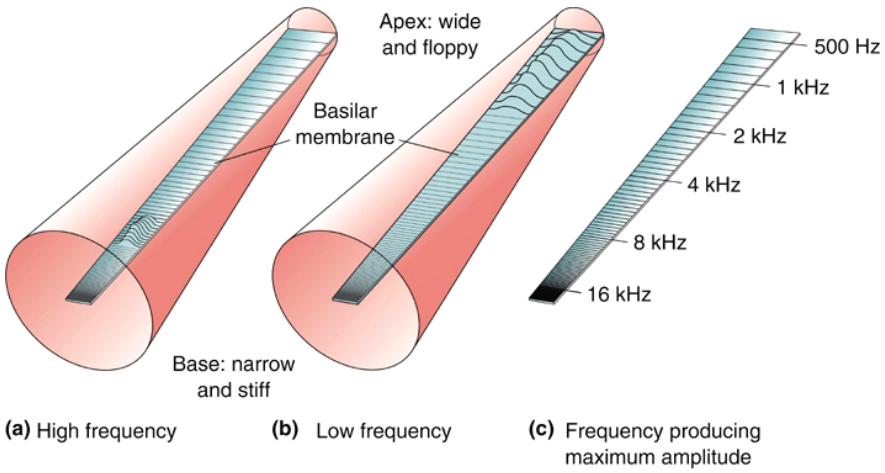
Inner Ear

- **Physiology of the Cochlea**
  - Pressure at oval window
  - Pressure dissipates
    - Scala vestibuli → Helicoterma → Scala tympani → Round window (bulges out)
  - Audible part of the energy enters the Scala media (or cochlear duct)
  - Waves in cochlear fluid (endolymph) set basilar membrane in motion
  - Sound converted to electrical signals by the Organ of Corti



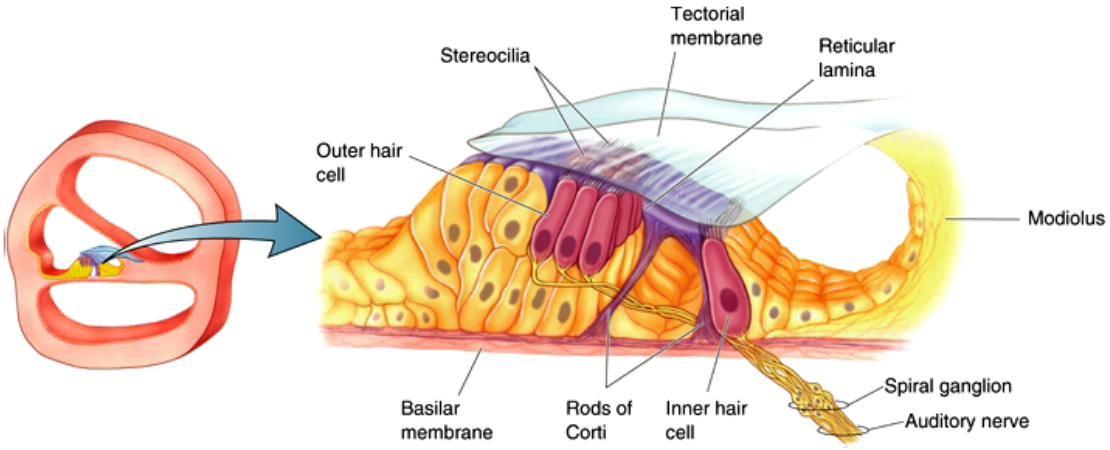
Inner Ear

- **The Response of Basilar Membrane to Sound**
  - Structural properties: Wider at apex, stiffness decreases from base to apex
  - Endolymph movement bends basilar membrane near base, wave moves towards apex



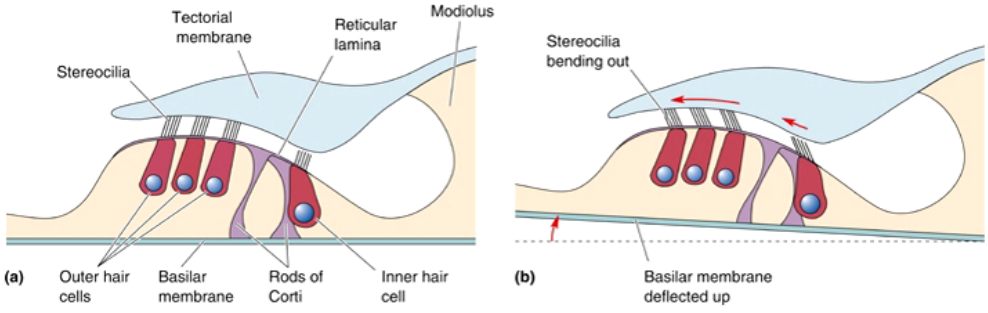
Inner Ear

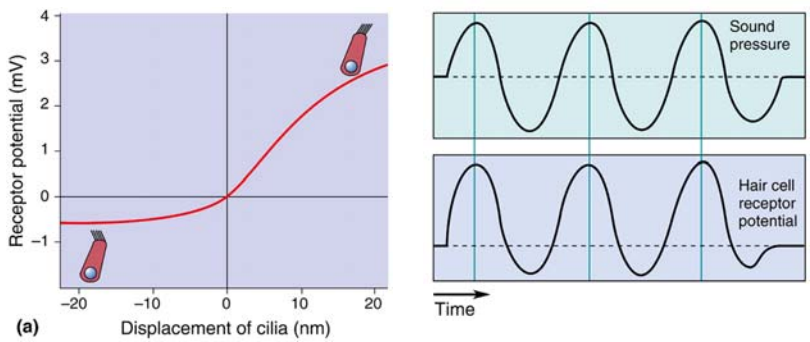
- **Organ of Corti**
  - Hair cells with ~ 100 sterocilia each
    - Inner hair cells (3 500 in a single row)
    - Outer hair cells (15 000-20 000 in three rows
    - Synapse with neurons of the auditory nerve



Signal Transduction

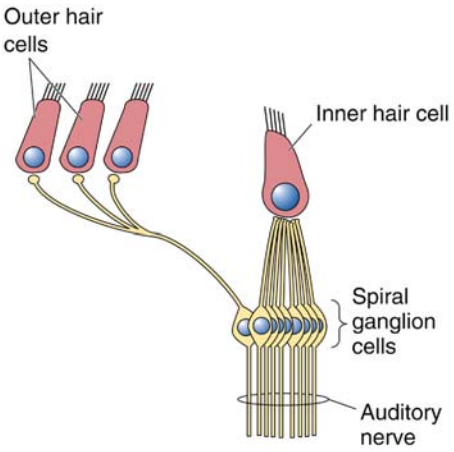
- **Transduction by Hair Cells**
  - Sound→Basilar membrane upward → reticular lamina up → stereocilia bend outward

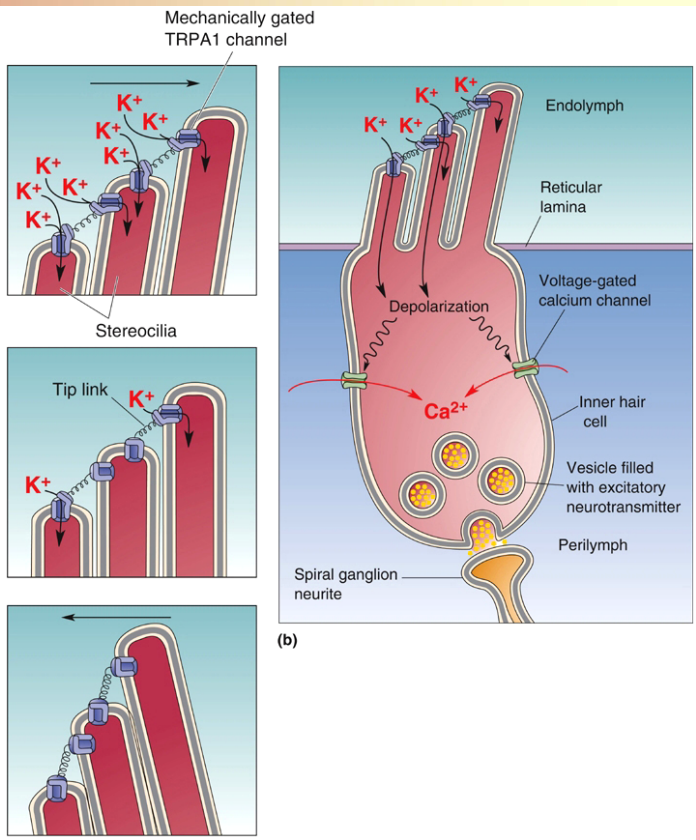




Signal Transduction

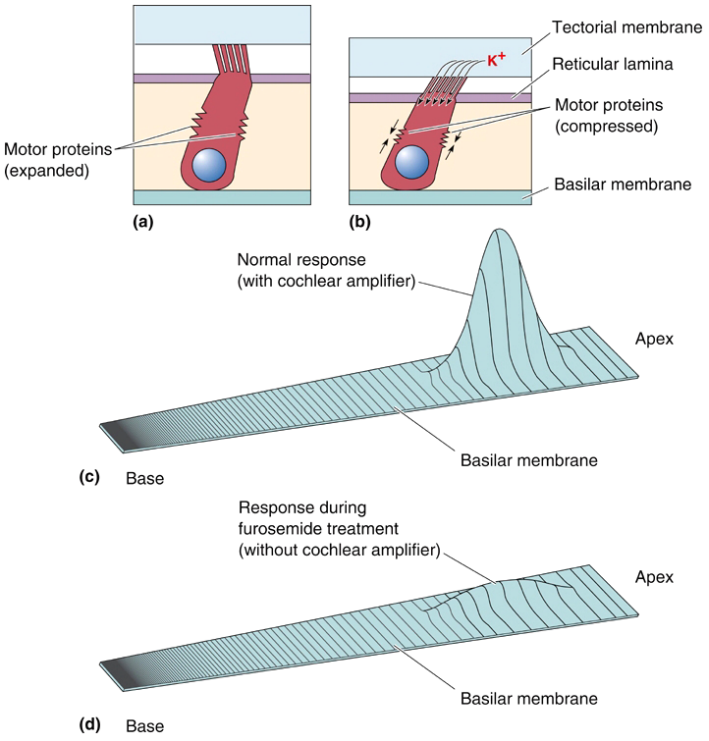
- **Mechanically gated channels**
  - Open and close → graded potentials
- **The Innervation of Hair Cells**
  - One spiral ganglion fiber: One inner hair cell, numerous outer hair cells
  - Many neurons per inner hair cell





Signal Transduction

- **Amplification by Outer Hair Cells**
  - Outer hair cells respond with change in length
  - Motor proteins: Change length of outer hair cells
    - Voltage (not ATP) driven(electromotility)
    - Accentuate motion of basilar membrane (100x) and fine tune response
  - Prestin: Required for outer hair cell movements



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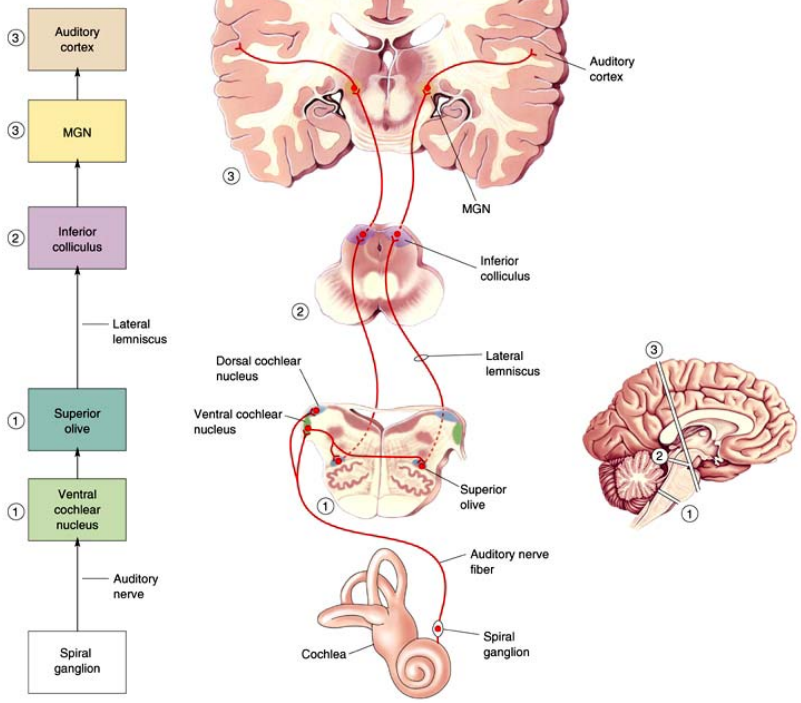
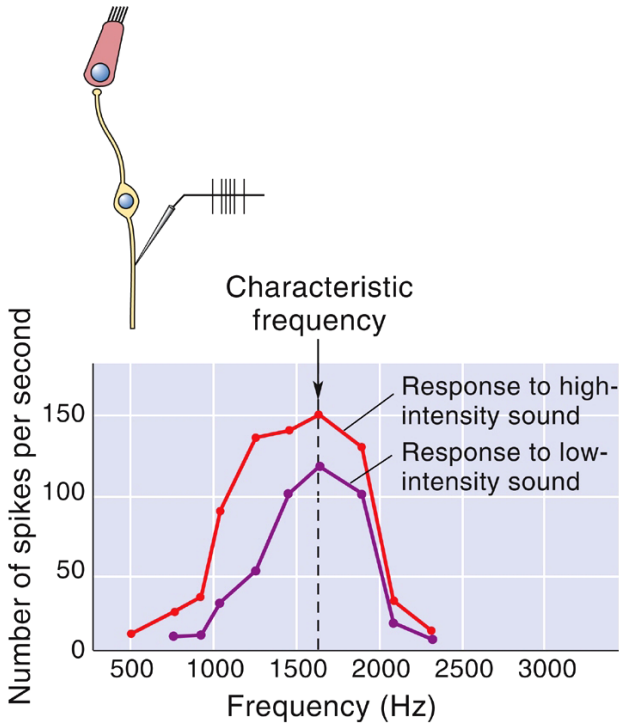
Central Auditory Processes

- **Auditory Pathway**
  - More synapses at nuclei than visual pathway, more alternative pathways
  - Extensive feedback



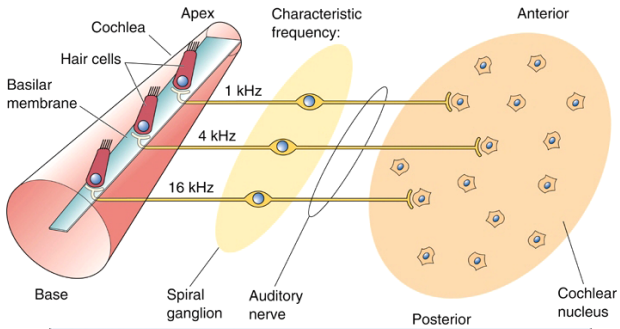
Central Auditory Processes

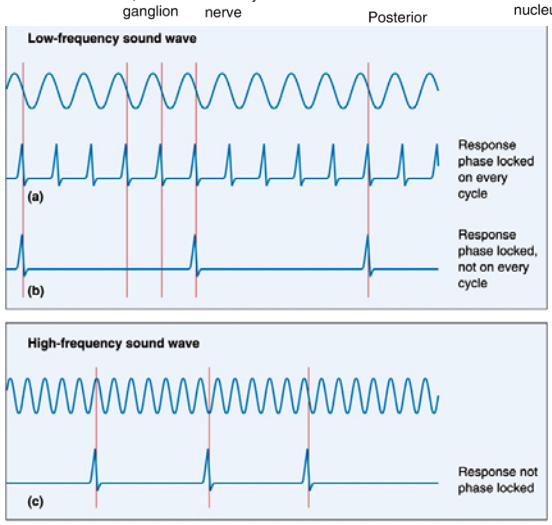
- **Response Properties of Neurons in Auditory Pathway**
  - Characteristic frequency
    - Frequency at which neuron is most responsive
  - Response
    - More complex and diverse on ascending auditory pathway in brain stem



Encoding Sound Intensity and Frequency

- **Encoding Information About Sound Intensity**
  - Firing rates of neurons
  - Number of active neurons
- **Stimulus Frequency, Tonotopy, Phase Locking**
  - Basilar membrane
    - Frequency sensitivity: Highest at base, lowest at cochlea apex
  - Tonotopy
    - Systematic organization of characteristic frequency within auditory structure
  - Phase Locking
    - Neurons fire in phase with sound
      - Not always on every cycle
    - Collection of neurons
      - One firing on every cycle → same f as sound
    - Above 4 kHz phase is random





Encoding Sound Intensity and Frequency

- **Loudness discrimination**
  - Exquisitely sensitive organ (motion less than a molecule of Hydrogen) → easily damaged
  - Wide range
    - Every 10 dB means 10-fold increase in intensity
  - Anything > 100 dB can cause permanent damage

Sound	Loudness in decibels (dB)	Comparison to faintest audible sound (hearing threshold)
Rustle of leaves	10 dB	10 x louder
Ticking of watch	20 dB	100 x
Hush of Library	30 dB	1000 x
Normal conversation	60 dB	1 million x
Food Blender	90 dB	1 billion x
Loud rock concert	120 dB	1 trillion x
Takeoff of jet plane	150 dB	1 quadrillion x

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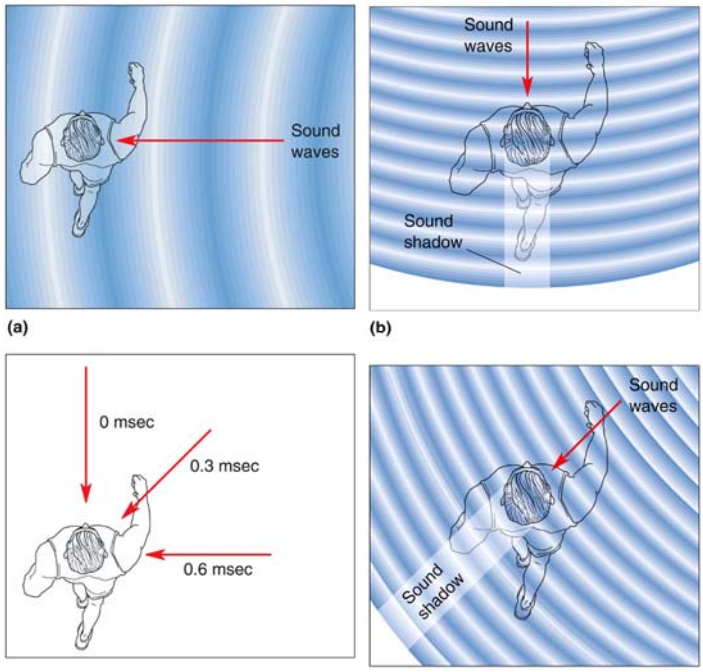
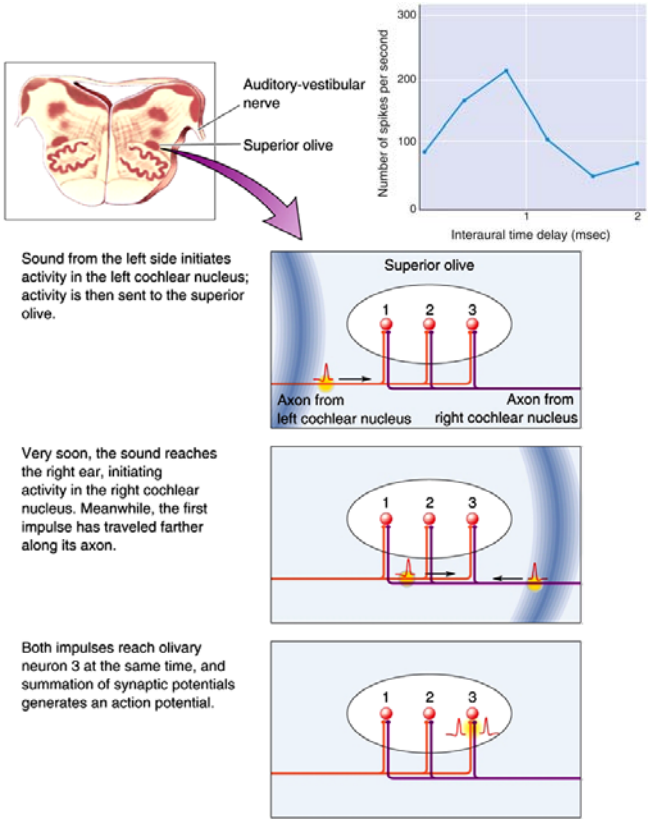
Mechanisms of Sound Localization

- **Techniques for Sound Localization**
  - Horizontal: Left-right, Vertical: Up-down
- **Localization of Sound in Horizontal Plane**
  - Precision: 2 degrees
  - Interaural time delay
    - Time taken for sound to reach from ear to ear
    - Continuous sounds → phase delay
  - Interaural intensity difference
    - Sound at high frequency from one side of ear
  - Duplex theory of sound localization:
    - Interaural time delay
      - 20-2000 Hz
    - Interaural intensity difference
      - 2000-20000 Hz



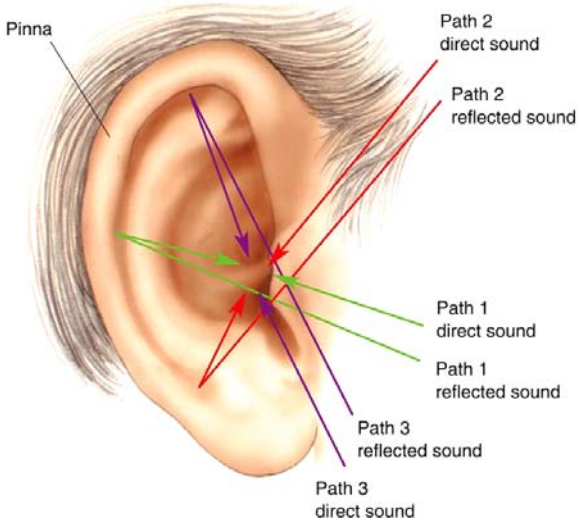
Mechanisms of Sound Localization

- **The Sensitivity of Binaural Neurons to Sound Location**
  - Monaural: Sound in one ear
  - Binaural: Sound at both ears
  - Superior olive: Cochlear nuclei input to superior olive, greatest response to specific interaural delay
- **Delay Lines and Neuronal Sensitivity to Interaural Delay**
  - Sound from left side, activity in left cochlear nucleus, sent to superior olive
  - Sound reaches right ear, activity in right cochlear nucleus, first impulse far
  - Impulses reach olivary neuron at the same time→ summation→ action potential



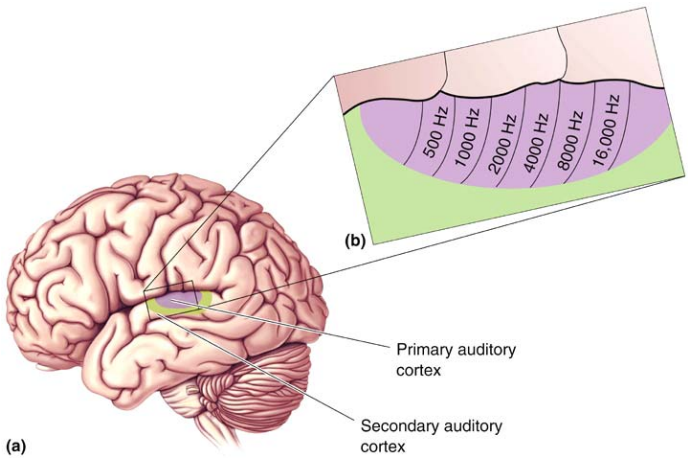
Mechanisms of Sound Localization

- **Localization of Sound in Vertical Plane**
  - Sweeping curves of outer ear
  - Some animals use other techniques
    - Owl → no pinna but ears at different levels
    - Bat → Ultrasound transmission (10 nsec time delays)



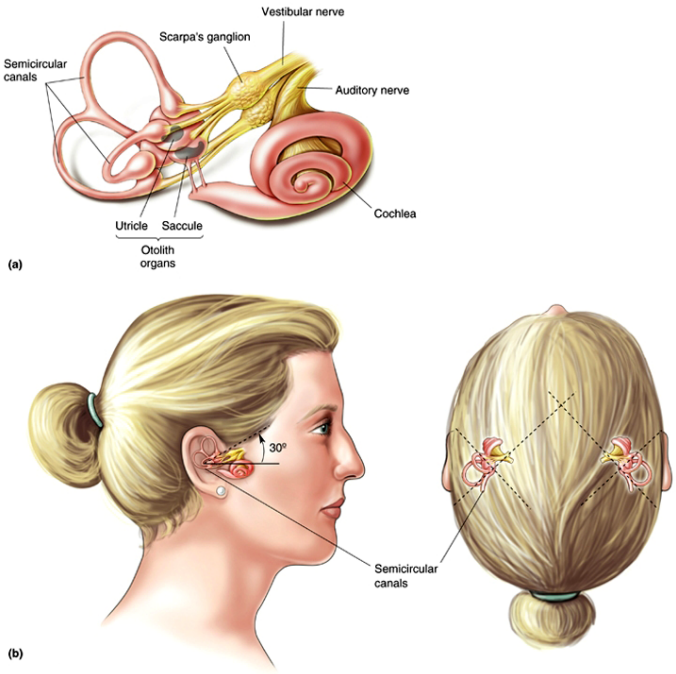
Auditory Cortex

- **Acoustic Radiation**
  - Axons leaving MGN project to auditory cortex via internal capsule in an array
  - Structure of A1 and secondary auditory areas: Similar to corresponding visual cortex areas
- **Neuronal Response Properties**
  - Frequency tuning: Similar characteristic frequency
  - Isofrequency bands: Similar characteristic frequency, diversity among cells
  - Tonotopy, columnar organization of cells with similar binaural interaction
- **The Effects of Auditory Cortical Lesions and Ablation**
  - Lesion in auditory cortex: Normal auditory function
    - Lesion in striate cortex: Complete blindness in one visual hemifield
  - Unilateral lesions → localization or particular frequency deficits
  - Specialized areas (we will see examples when we talk about language)



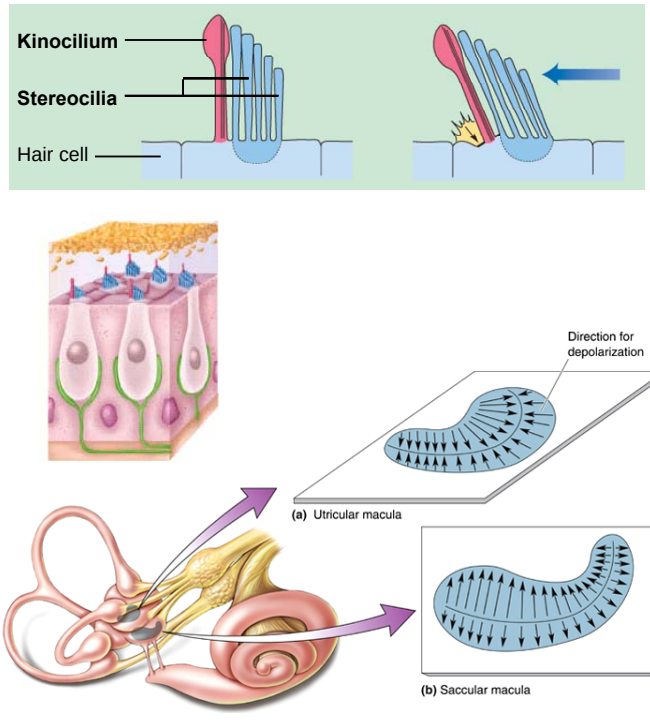
The Vestibular System

- **Importance of Vestibular System**
  - Balance, equilibrium, posture, head, body, eye movement
- **The Vestibular Labyrinth**
  - Fluid filled tunnels In the inner ear (endolymph)
  - Semicircular canals
    - Three circular tunnels arranged on perpendicular planes
  - Otolith organs (Utricle and saccule)
    - Two bulges arranged in perpendicular directions
- **Function**
  - Sense changes in motion (i.e. acceleration)



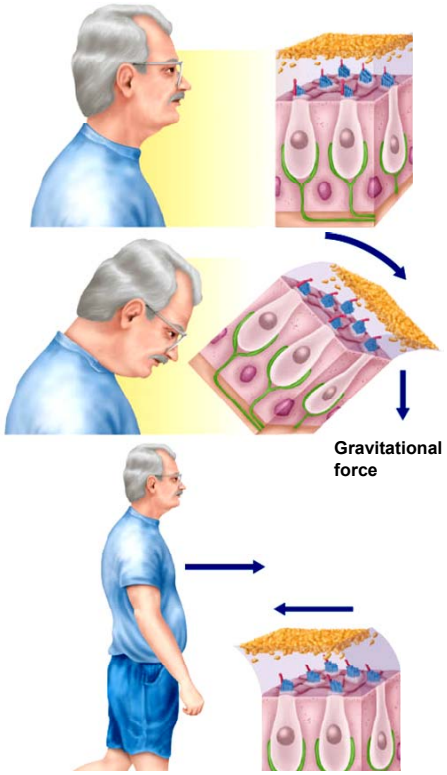
Otolith Organs

- **Detect changes in rate of linear movement in any direction**
- **Arranged in perpendicular directions**
- **Provide information important for determining head position in relation to gravity**
- **Hair cells**
  - Have on kinocilium and several sterocilia (mikrovilli)
  - Embedded in gelatinous material
  - Fire only when bend towards the kinocilium
  - In addition, calcium carbonate crystals (otoliths) are embedded in within the gelatinous layer
    - Increased inertia
    - Sensitivity to gravity



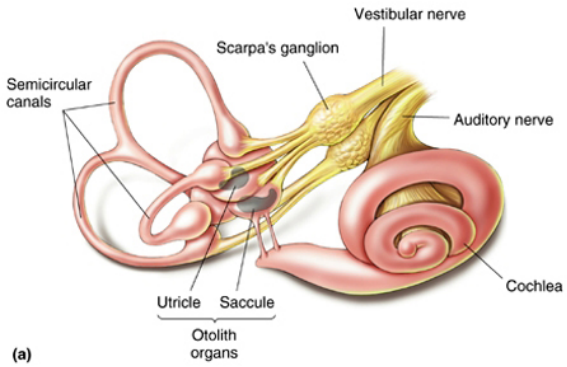
Otolith Organs

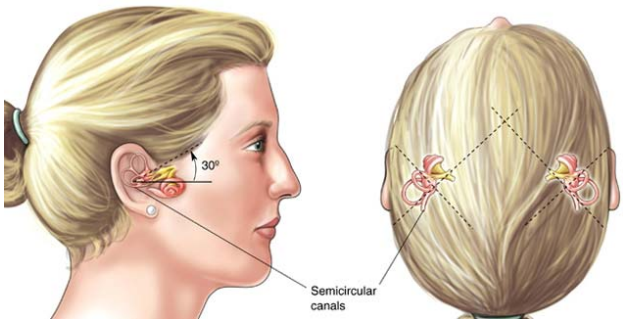
- **Signal transduction**
  - Utricle → Forward or backward motion or tilt (motion due to gravitational force)
  - Saccule → vertical motion
  - Endolymph and gelatinous mass with otoliths move in the opposite direction
  - Cilia bent and K^+ channels open or close
  - The haircells are depolarized or hyperpolarized
  - Neurotransmitter realize from the hair cells is modified
  - Firing of the vestibular nerve is modified



Semicircular canals

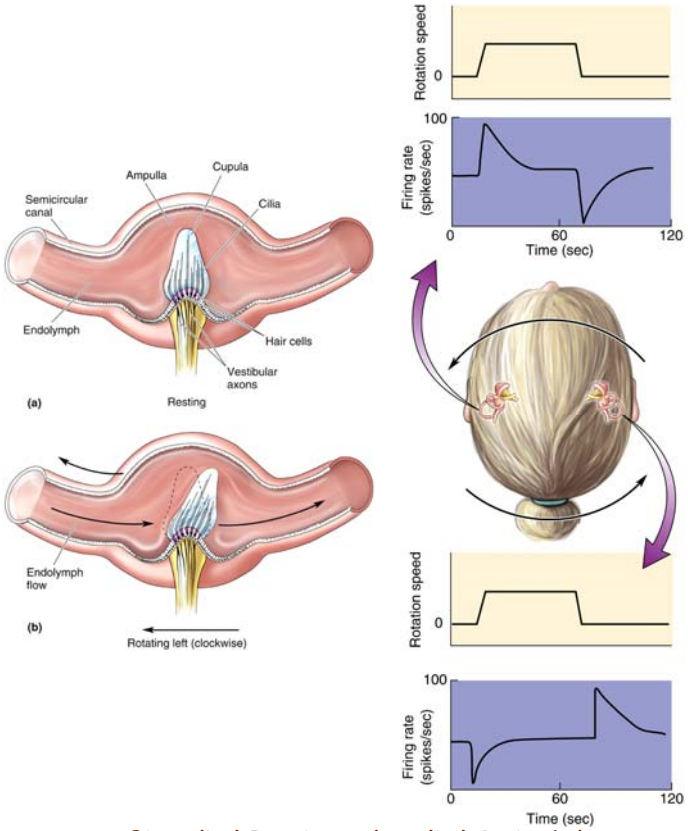
- **Three circular tunnels arranged on perpendicular planes**
- **Detect rotational acceleration or deceleration in any direction**
  - Speed is calculated by integrating circuitry in the brain stem
- **Hair cells**
  - On a ridge in the ampulla
  - Have on kinocilium and several sterocilia (mikrovilli)
  - Kinocili oriented in same direction so all excited or inhibited together
  - Embedded in gelatinous material, the cupula





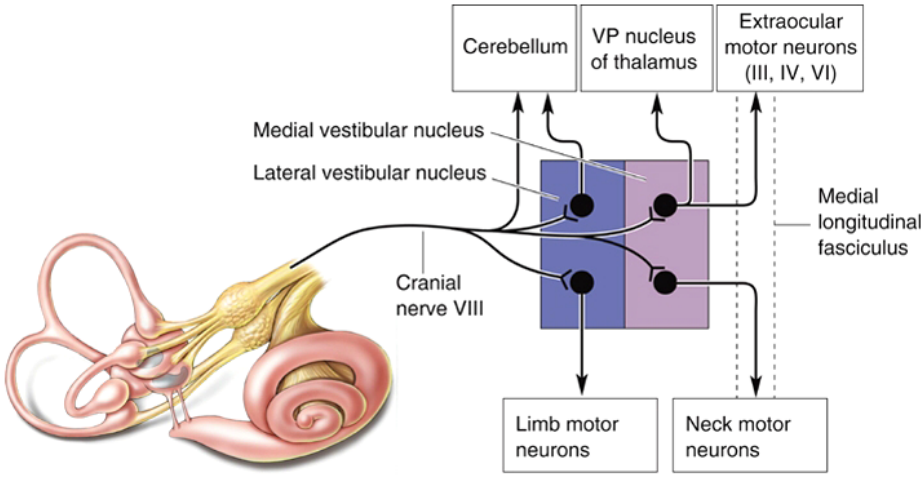
Semicircular canals

- **Signal transduction**
  - Head is rotated
  - Two of the canals are rotated around their axis in opposite directions
  - Endolymph moves opposite to the direction of motion (inertia)
  - Cupula leans in that direction
  - Cilia bent and K^+ channels open or close
  - The haircells are depolarized or hyperpolarized
  - Neurotransmitter realize from the hair cells is modified
  - Firing of the vestibular nerve is modified
- **Push-Pull Activation of Semicircular Canals**
  - Three semicircular canals on one side
    - Helps sense all possible head-rotation angles
  - Each paired with another on opposite side of head
  - Push-pull arrangement of vestibular axons: Rotation causes excitation on one side, inhibition on the other



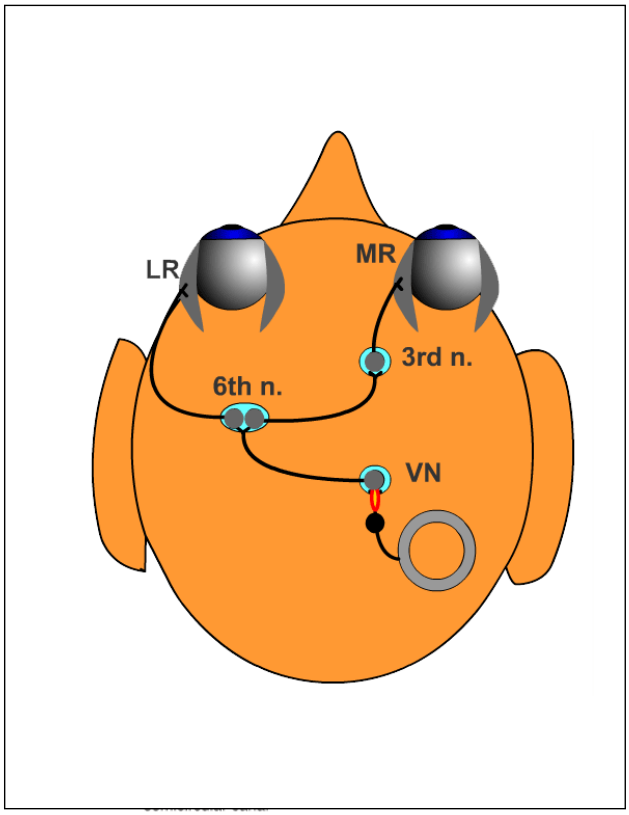
Central Vestibular Pathways

- **Vestibular nuclei of the brain stem**
  - Receive
    - Ipsilateral vestibular information
    - Information form other parts (visual, somatosensory, cerebellum etc.)
  - Project to many sites
  - Cortex continually maintains a representation of body position and orientation



The Vestibulo-Ocular Reflex (VOR)

- **Function**
  - Line of sight fixed on visual target
- **Mechanism**
  - Senses rotations of head
  - Commands compensatory movement of eyes in opposite direction
- **Connections**
  - Semicircular canals → vestibular nucleus → cranial nerve nuclei
  - Excite extraocular muscles



Vestibular Pathology

- **Otolith dislocation can cause nausea**
- **Drugs can damage vestibular system**
- **Effects:**
  - Trouble fixating on visual targets
  - Walking and standing difficult
  - "World moving around them"

Επόμενη Διάλεξη …

Διάλεξη 12

Σωματοαισθητικό Σύστημα

(Somatosensory System)