NSII
Neurophysiology
lecture 6
Function of the vestibular system
Equilibrium and balance

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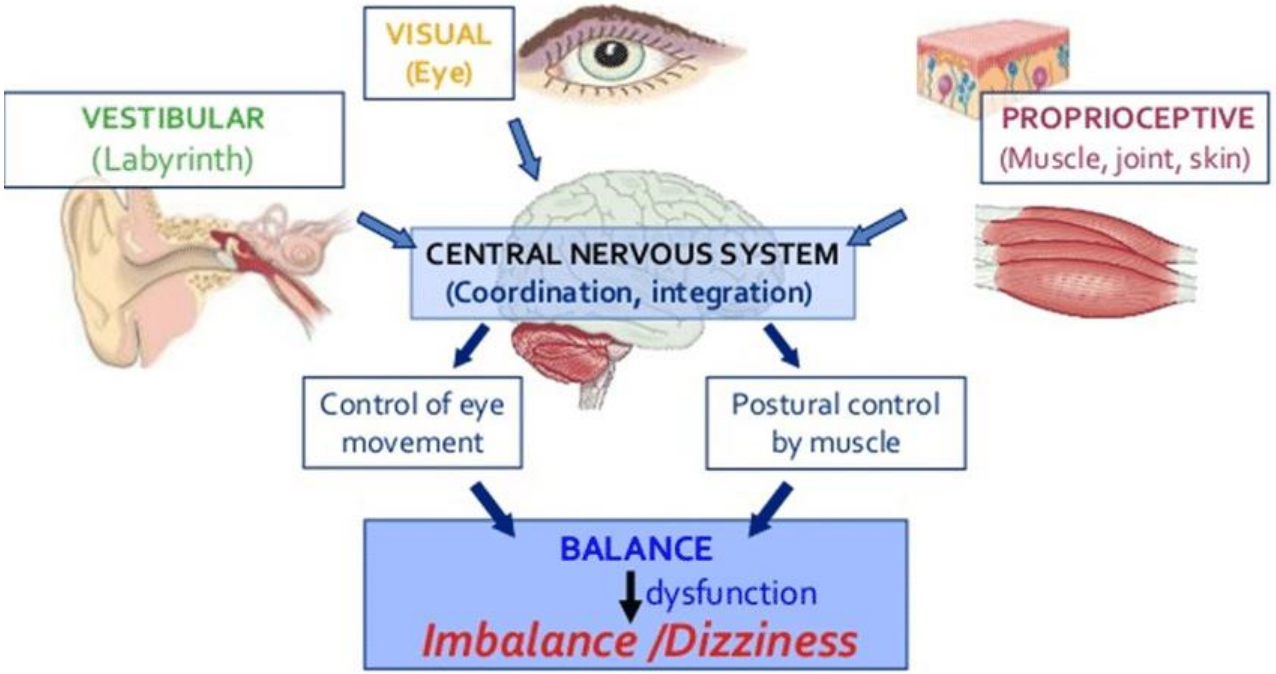
Learning Objectives

- List the major function of the vestibular system
- Describe the structure, normal stimulus, transduction at the receptor level, and function of the otolith organs.
- Describe the structure, normal stimulus, transduction at the receptor level, and function of the semicircular canals.
- Describe the central connections of the vestibular nerve and relate these to the major functions of the vestibular apparatus.

Overall central of body posture

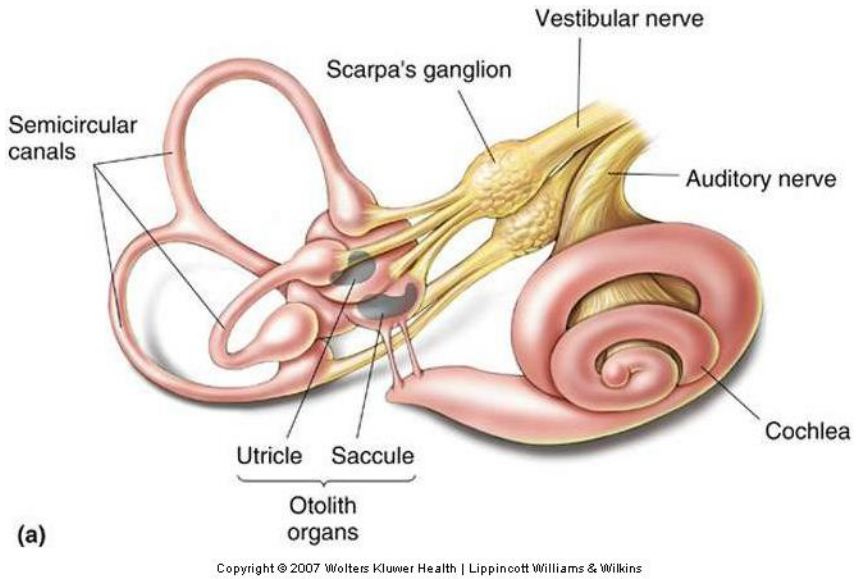


Overall control of balance and body posture

- The brain (specifically, the cerebellum brainstem Vestibular nuclei) receives sensory information and coordinates the actions of the muscles to maintain balance.
- The vestibular system in the inner ear detects head position and motion.
- The eyes provide visual feedback about the body's position
- and motion relative to the surroundings.
- Receptors in the skin, muscles, and joints send information about body position and movement, For example, pressure receptors in the skin can tell if you're standing or sitting, while stretch receptors in the muscles and joints can tell if a body part is stationary or moving

The Vestibular System

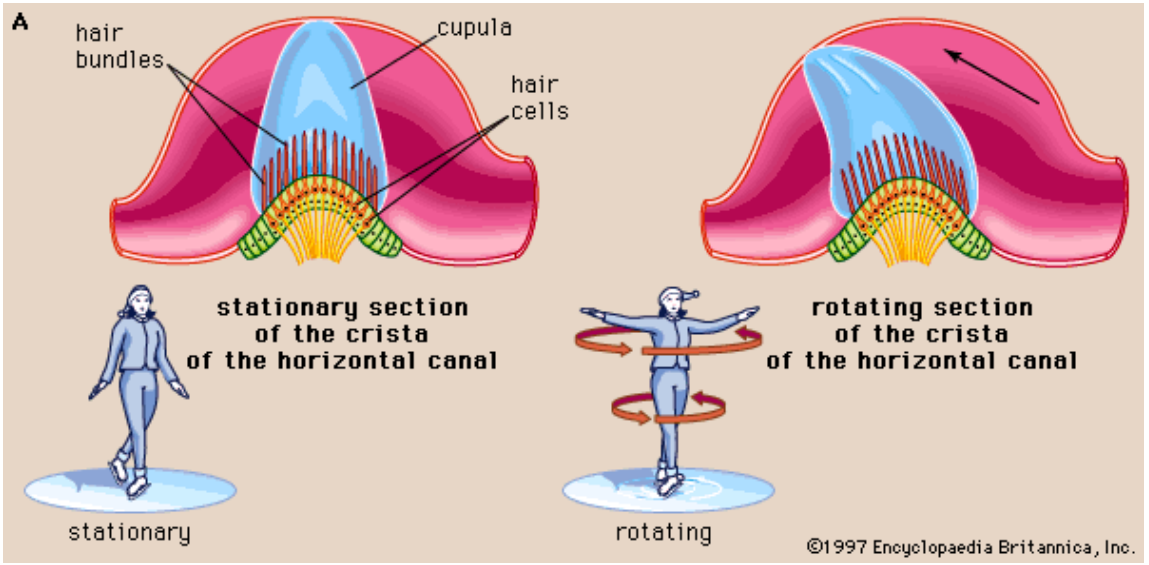
- Importance of Vestibular System
  - Balance, equilibrium, posture, head, body, eye movement
- Vestibular Labyrinth
  - Otolith organs - gravity and tilt
  - Semicircular canals - head rotation
  - Use hair cells, like auditory system, to detect changes



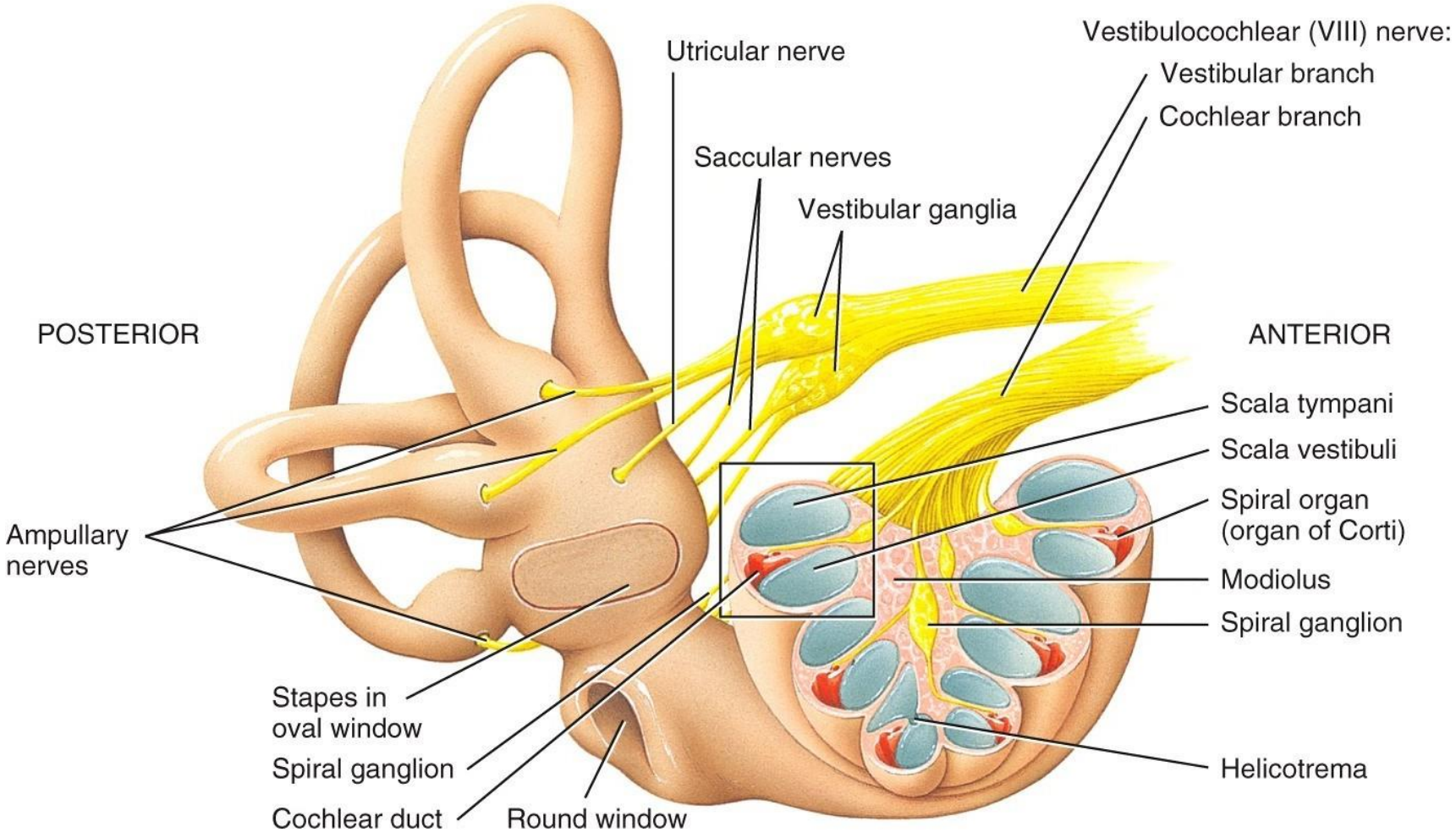
Functions of vestibular system

Semi-circular canals transduce,
or convert, the physical energy
of rotational angular accelerations into neural impulses.

The utricle and saccule transduce the physical energy of linear accelerations into neural Impulses
Detecting Orientation of the Head With Respect to Gravity.



Functional anatomy of the vestibular apparatus and its innervation



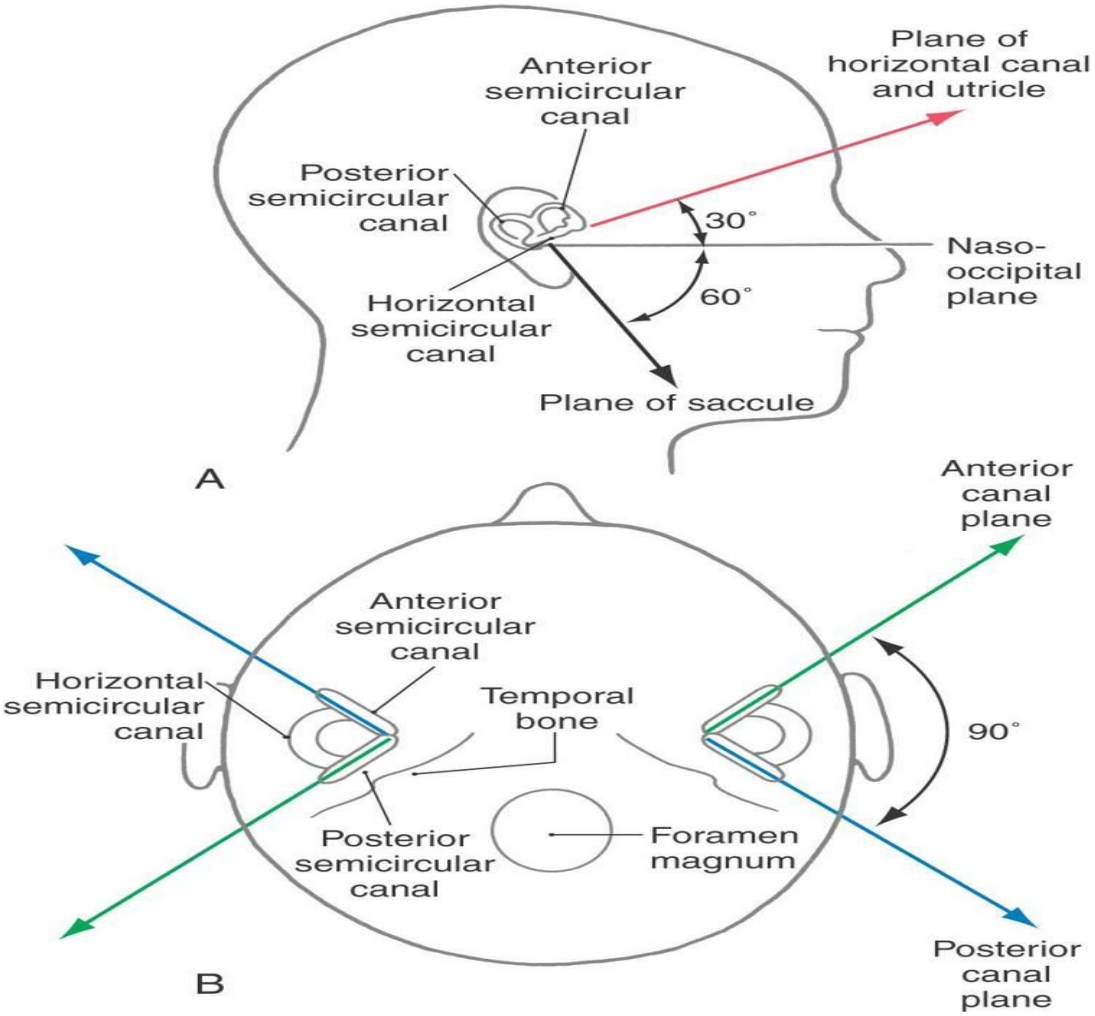
(b) Components of the vestibulocochlear (VIII) nerve

Planes of semicircular canals

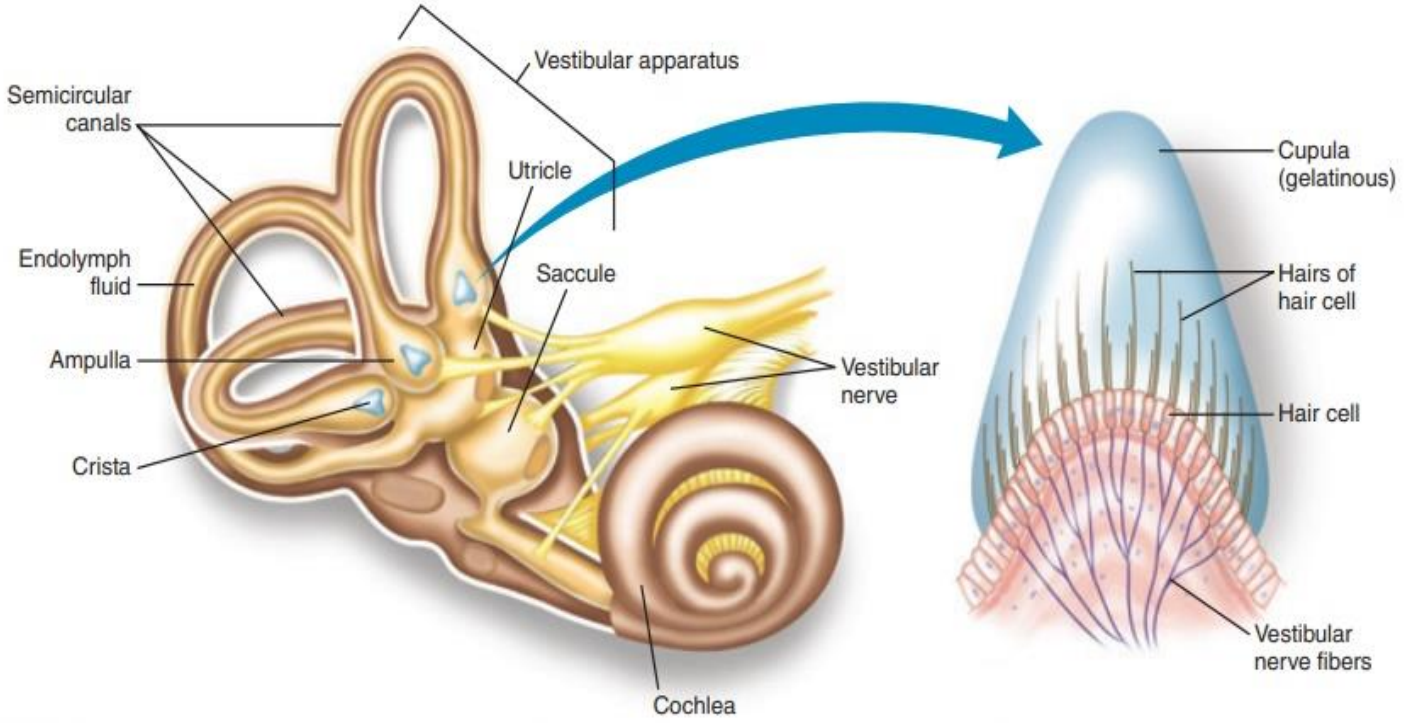
When the head is bent forward about 30 degrees
Lateral semicircular ducts are approximately horizontal

Anterior ducts are in vertical planes that project *forward and 45 degrees outward,*

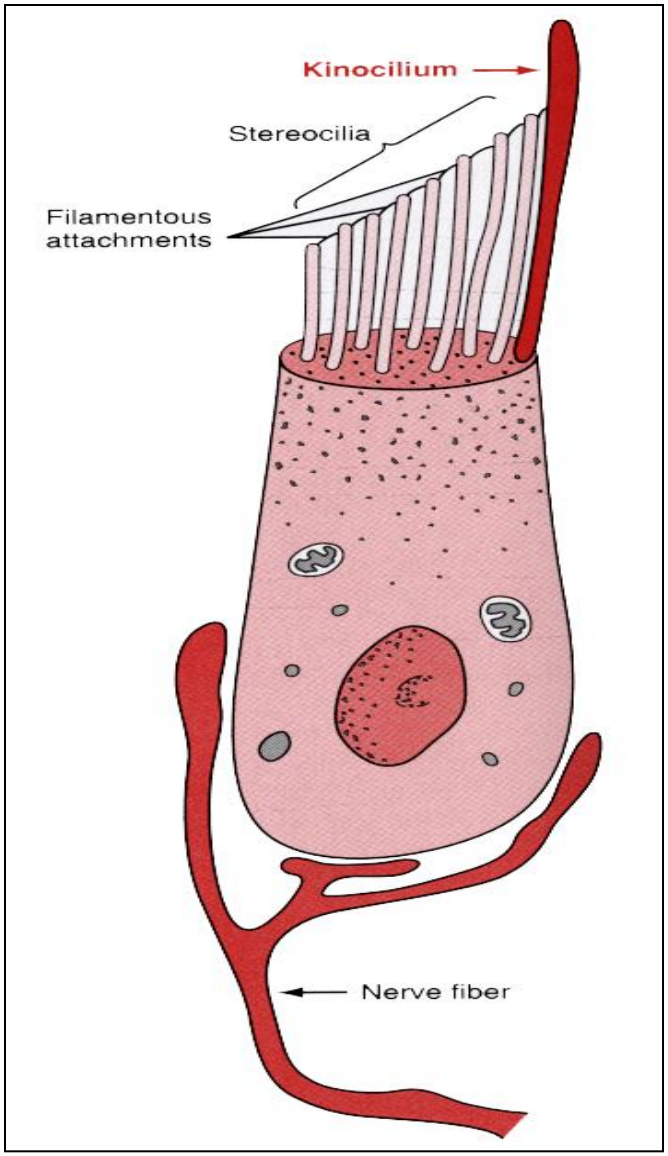
*P*osterior ducts are in vertical planes that project *backward and 45 degrees outward.*
Each semicircular



Sensory organs within the semicircular canal ampulla's sensory organ, the crista ampullaris



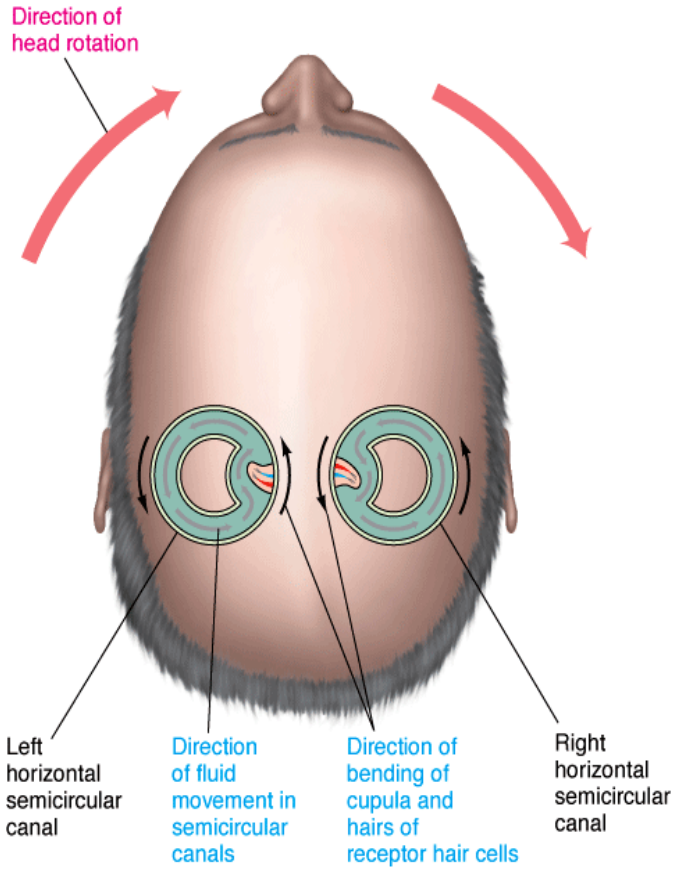
Hair cells of labyrinth

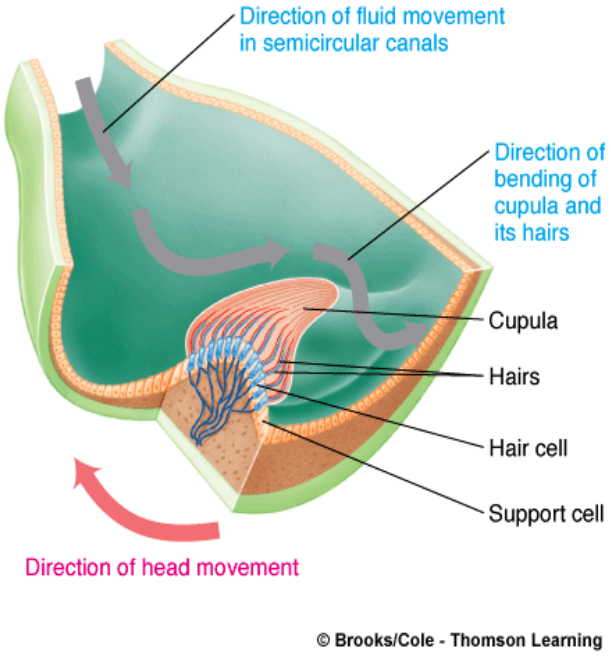


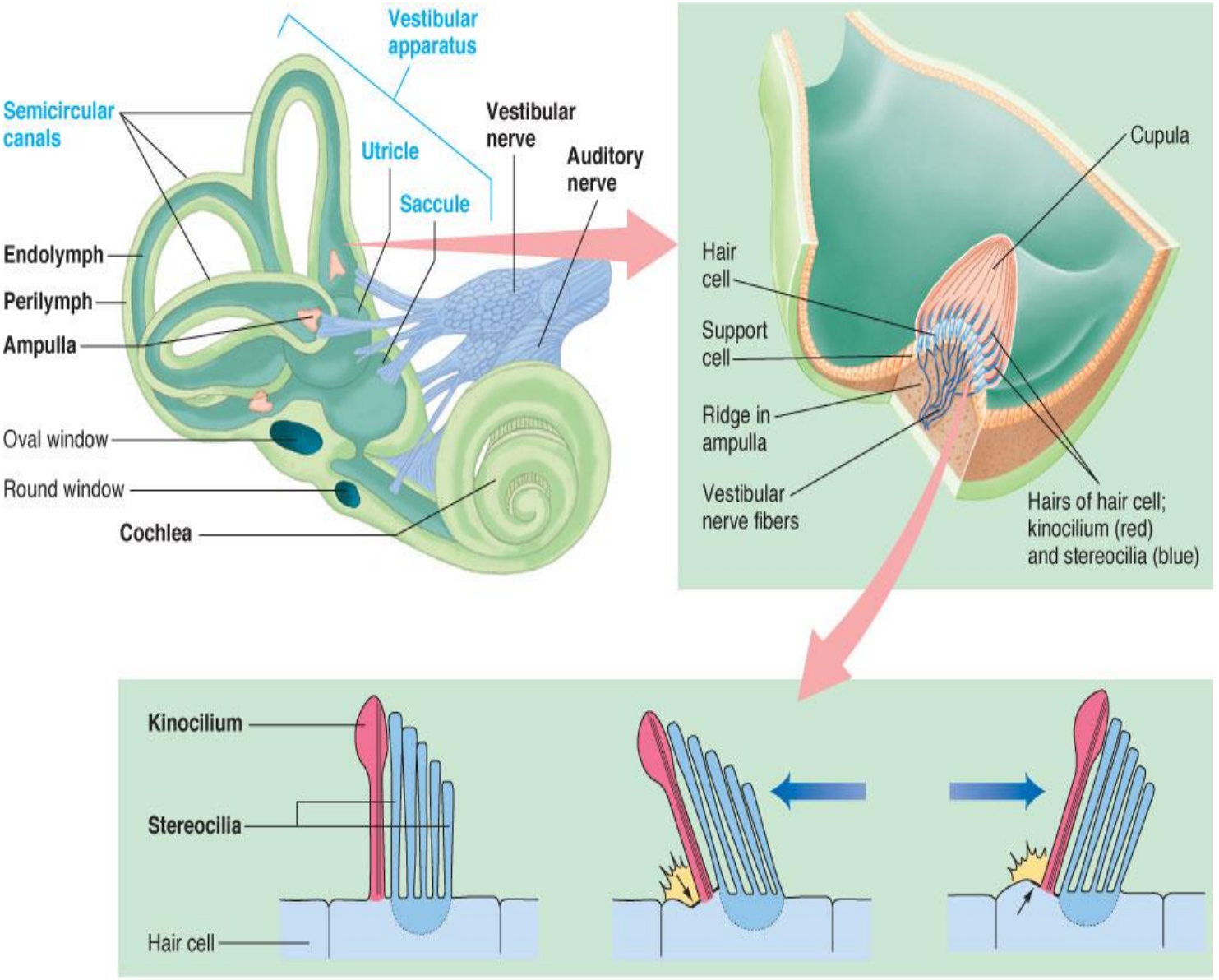
Vestibular Hair Cells

- Similar in structure to hair cells in the cochlea
- movement of the stereocilia toward the kinocilium in the vestibular end-organs opens mechanically gated transduction channels located at the tips of the stereocilia of kinocilium
- Opening of mechanically gated channels and depolarization depolarizing the hair cell and causing neurotransmitter release onto (and excitation of) the vestibular nerve fibers

Endolymph movement within the ampulla during head rotation



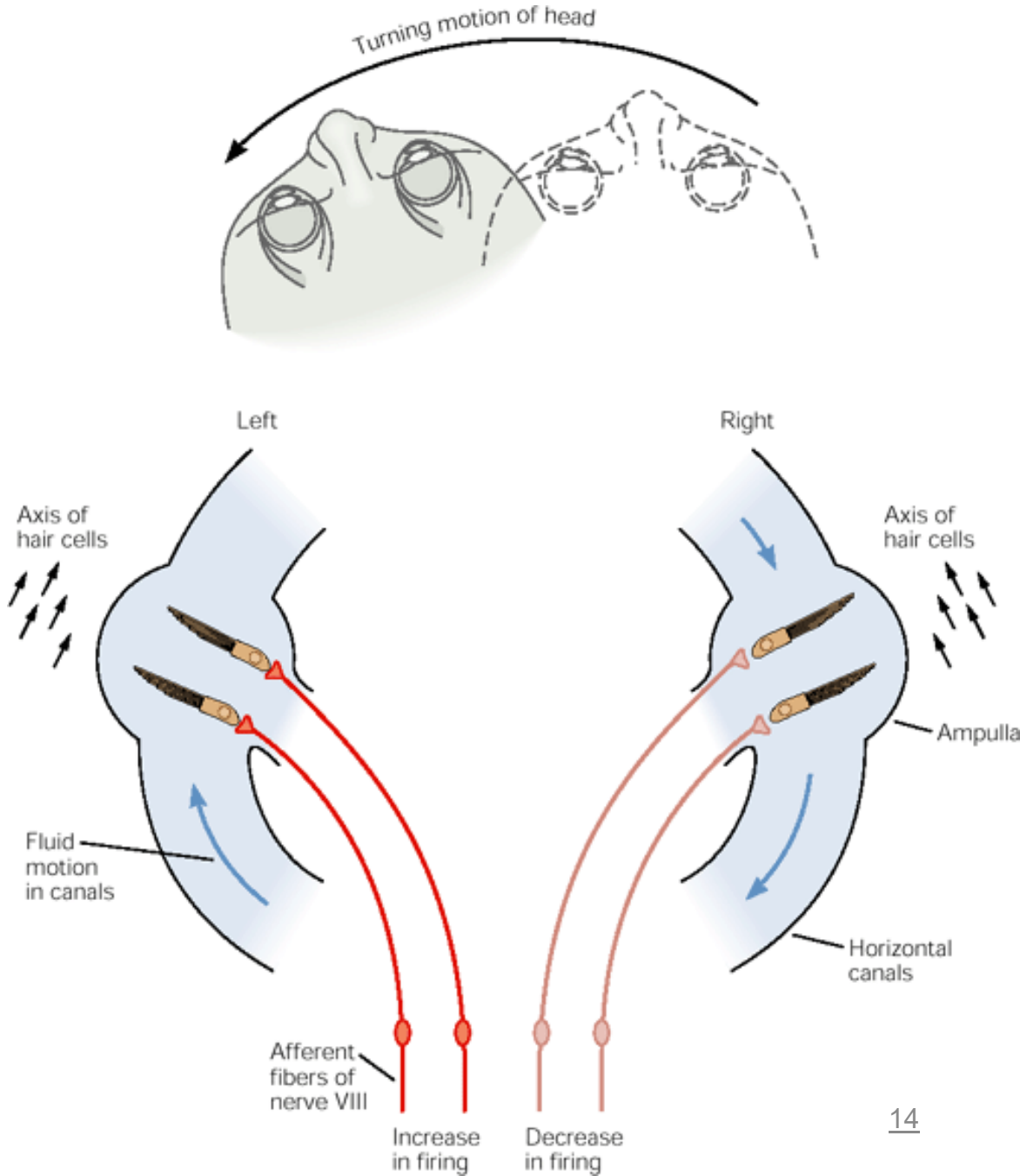


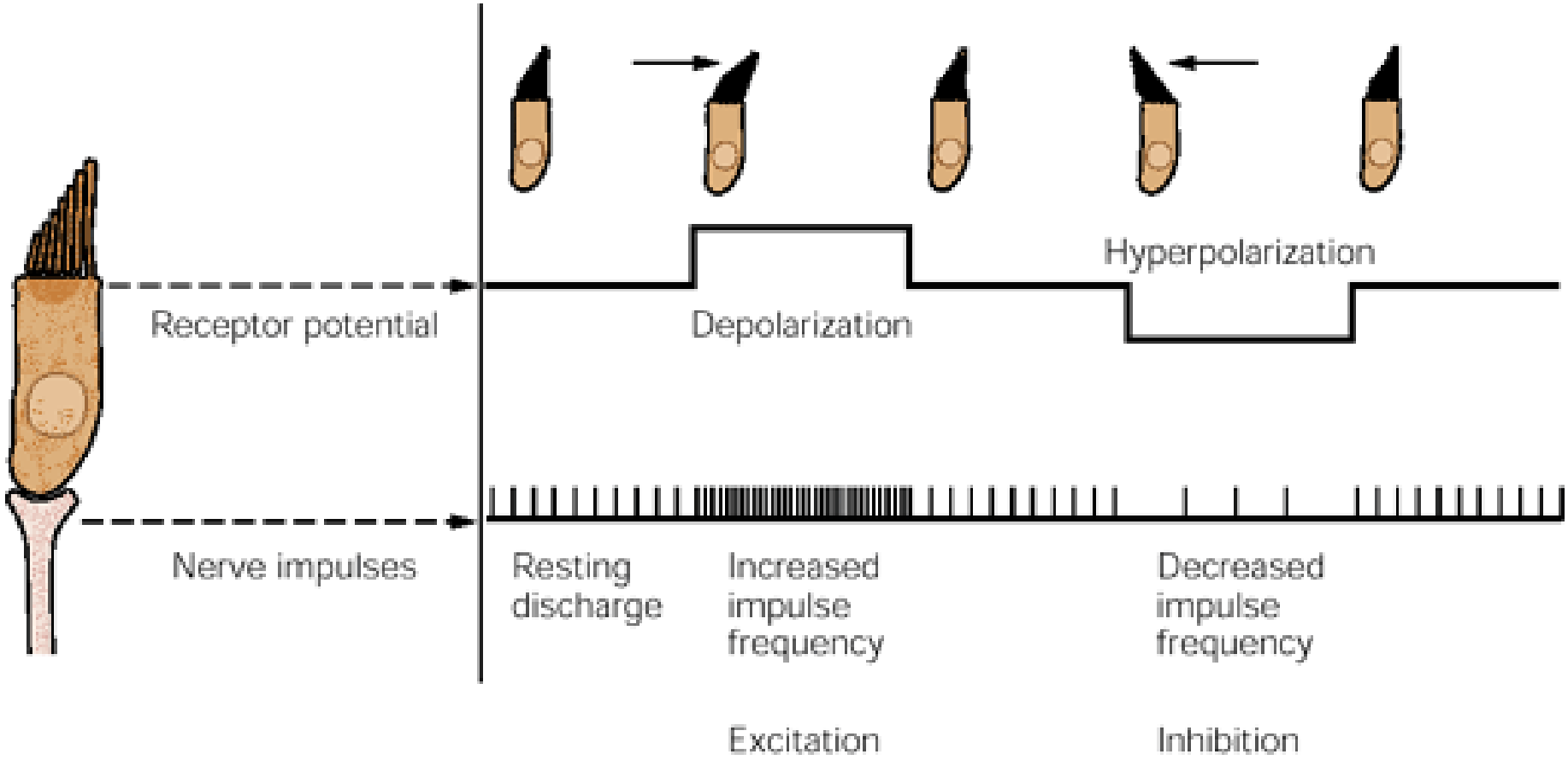


Hair cell depolarized when stereocilia are bent toward kinocilium

Hair cell hyperpolarized when stereocilia are bent away from kinocilium

Horizontal canals work together : Movement of the head towards the left, excites the left and inhibits the right semicircular canals.





Hair cell in the vestibular labyrinth: Mechanical stimuli into electrical signals.

Vestibular transduction summary

I. When the head rotates left, the left horizontal semicircular canal and its ampulla rotate in the same direction.

2. The anchored cupula moves before endolymph flow begins, leading to displacement and bending of the hair cells' cilia.

- Cilia Bending and Neuron Firing:
- 1. Bending towards the kinocilium: Hair cells depolarize, and afferent vestibular nerves fire more
- rapidly.
- 2. Bending away from the kinocilium: Hair cells hyperpolarise and afferent vestibular nerves fire less frequently.
- 3. During initial leftward head rotation, the left canal is excited, and the right canal is inhibited and the opposite occurs in the opposite canals
- When rotation is stopped the right canal is stimulated and the left canal is inhibited

Utricle and Saccule
Otolith Organs

- These are responsible for detecting linear acceleration and Gravity Detection.
- Both the utricle and saccule contain a small sensory structure known as a macula
- Maculae" are the sensory organs of the utricle and saccule, crucial for detecting head orientation concerning gravity.
- Each macula is covered by a gelatinous layer containing numerous small calcium carbonate crystals known as statoconia (composed of mucopolysaccharides and calcium carbonate crystals)
- When the head tilts, gravitational forces act on the otolith mass, moving it across the
- .The *utricle macula* lies primarily in the horizontal plane on the utricle's inferior surface, important for determining head orientation when *upright*.
- In contrast, the *saccule's* macula is located mainly in a vertical plane, signaling head orientation when the person *is lying down*.

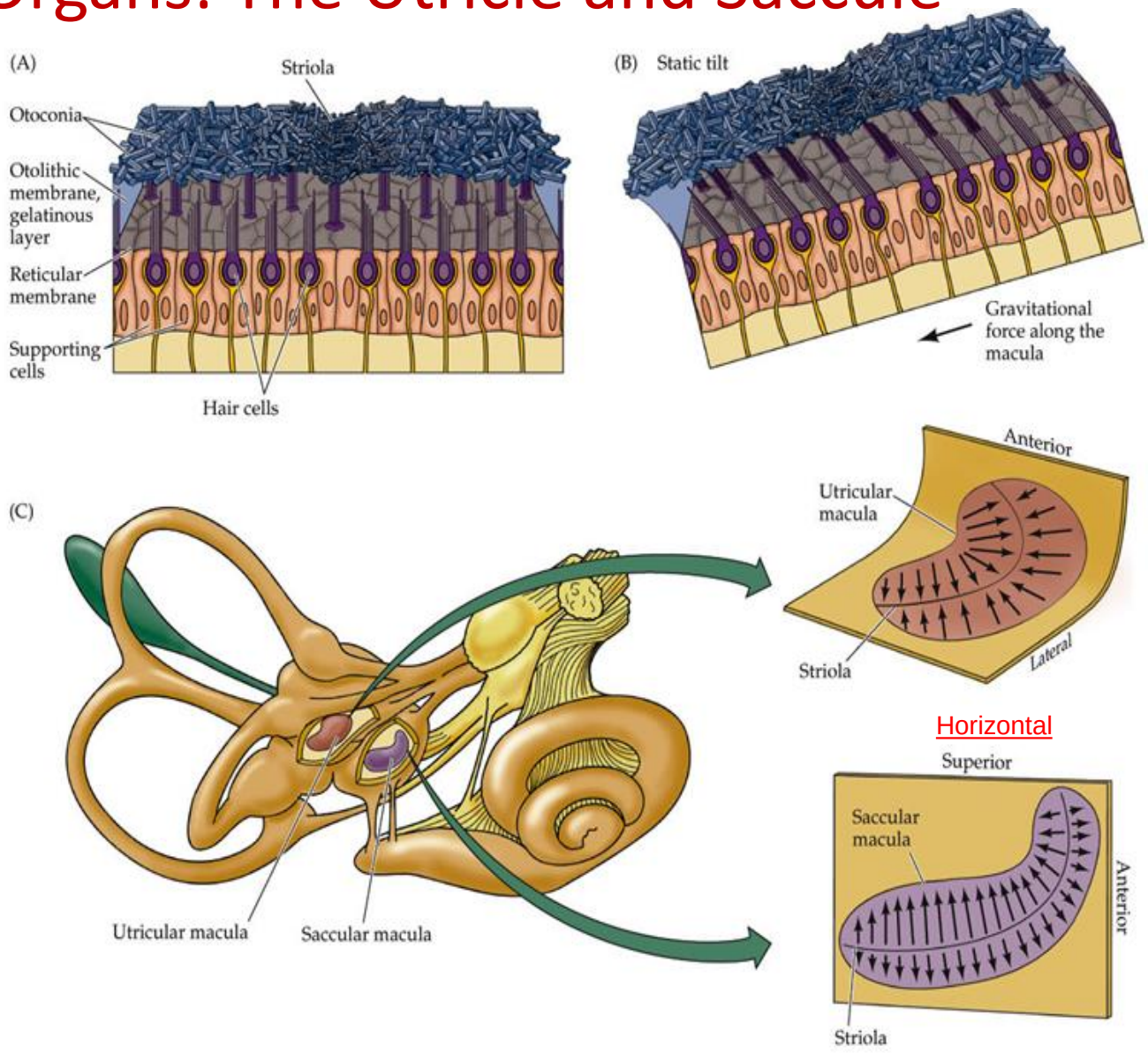
Otolith Organs: The Utricle and Saccule

1.stimullated by head tilt (gravitational force)

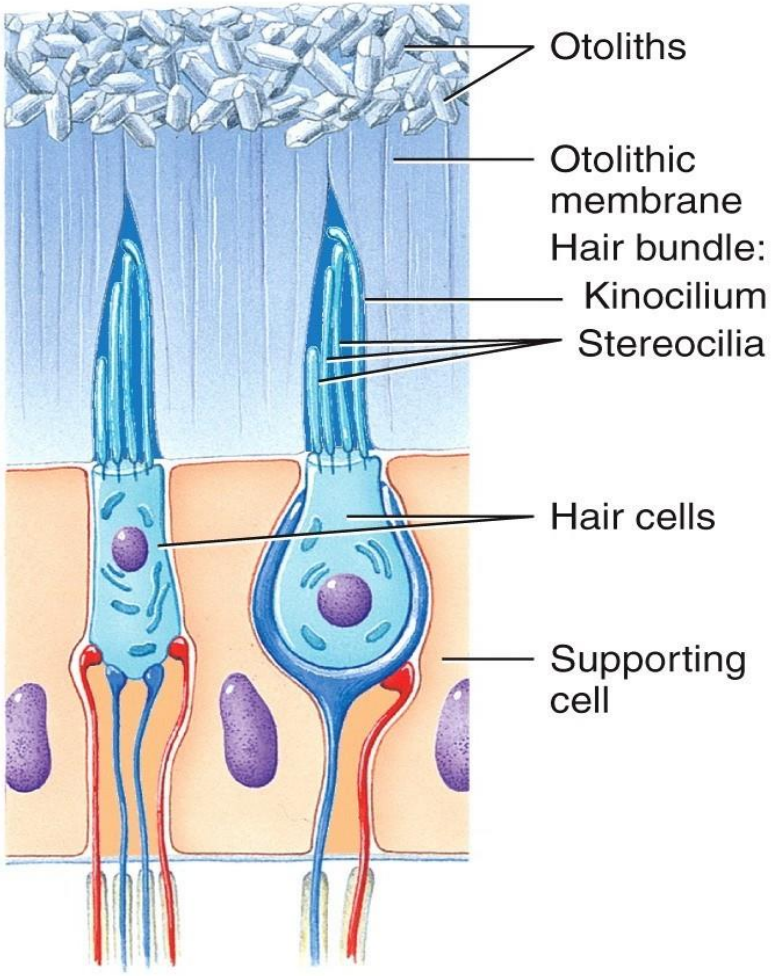
2. Utricle for horizontal acceleration

3. Saccule for vertical acceleration

Linear acceleration: e.g., Riding a car, taking a left



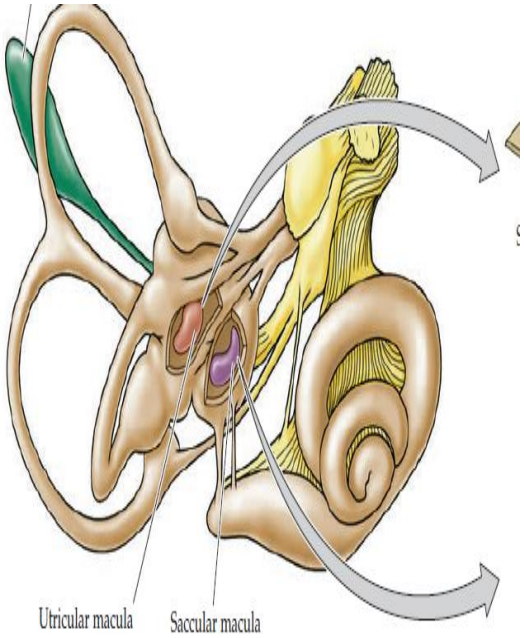
Hair cells otoliths organs of utricle and saccule

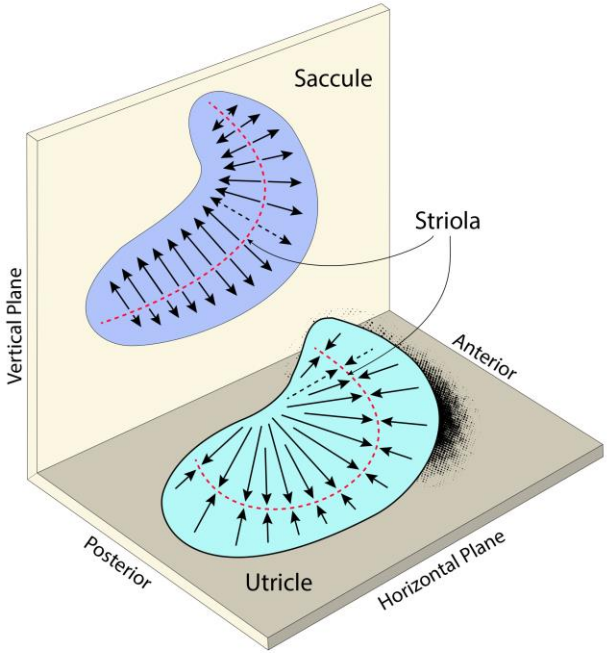


(b) Details of two hair cells

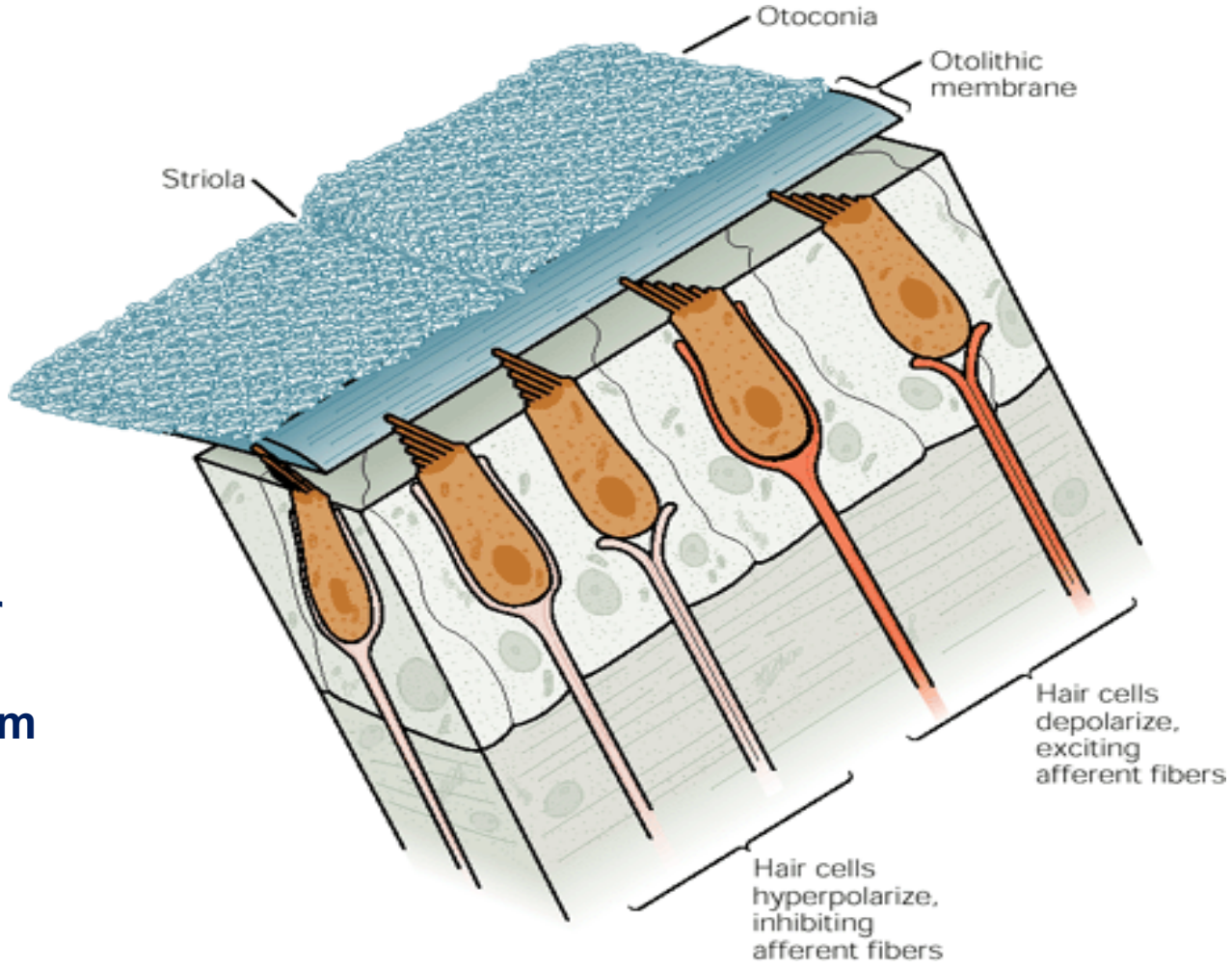
Utricle and saccule

In the utricle and saccule, a specialized area called the striola, divides the hair cells into two populations having opposing polarities



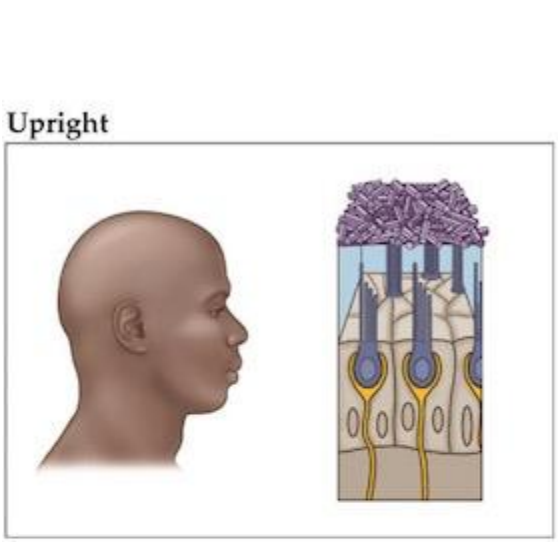


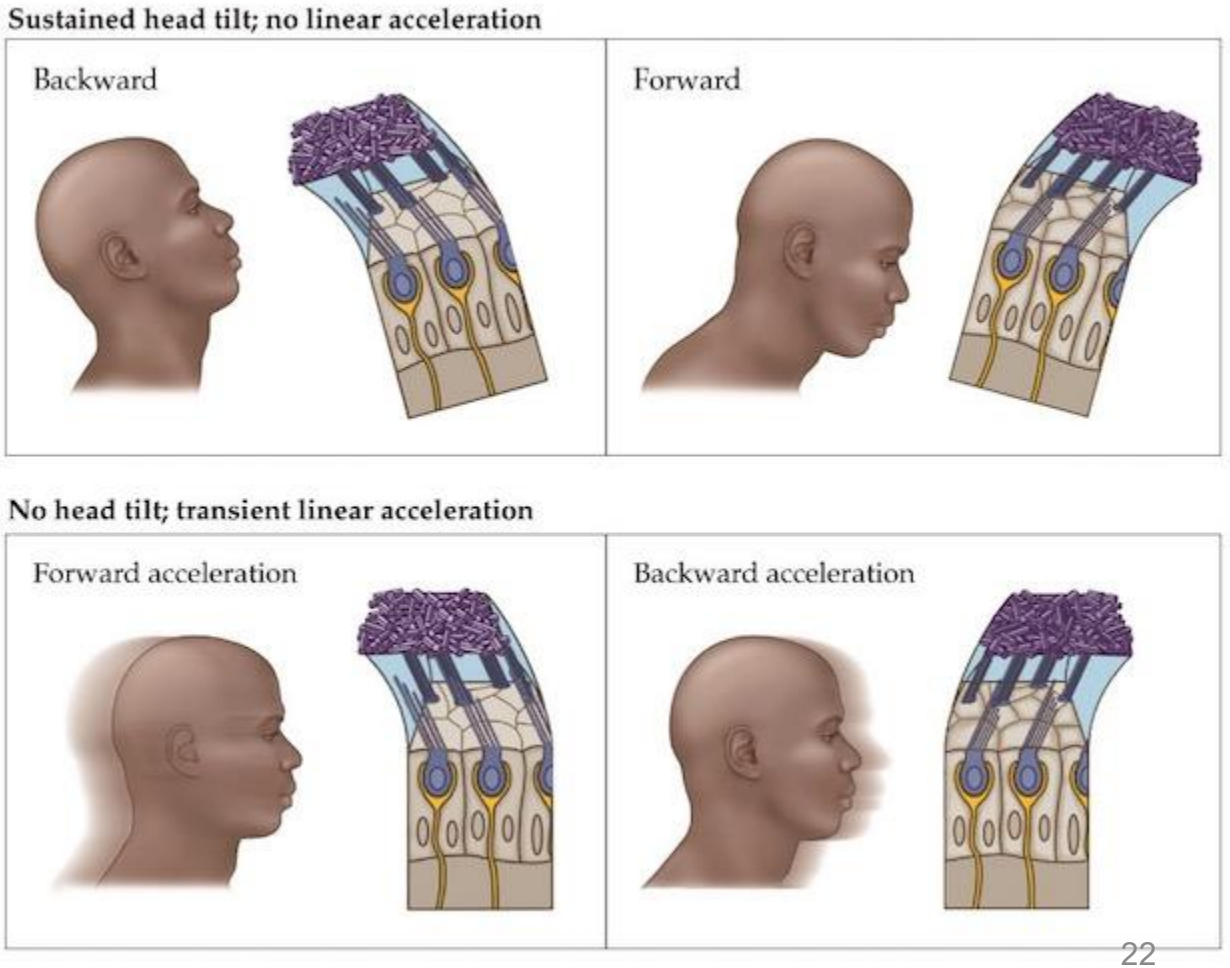
Response to head tilt caused depolarization in some cells, and hyperpolarization in others (depends on the orientation of the hairs)



Otoconia
Calcium carbonate crystals in utricular macula . Each otoconium is 50 µm long.

The utricle is stimulated by head tilting, where gravity pulls the otoconia in one direction or another, and also by acceleration in the horizontal plane (e.g. starting and stopping a car.





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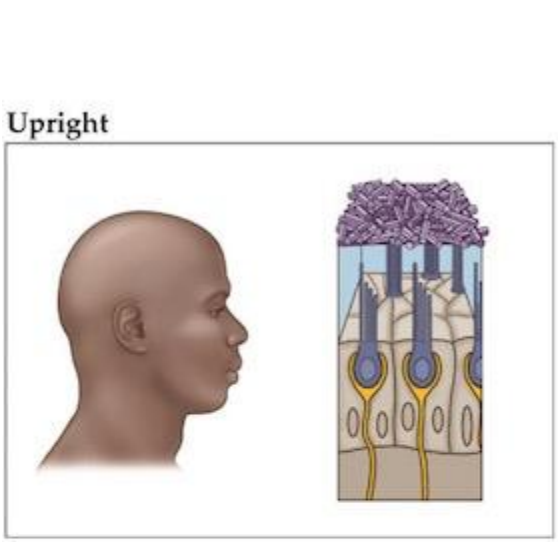
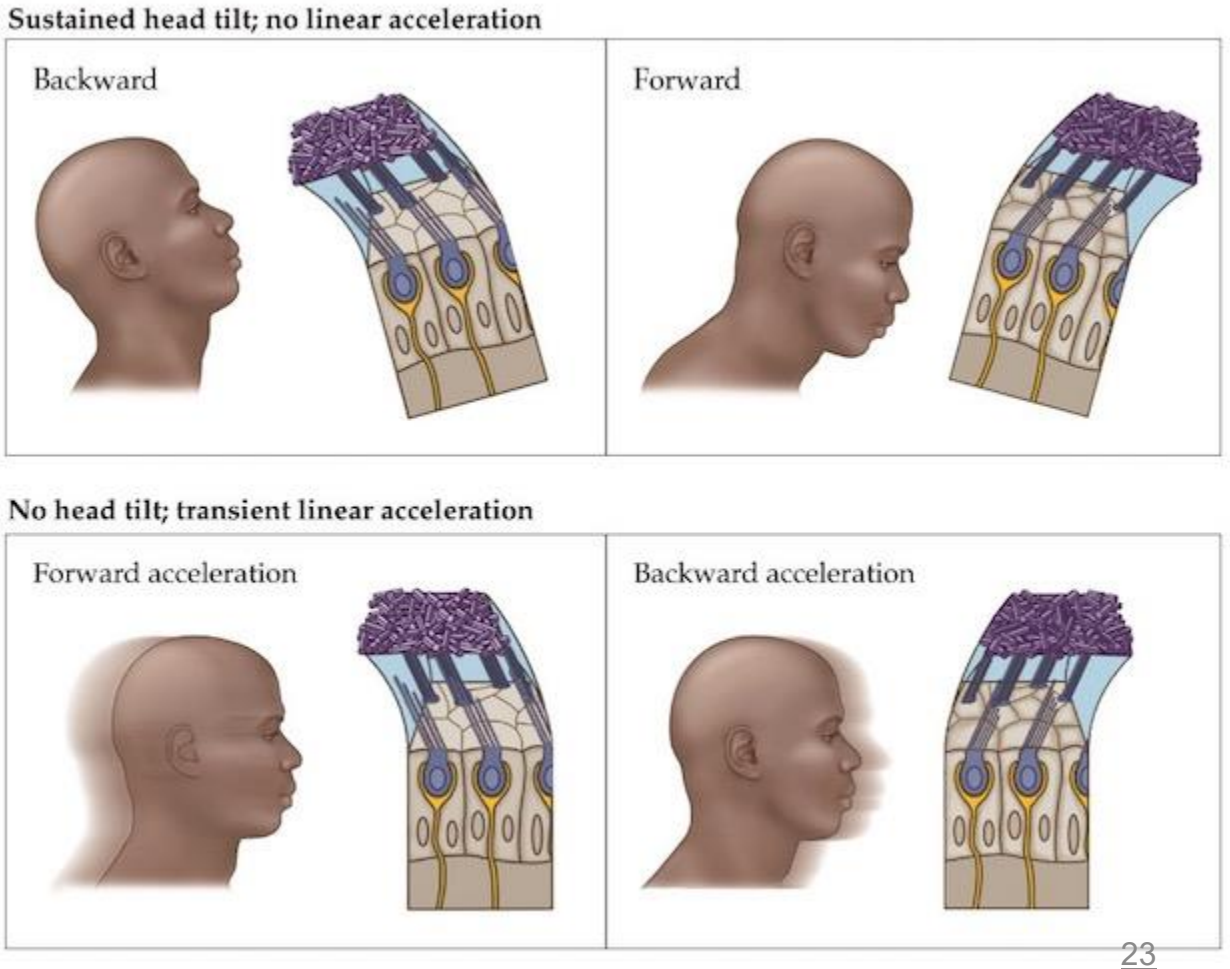


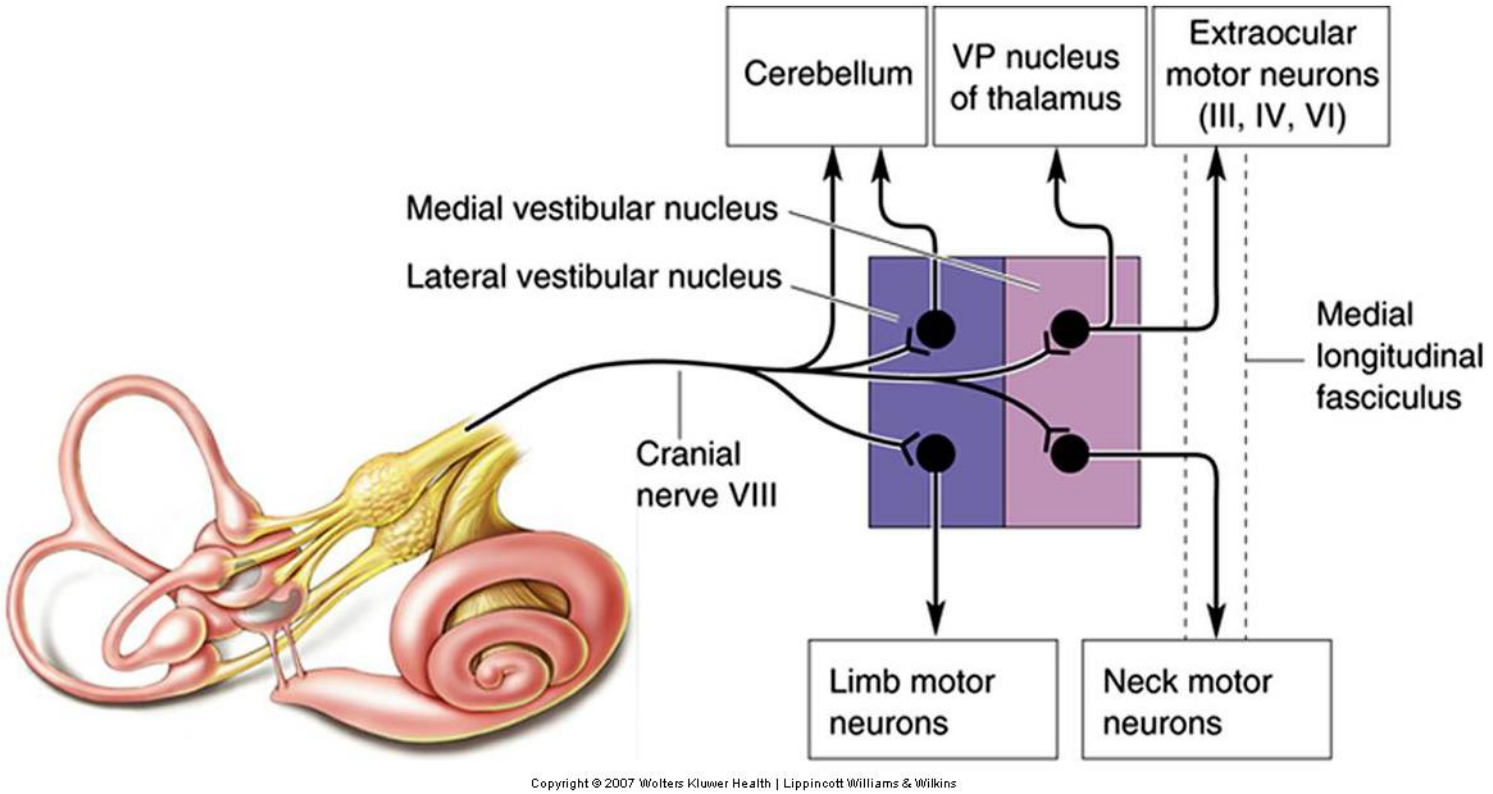


Vestibular Transduction in Otolith Organs

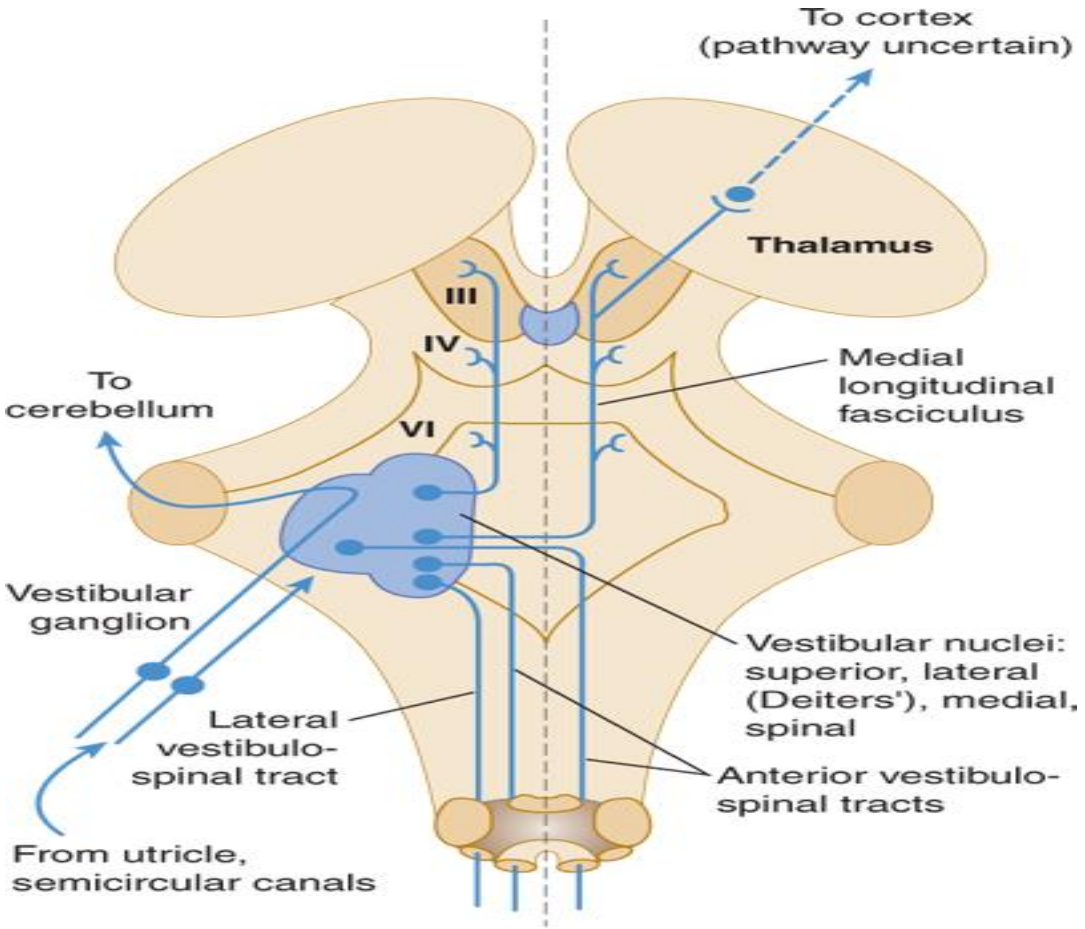
- Otolith organs, or maculae, are sensitive to linear acceleration, including gravitational forces.
- The hair cells of the maculae are embedded in the otolith mass. When the head tilts, gravity causes the otolith mass to slide across the vestibular hair cells, bending the stereocilia.
- If the stereocilia bend towards the kinocilium, the hair cell depolarizes and is excited. Bending away from the kinocilium results in hyperpolarization and inhibition.
- With the head upright, the utricle's macula is horizontal and the saccule's is vertical.
- Tilting the head forward or laterally excites the ipsilateral utricle, while tilting backwards or medially inhibits it

The Vestibular System

- Central Vestibular Pathways



Ascending vestibular connections



Vestibular reflexes

- Ocular reflexes (VOR)
- Postural reflexes
- Autonomic reflexes

Vestibulo-ocular Reflexes

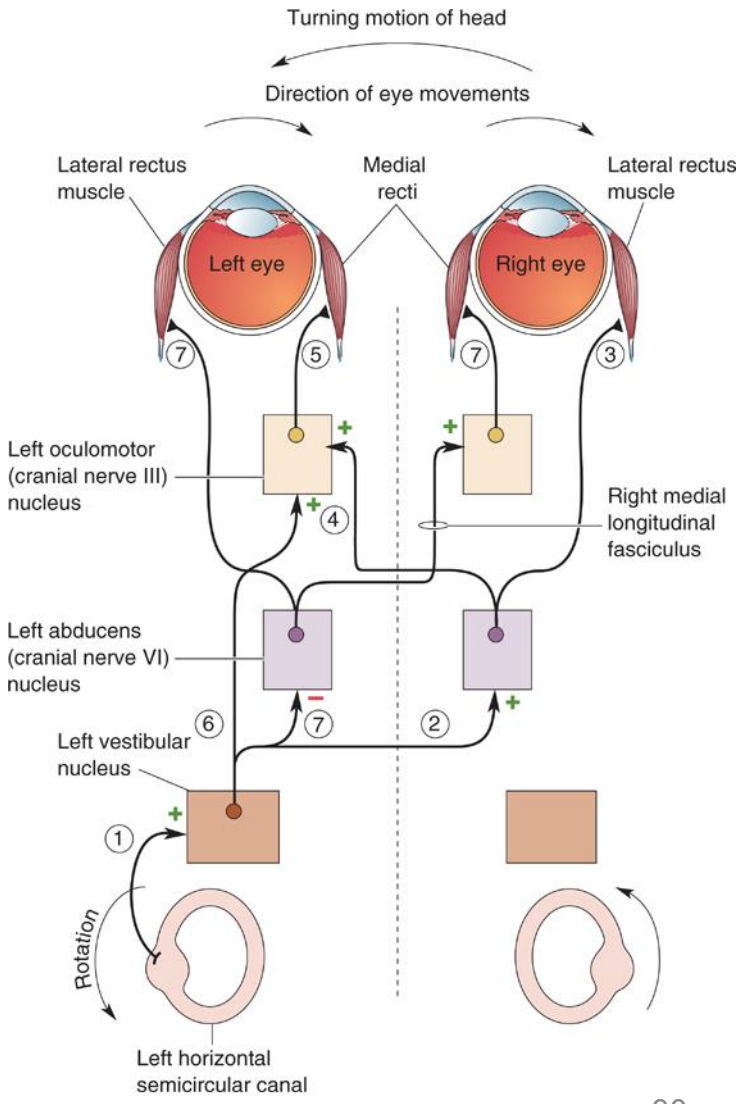
- Vestibulo-ocular reflexes respond to head movements.
- Nystagmus is one such reflex occurring due to angular or rotational head
- acceleration.
- When the head rotates, the eyes initially move in the opposite direction to
- maintain a steady gaze. This is the slow component of nystagmus.
- When the eyes near the limit of their lateral movement, a rapid eye movement in the direction of head rotation occurs.
- This is the rapid component of nystagmus, where eyes "jump ahead" to fix on a new position.
- The direction of this rapid component defines Nystagmus.

The Vestibular System
VOR

- 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 from semicircular canals, to vestibular nucleus, to cranial nerve nuclei → excite extraocular muscles →eye movement

The Vestibular System

- The Vestibulo-Ocular Reflex (VOR)



Vestibulospinal reflexes

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- Coordinate head and neck movement with the trunk and body .
- Thus maintaining the head in an upright position
- Two tracts
  - **LATERAL VESTIBULOSPINAL:** postural changes to compensate for tilts and movements of the body
  - **MEDIAL VESTIBULOSPINAL:** stabilizes head position fro example during walking

Lateral vestibulospinal tract

- The lateral vestibule spinal tracts receives inputs from the utricle and saccule
- Arises in the lateral vestibular nucleus.
- Below the medulla the lateral vestibulospinal tract descends in the anterior white matter down the entire length of the spinal cord.
- Excites spinal motor neurons controlling muscles in the legs that help maintain posture
- This tract modulates postural adjustments to head movements.
-

Medial Vestibulospinal Tract

- The Medial vestibular and the superior nucleus receives inputs mainly from the semicircular canal.
- MVT arise in the medial vestibular nucleus.
- It is a bilateral tract.
- It descends no lower than the mid-thoracic cord.
- Control the muscles of the neck and shoulder
- .his pathway helps the head stay straight even as the body spins around below it.

Abnormalities related to vestibular functions

- Benign paroxysmal positional vertigo is the most common vestibular disorder characterized by episodes of vertigo that occur with particular changes in body position (eg, turning over in bed and bending over). One possible cause is that otoconia from the utricle separate from the otolith membrane and become lodged in the canal or cupula of the semicircular canal. This causes abnormal deflections when the head changes position relative to gravity.
- Ménière disease is an abnormality of the inner ear causing vertigo or severe dizziness, tinnitus
- Motion sickness is a common condition that happens when you're in motion, like riding in a vehicle, while sitting still. It happens when your eyes, inner ear and body send conflicting messages to your brain
- Associated with dizziness nausea, blood pressure changes, sweating, pallor, and vomiting

Vertigo

Vertigo is a sensation of feeling off balance. If you have these dizzy spells, you might feel like you are spinning or that the world around you is spinning.

- Other symptoms that may accompany vertigo include:
- Feeling nauseated
- Vomiting
- Abnormal or jerking eye movements (nystagmus)
- Headache
- Sweating
- Ringing in the ears or hearing loss
-