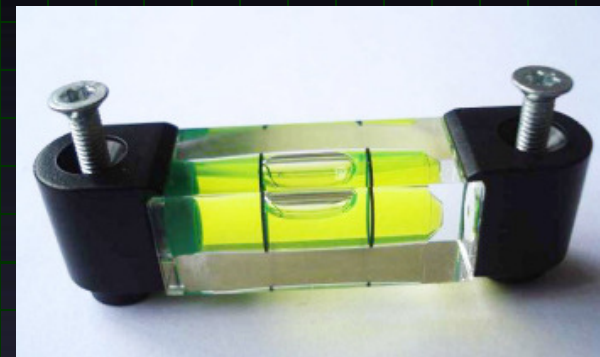


PHYSIOLOGY OF INNER EAR IN BALANCE



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OBJECTIVES

At the end of this lecture you should be able to describe:

- ▶ Functional anatomy of Vestibular apparatus
- ▶ Dynamic and static equilibrium
- ▶ Role of utricle and saccule in linear acceleration
- ▶ Role of semicircular canals in angular motions
- ▶ Vestibular Disorders

9/25/2018



Overview of Proprioception & Balance

Equilibrium

Static Equilibrium
Utricle & Saccule

Linear Acceleration
Horizontal (Utricle)

Linear Acceleration
Vertical (Saccule)

Angular Acceleration
(SCCs)

Predictive Functions
(SCCs)

Proprioception

Static
position sense (Ia)

Dynamic
position sense (II)

Neck
Proprioceptors

Visual Information
(vestibulo Ocular)

Vestibular Apparatus

Chest Wall
Proprioceptors

air pressure against
body

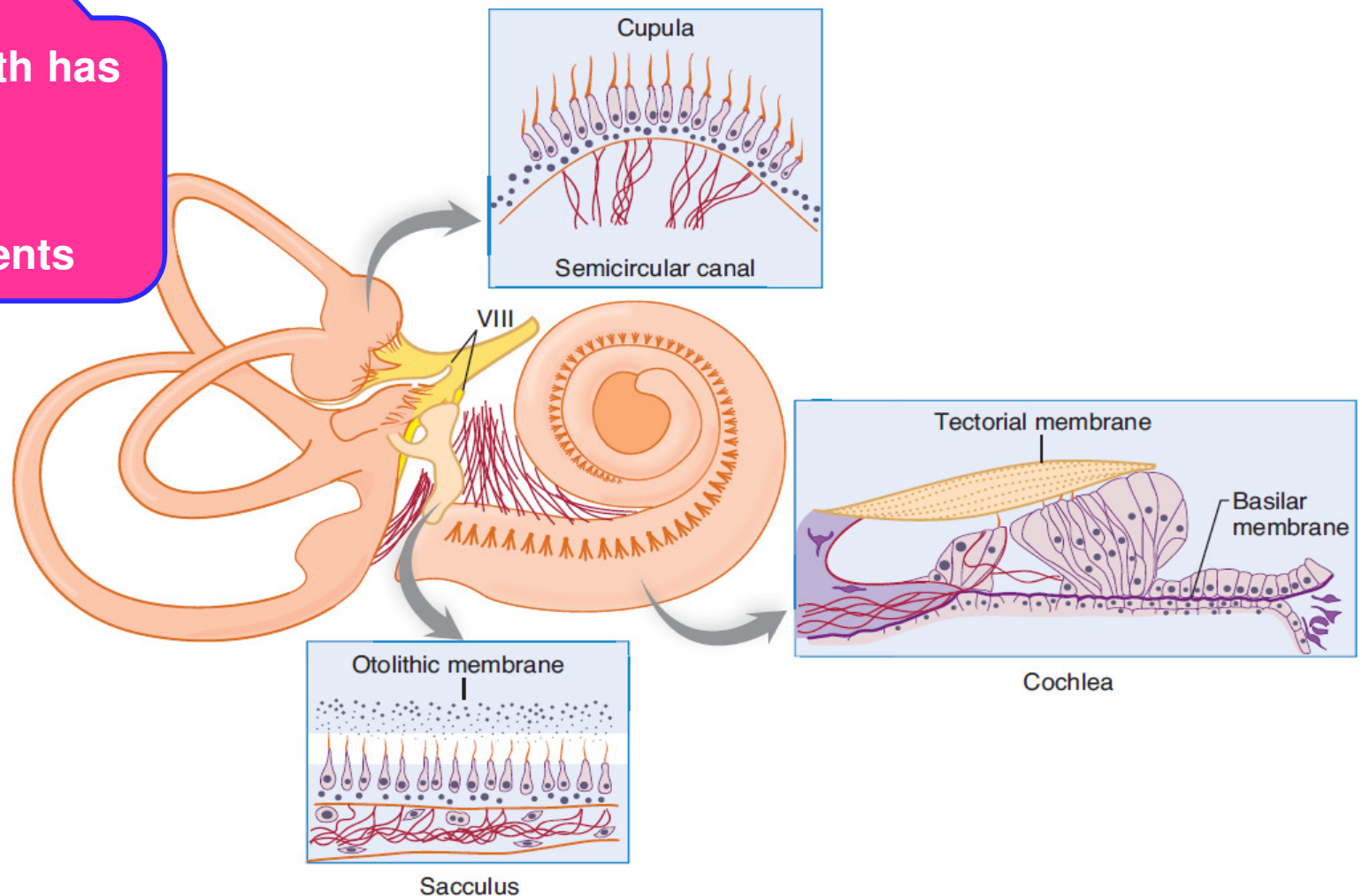
Footpads pressure

- **Cochlea** (**Organ of Corti** containing receptors for hearing)
- **Semicircular canals** (**Crista ampullaris** containing receptors that respond to head rotation)
- **Utricle & Saccule** (**Macula** contain otolith organs and receptors that respond to gravity and head tilt)

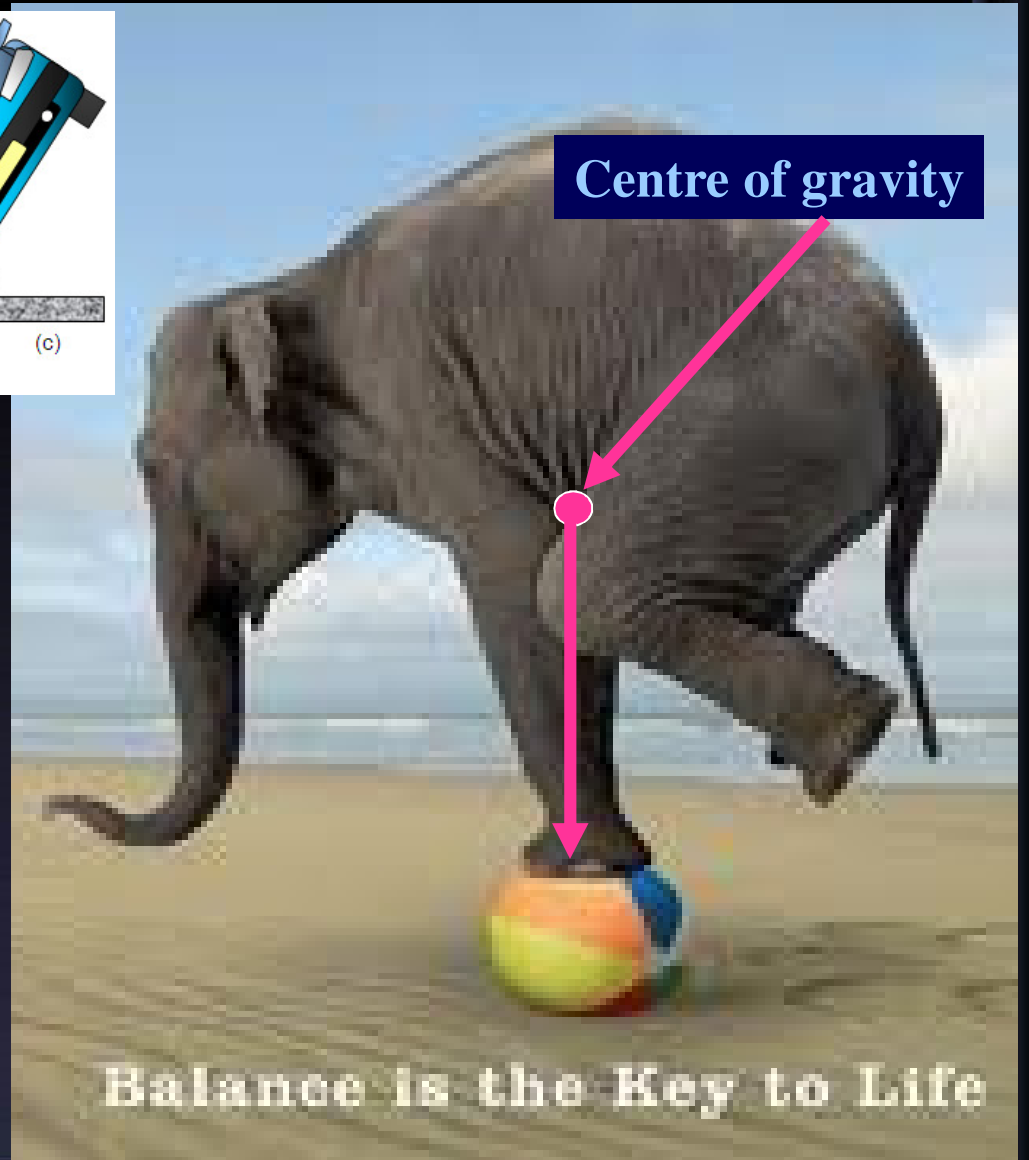
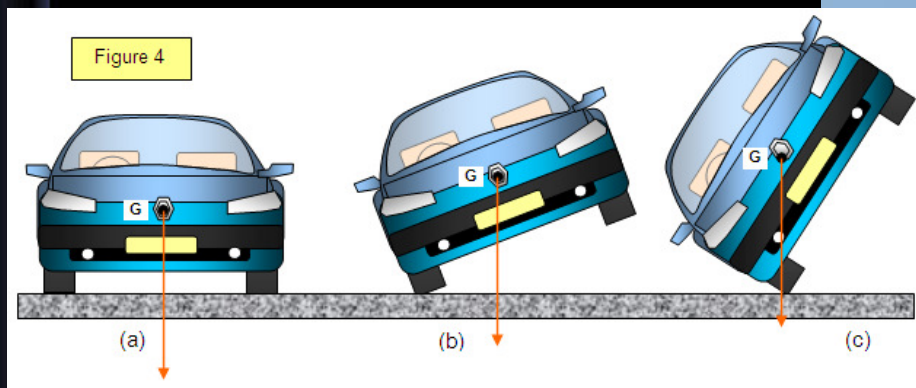
The labyrinth has

3

Components



To balance the centre of gravity must be above the support point at which the weight is evenly dispersed



Balance is the Key to Life

Balance & Equilibrium

Balance is the ability to maintain the equilibrium of the body

- Foot position affects standing balance

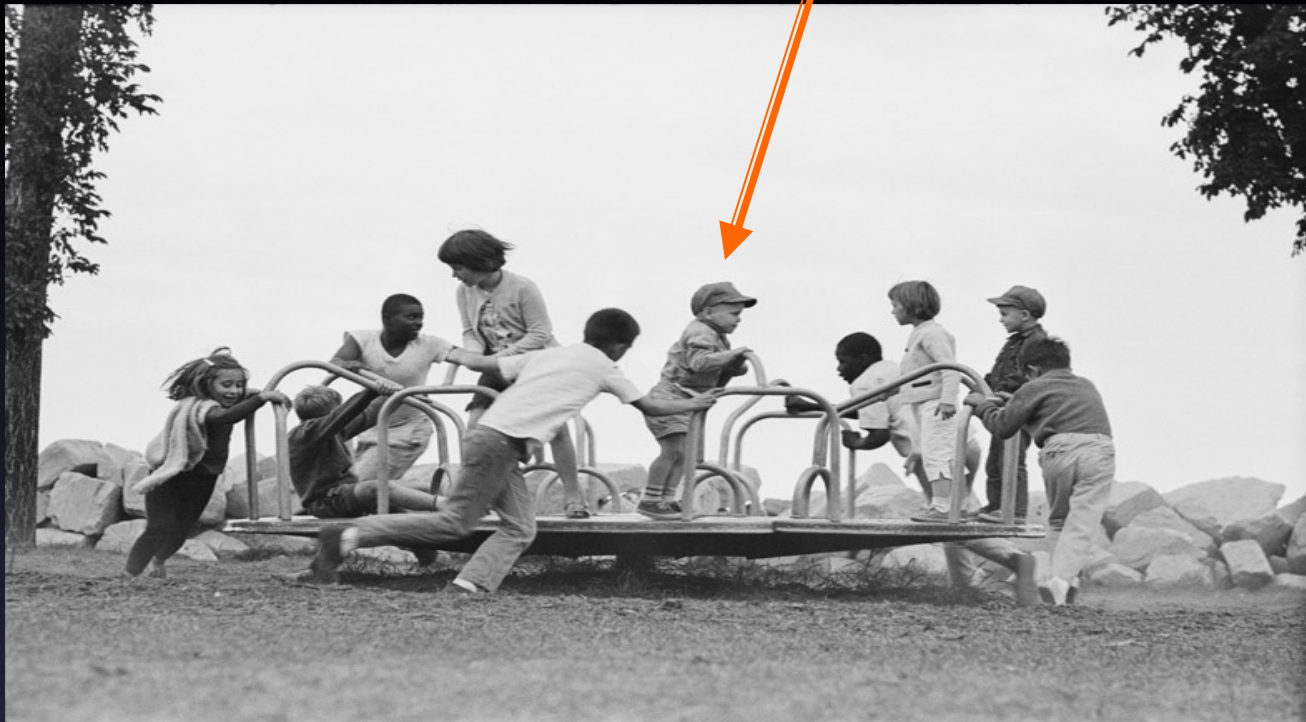
Equilibrium is the state of a body or physical system at rest or in un accelerated motion in which the resultant of all forces acting on it is zero and the sum of all torques about any axis is zero.

There are 2 types of **Equilibrium**

- » Static -
- » Dynamic –

Static Equilibrium

keep the body in a desired position



Static equilibrium –The equilibrium is maintained in a **FIXED POSITION**, usually while stood on one foot or maintenance of body posture relative to gravity while the body is still.

Dynamic Equilibrium to move the body in a controlled way

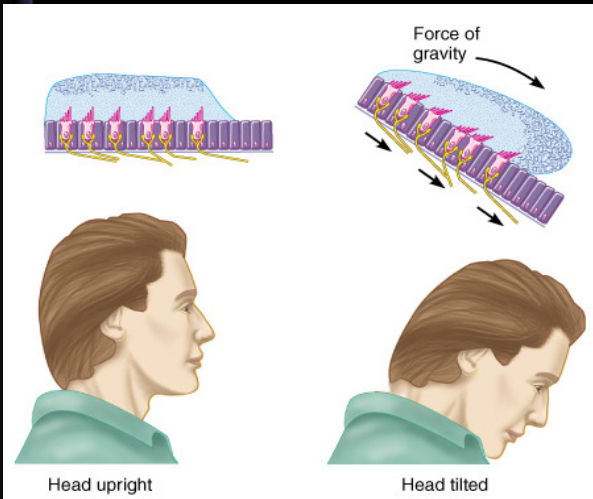
Static Equilibrium -
sense the position of the
head, maintain stability
and posture

Dynamic Equilibrium
(semicircular canals) -
balance the head during
sudden movement

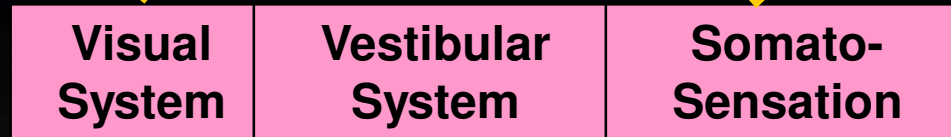


Dynamic equilibrium The equilibrium must be maintained **while performing a task** which involves MOVEMENT e.g. Walking the beam – maintenance of the body posture (mainly the head) in response to sudden movements. Tracking a moving object.

Acceleration Linear & Angular (Rotational)



Compare, Select & Combine Senses



Visual
System

Vestibular
System

Somato-
Sensation

SENSORY INPUTS

Vision

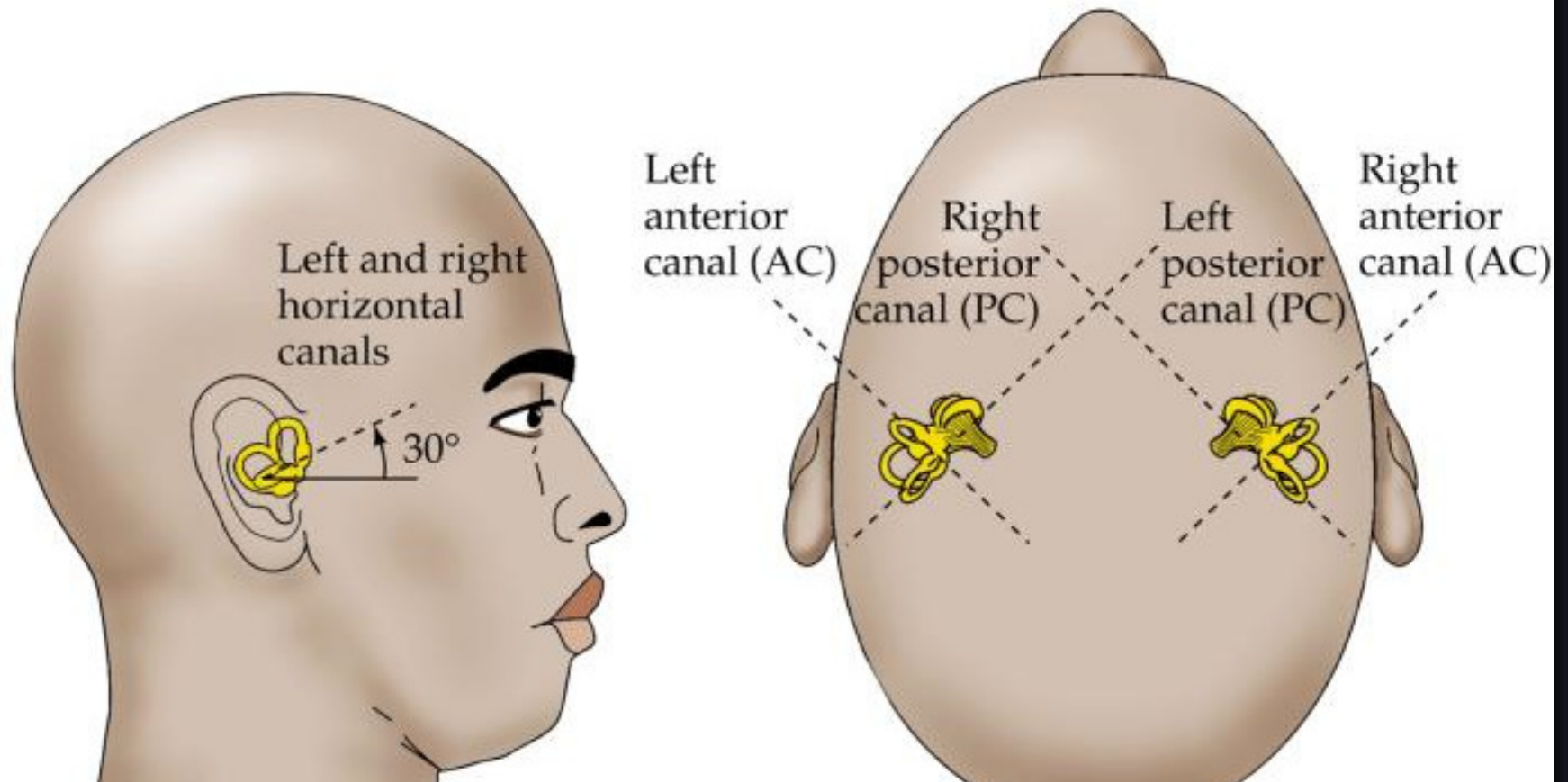
Vestibular

Somatosensory

(Proprioceptors & Cutaneous)

The vestibular labyrinth

(C)

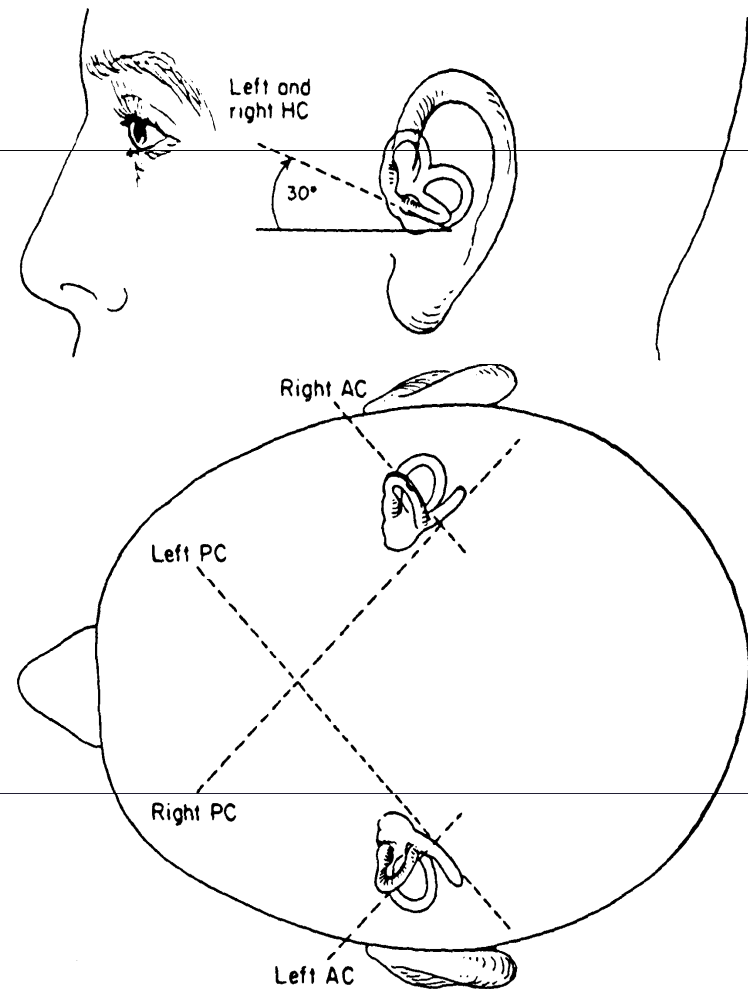


- posterior canal shares plane with contralateral anterior canal.
- horizontal canals share plane.

The Vestibular Apparatus

Components

- Three SCCs
 - Anterior (Superior)
 - Posterior (Inferior)
 - Lateral
- a. Vestibule (Utricle and Saccule)
- b. Vestibular nerve and nuclei



Maintaining Equilibrium

Semi-circular canals

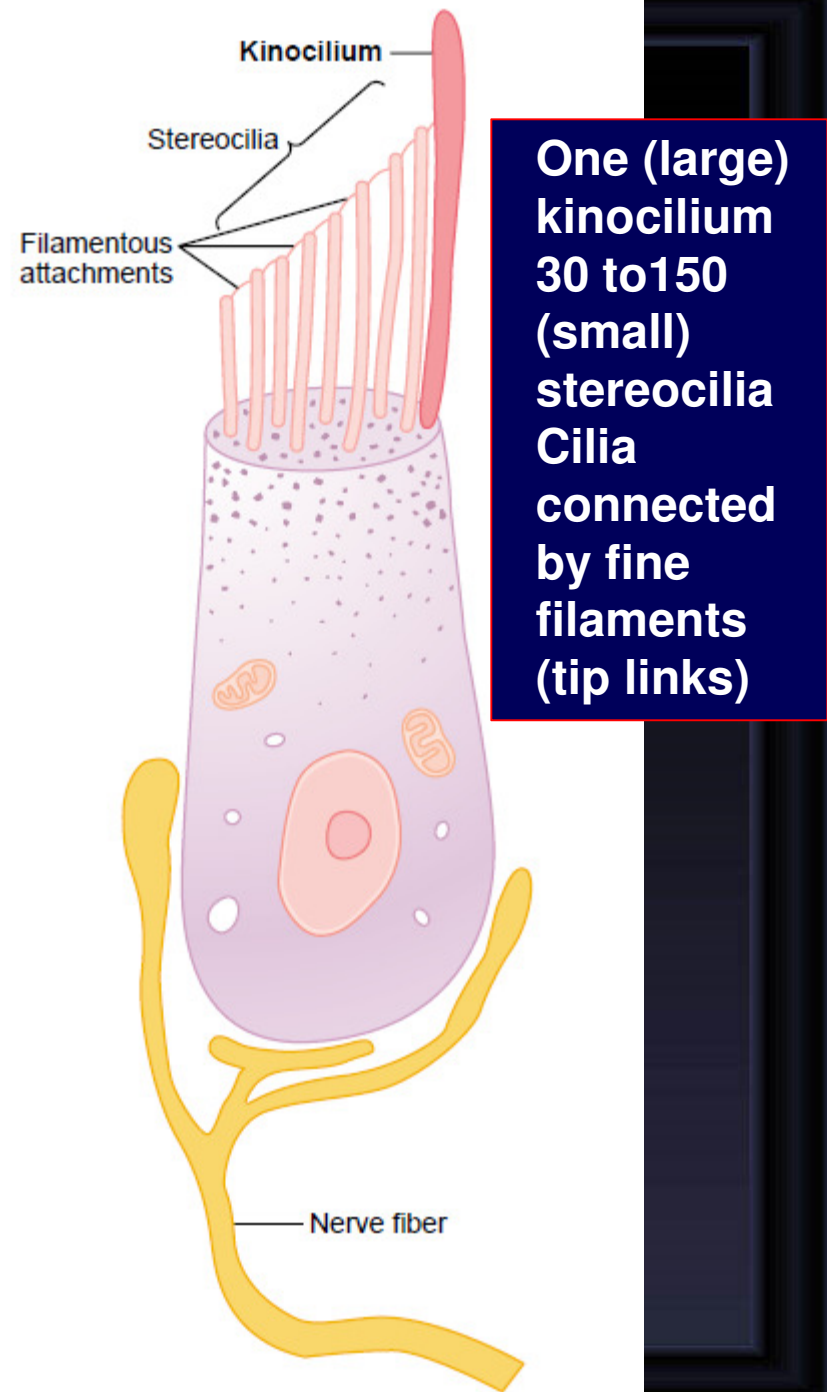
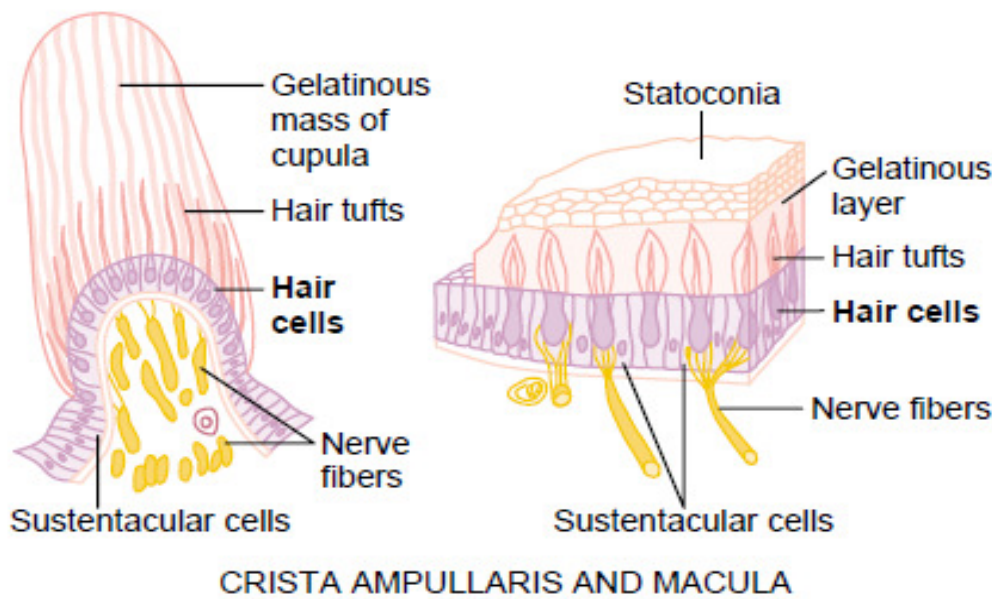
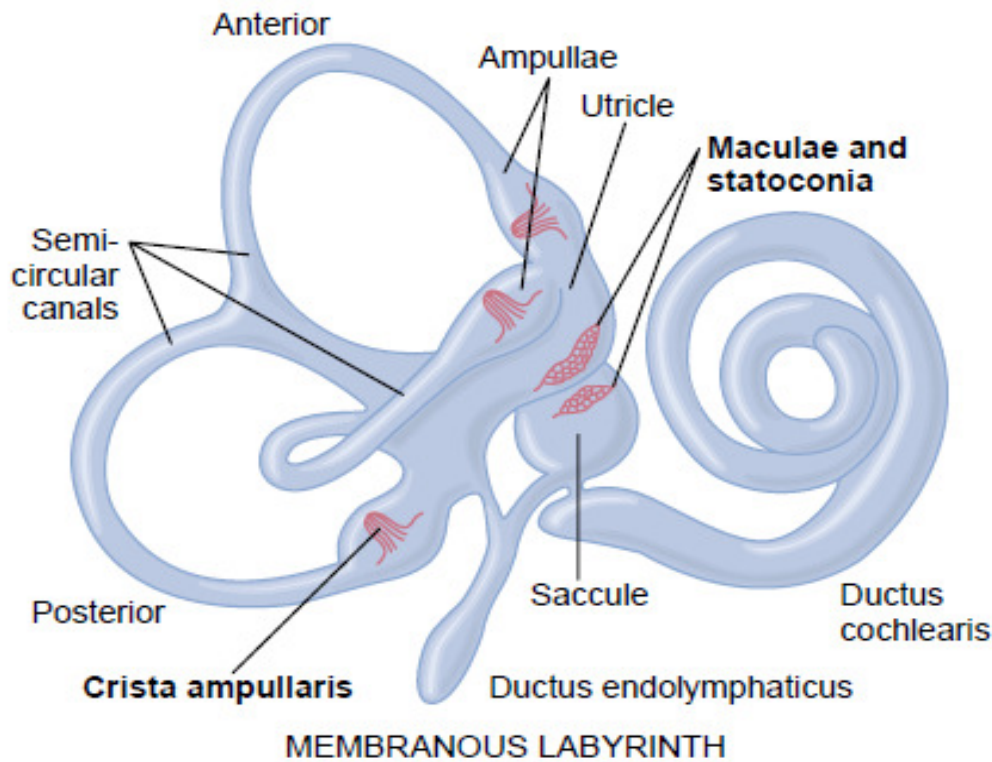
(Ant,Post,Lat)

- **Crista ampullaris**
- **Hair cells in each crista are oriented in the same direction**
- **Dynamic Equilibrium and angular motion**

Vestibule

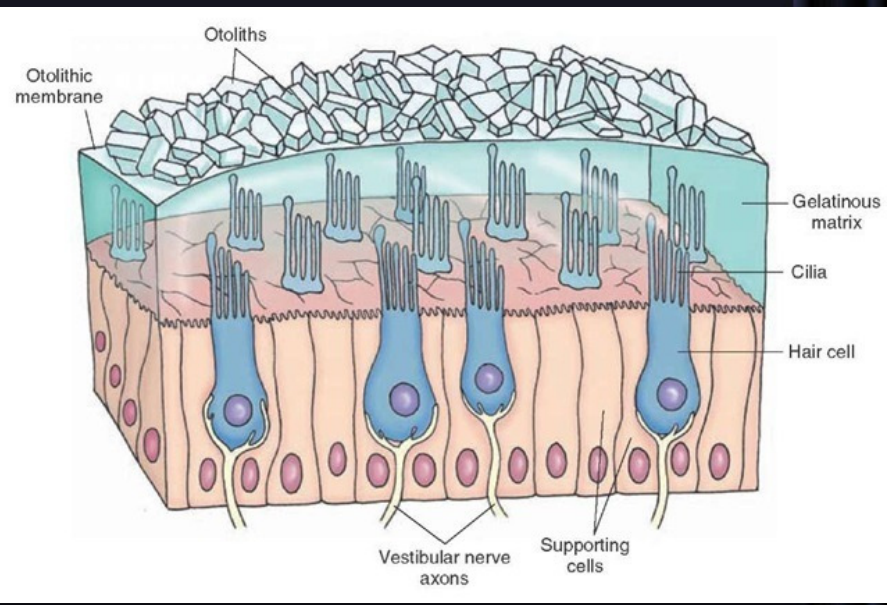
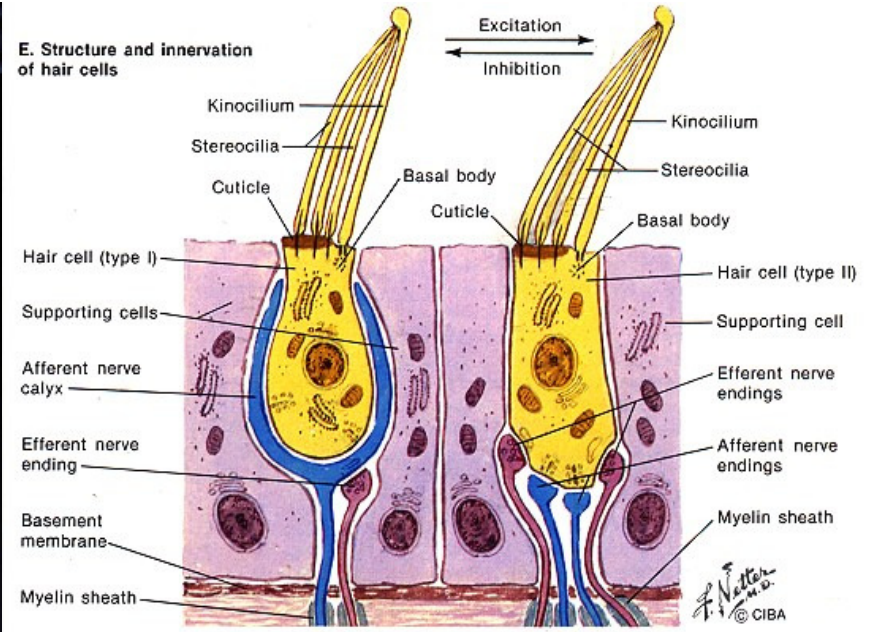
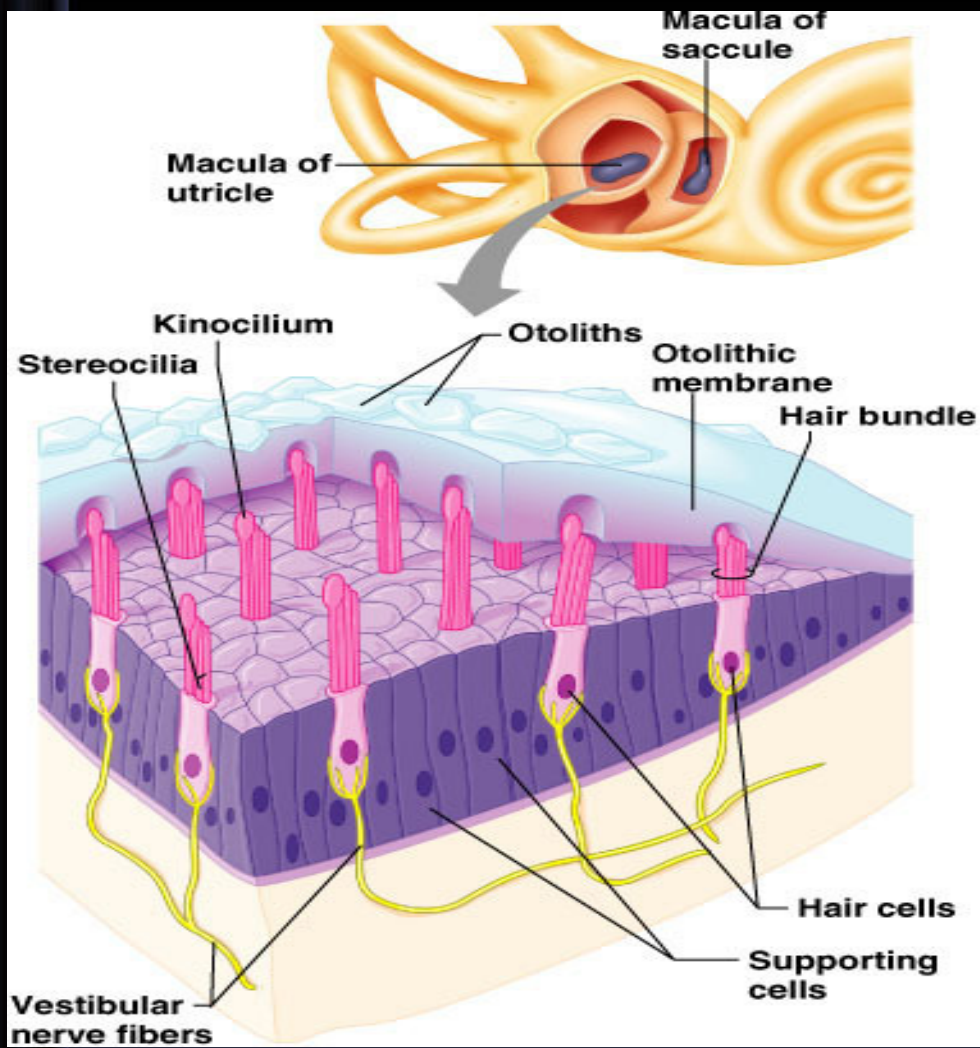
(saccule and utricle)

- **Maculae**
- **Hair cells in each macula are oriented in all direction**
- **Otoliths** (calcium carbonate crystals)
- **Static equilibrium and Linear Acceleration**



**One (large) kinocilium
30 to 150 (small) stereocilia
Cilia connected by fine filaments (tip links)**

Maculae



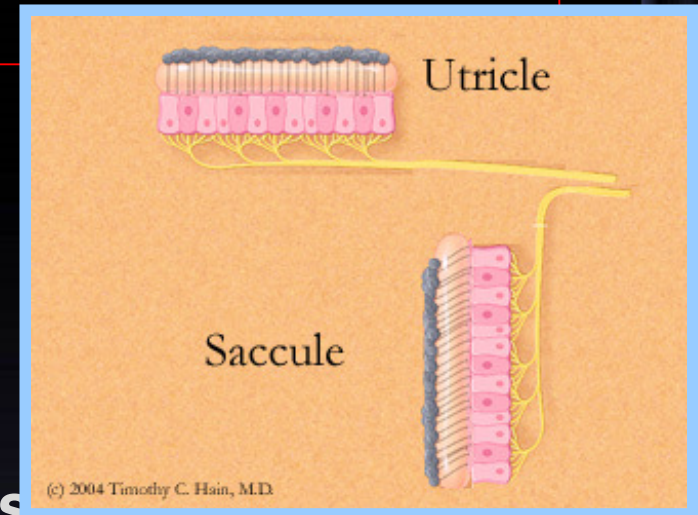
Hair cells in Utricle & Sacculle

Vestibule (between cochlea and semi-circular canals) contains static equilibrium receptors called maculae.

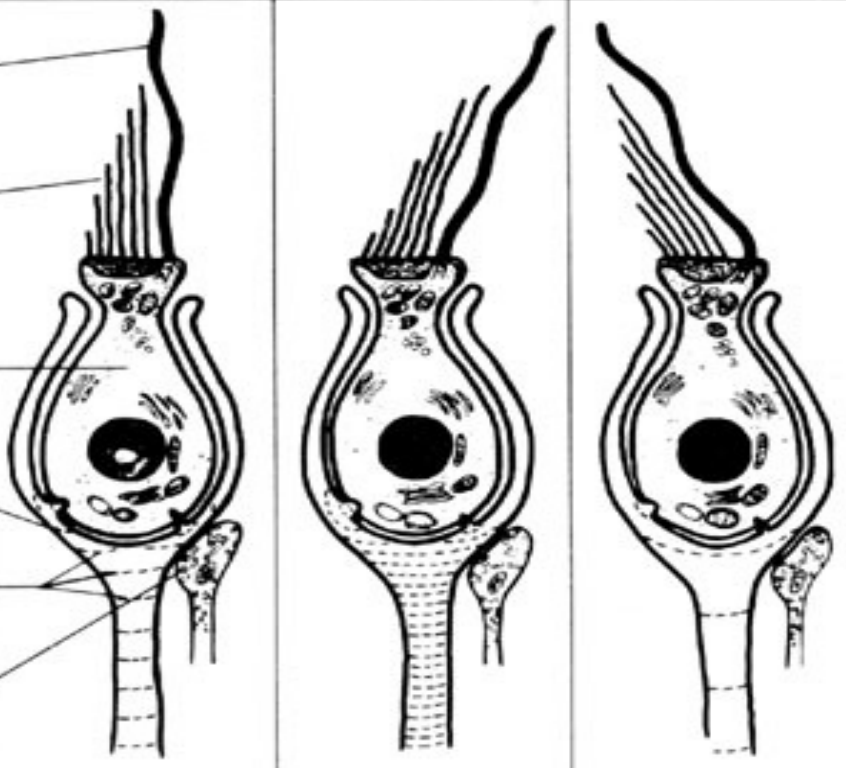



In upright position: (Head vertical)

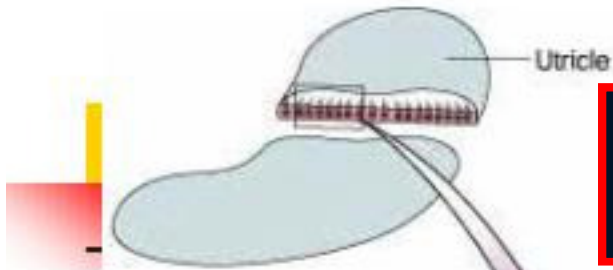
- In utricle:
 - Macula in horizontal plane
 - Hairs pointing upwards
 - Hair cells signal head movements in any direction
- In sacculle:
 - Macula in vertical plane
 - Hairs pointing laterally
 - Hair cells operate when one is lying down

inform the brain of orientation
of head in space



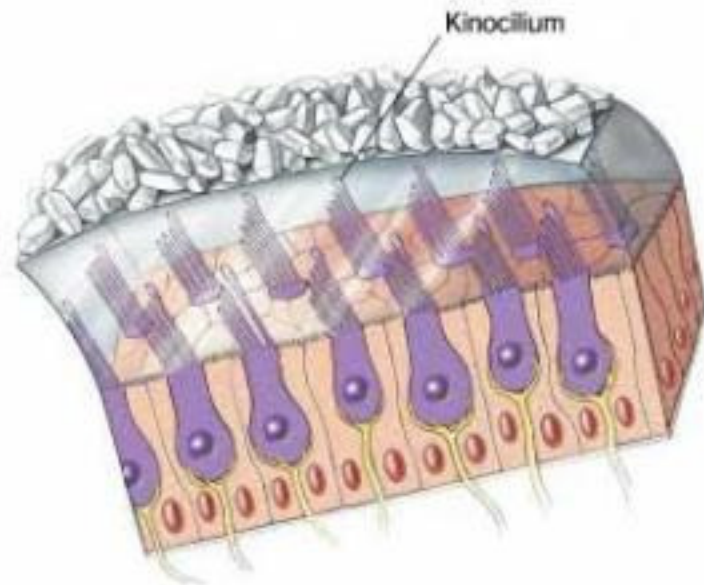
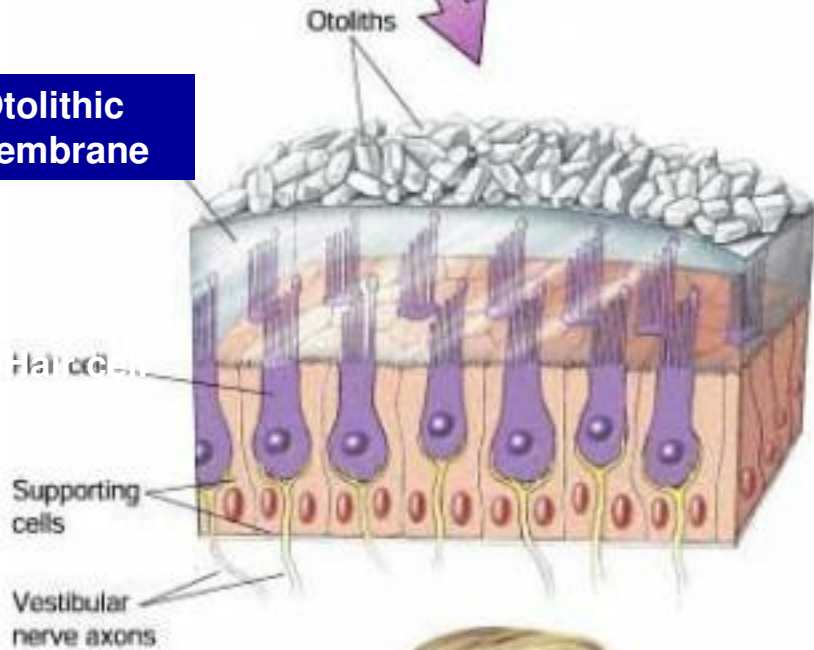
*Saccular maculae detect vertical acceleration
*Utricle maculae horizontal acceleration

| POSITION OF CILIA | NEUTRAL | TOWARD KINOCILIUM | AWAY FROM KINOCILIUM |
|---|---|--|--|
| <p>KINOCILIUM (1)</p> <p>STEREOCILIA (60 - 100)</p> <p>HAIR CELL</p> <p>VESTIBULAR AFFERENT NERVE ENDING</p> <p>ACTION POTENTIALS</p> <p>VESTIBULAR EFFERENT NERVE ENDING</p>  |  |  |  |
| POLARIZATION OF HAIR CELL | NORMAL | DEPOLARIZED | HYPERPOLARIZED |
| FREQUENCY OF ACTION POTENTIALS | RESTING | HIGHER | LOWER |



Anatomy: Maculae of Utricle or Sacculle
Physiology: Linear acceleration of head

Otolithic membrane

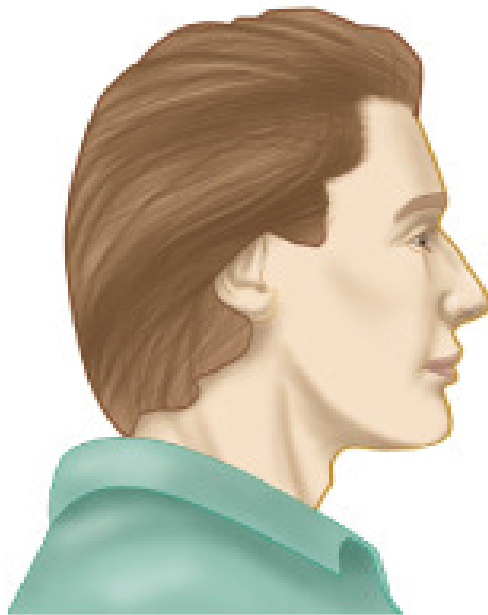
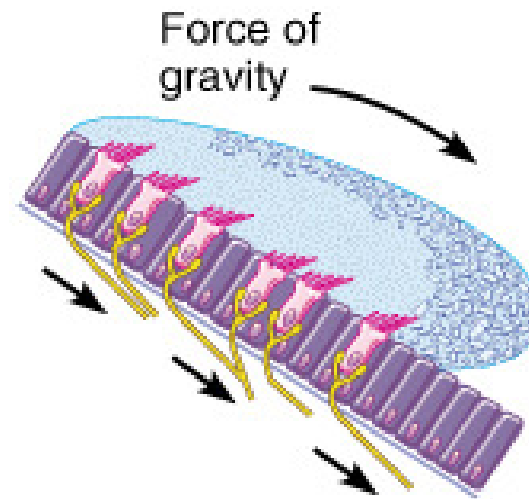
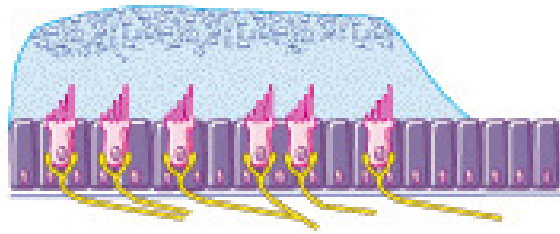


Head straight

“ear rocks”



Head tilted



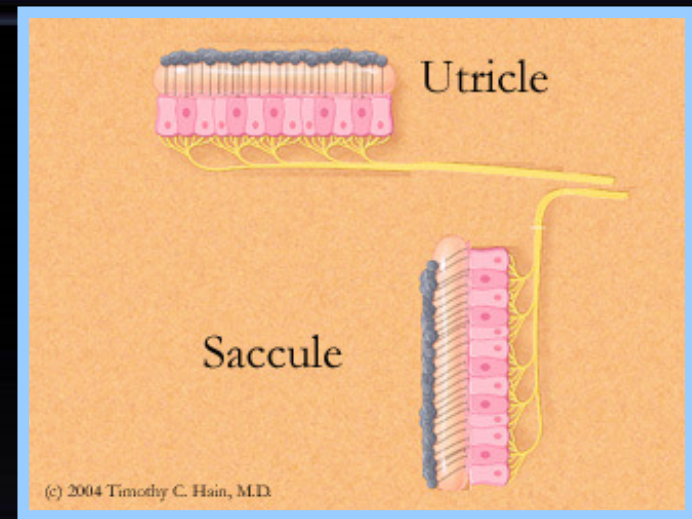
Head upright



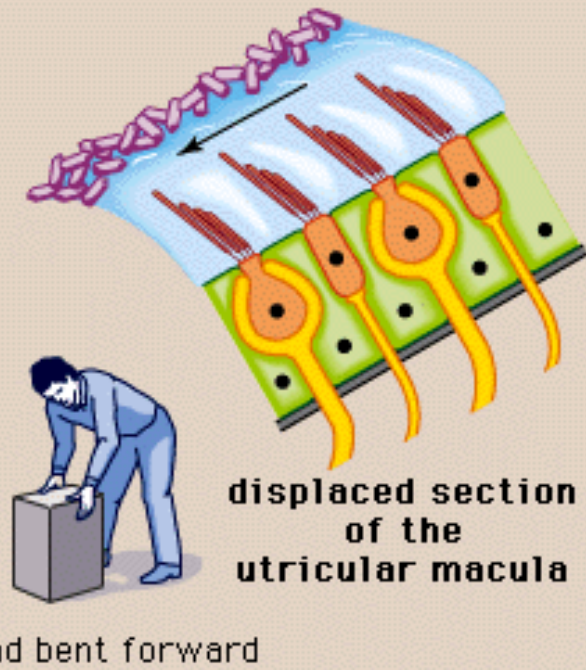
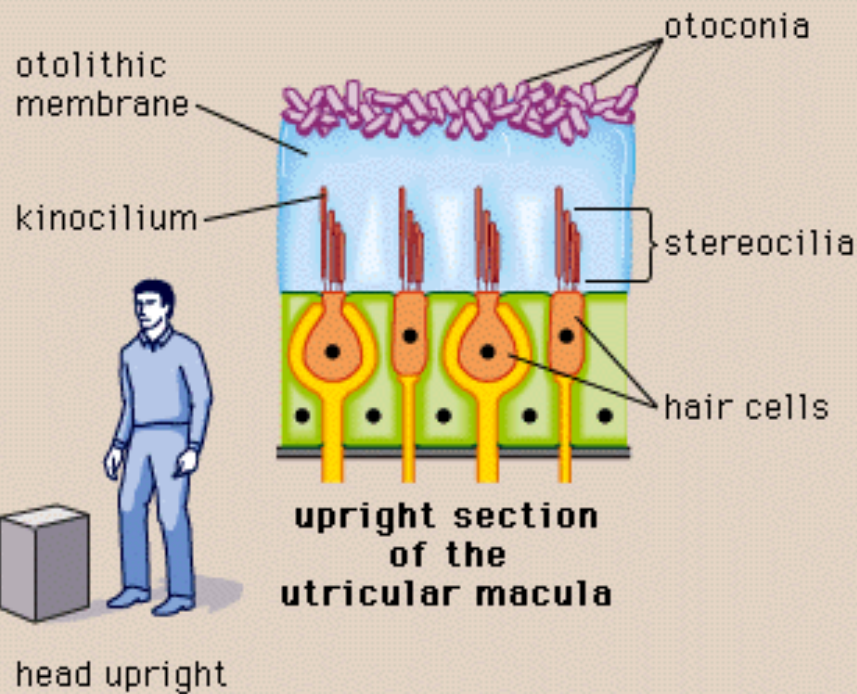
Head tilted

In macula: hair cells are oriented in different direction and tilt Of Head In Any Direction is Signaled

The two maculae, the utricle and saccule, are oriented in the horizontal and vertical planes and tell us how we are aligned relative to gravity.



B



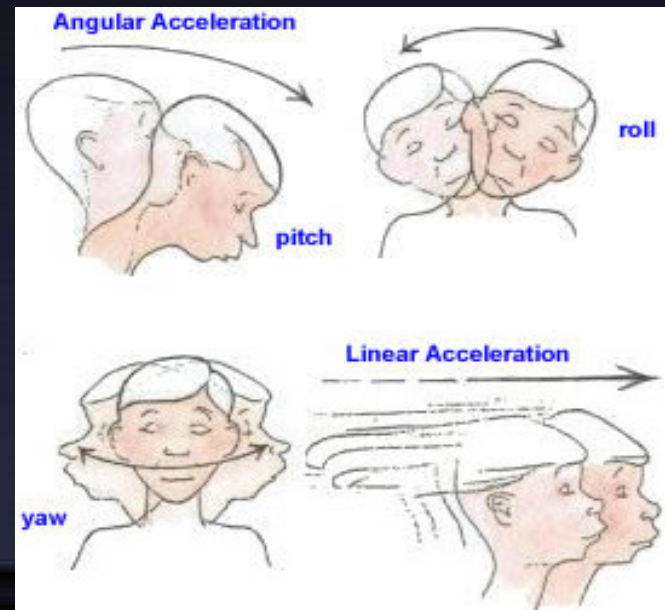
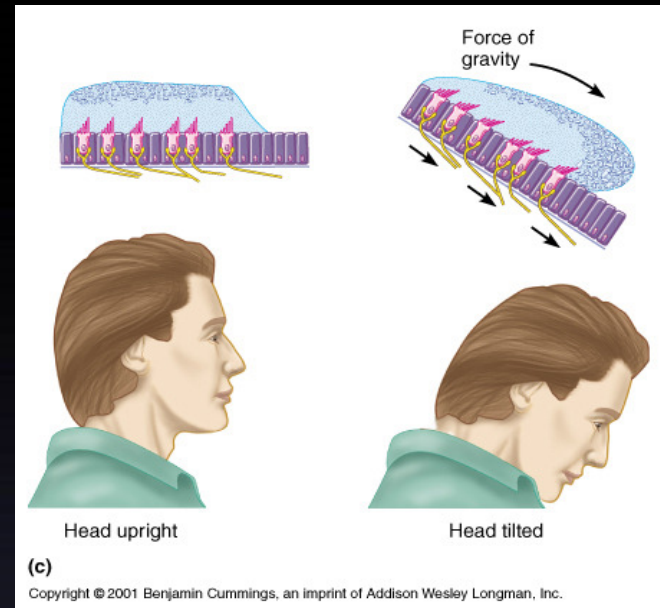
Function of utricle and saccule

Detection of static tilt

- Upright vertical position: Impulses from both utricle maculae balance each other
- Body tilts to one side: Two maculae send signals informing brain of
- new position of head in space
- Sensation of imbalance
(Response???)

Detection of linear acceleration:

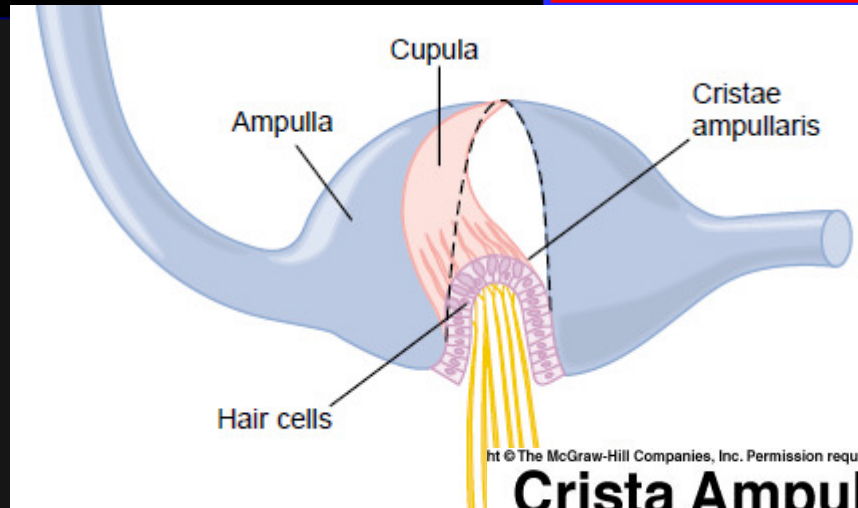
Sudden acceleration >>> Falling backwards >>> Otoliths falls back on hairs >>> sensation of mal-equilibrium >> Correction by leaning forward



Three Semicircular Canals

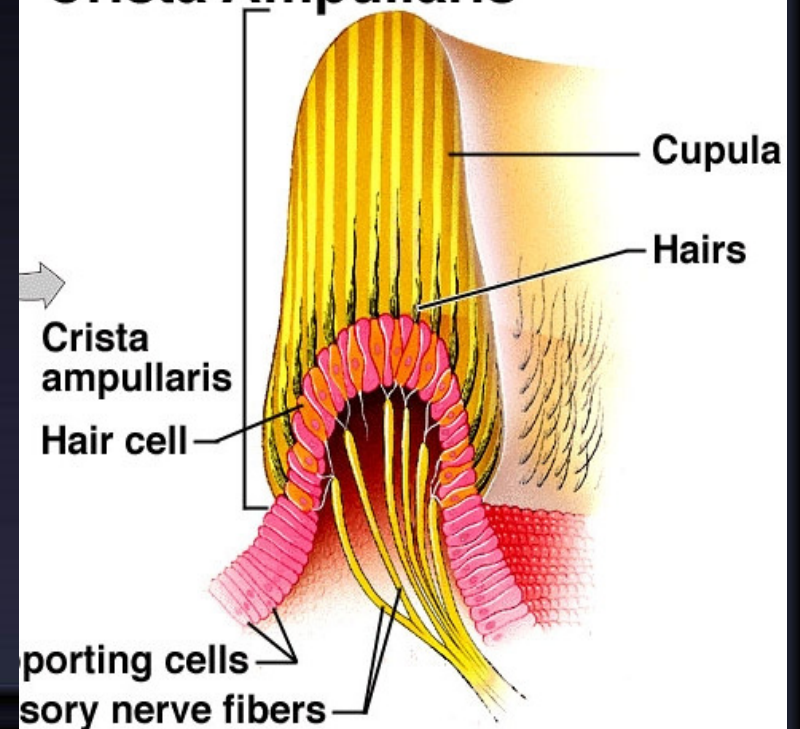
**SENSORY ORGAN:
CRISTA AMPULLARIS**

- Contain Endolymph
- Each canal has a dilated end Ampulla
- The ampulla houses the sensory hair cells (oriented in same direction unlike macula) covered by a gelatinous material (Cupula)



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Crista Ampullaris

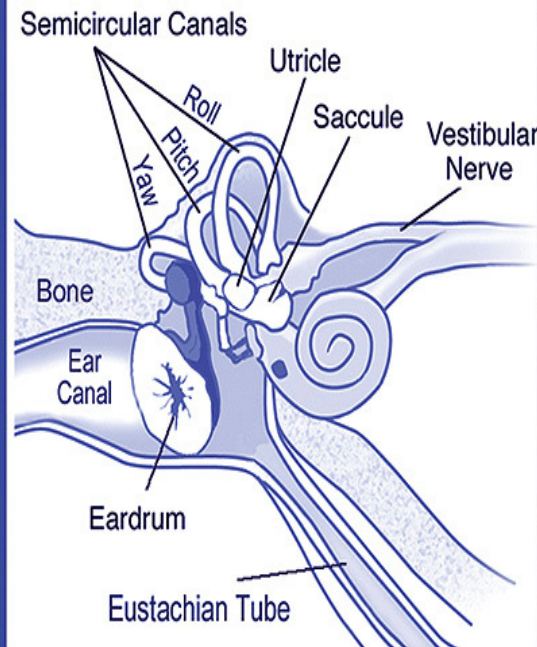
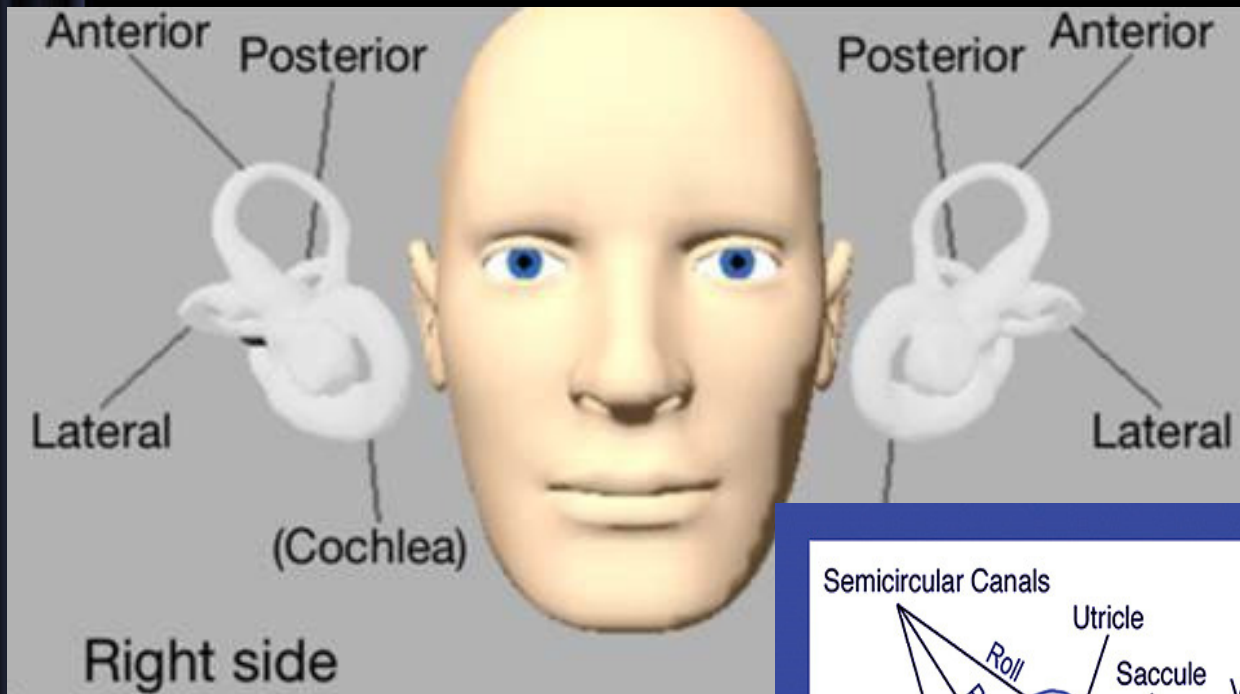


3 SCCs

Horizontal
(lateral)

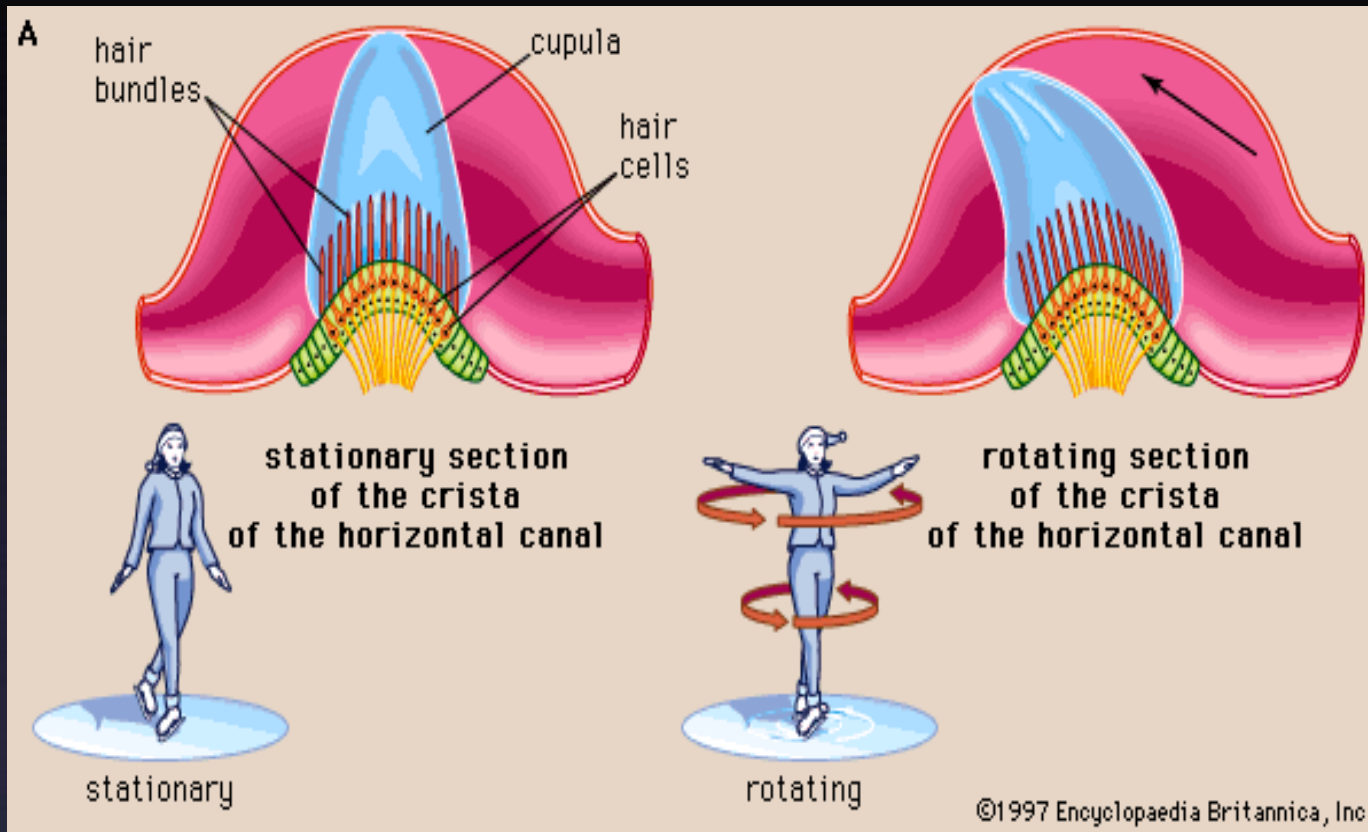
Vertical:

- Anterior
- Posterior



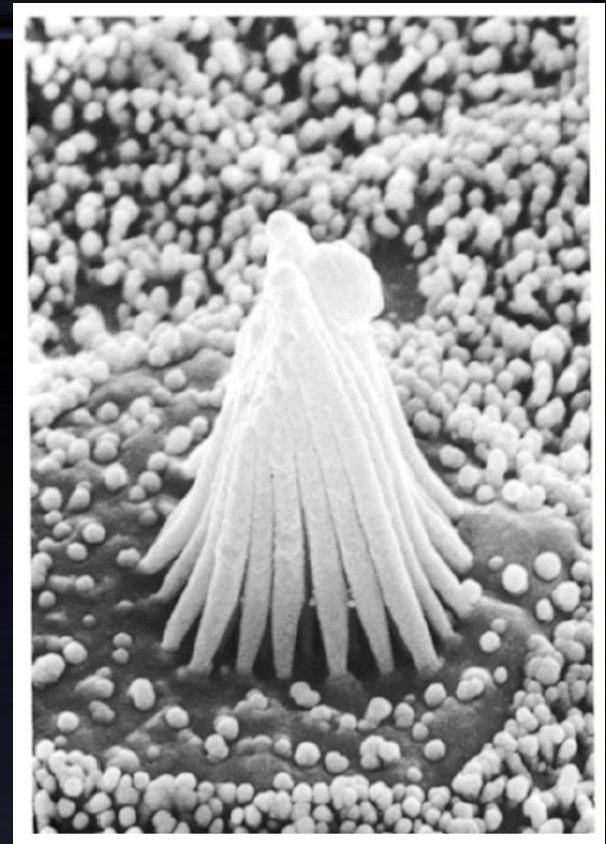
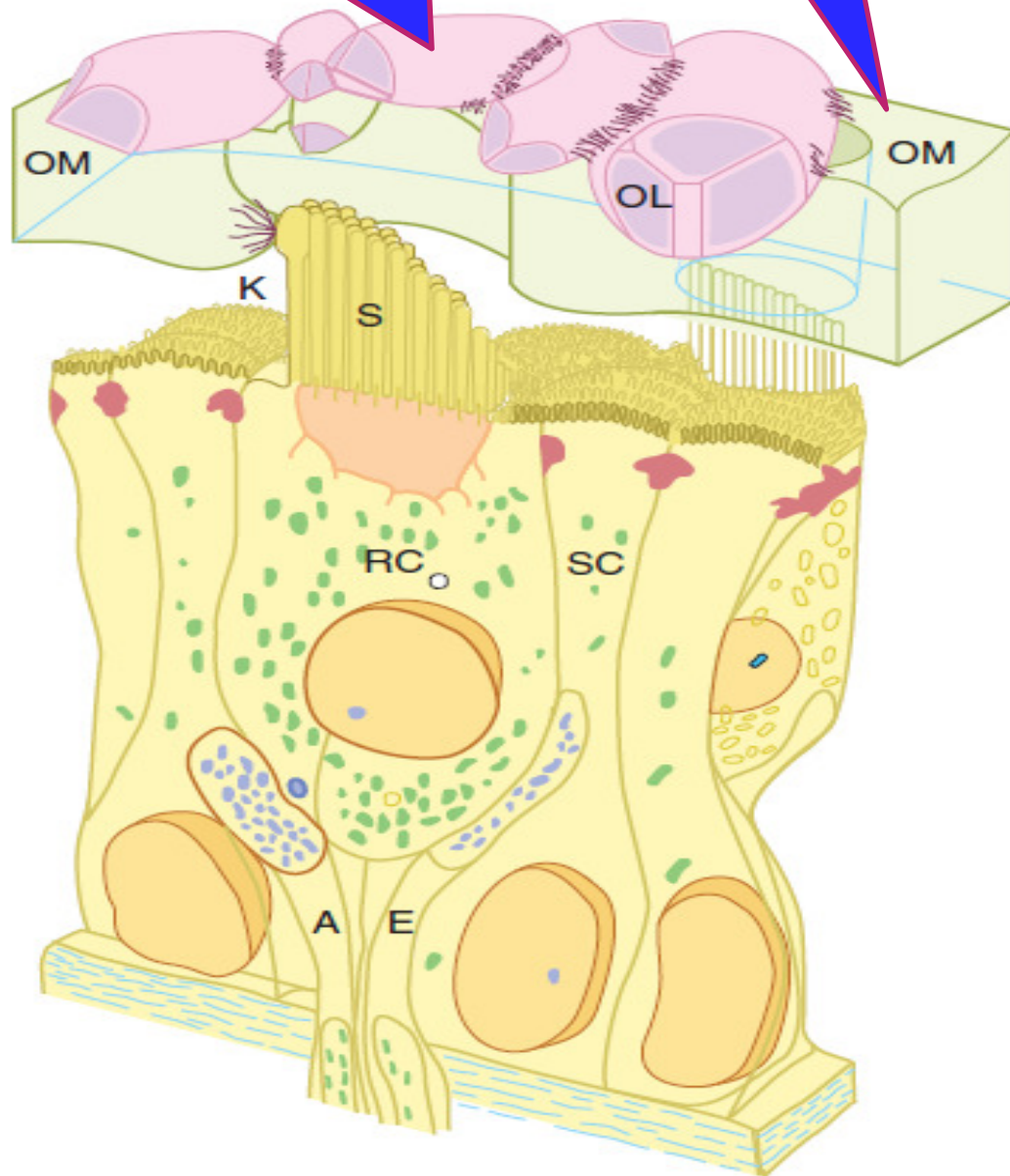
Plane of rotation determines the canal to be stimulated:

1. Rotation of head on vertical axis → Horizontal
2. Lateral movement of head (AP axis) (approximate head to shoulder) → posterior
3. Anterolateral or posterolateral head movement (Oblique axis) → Superior

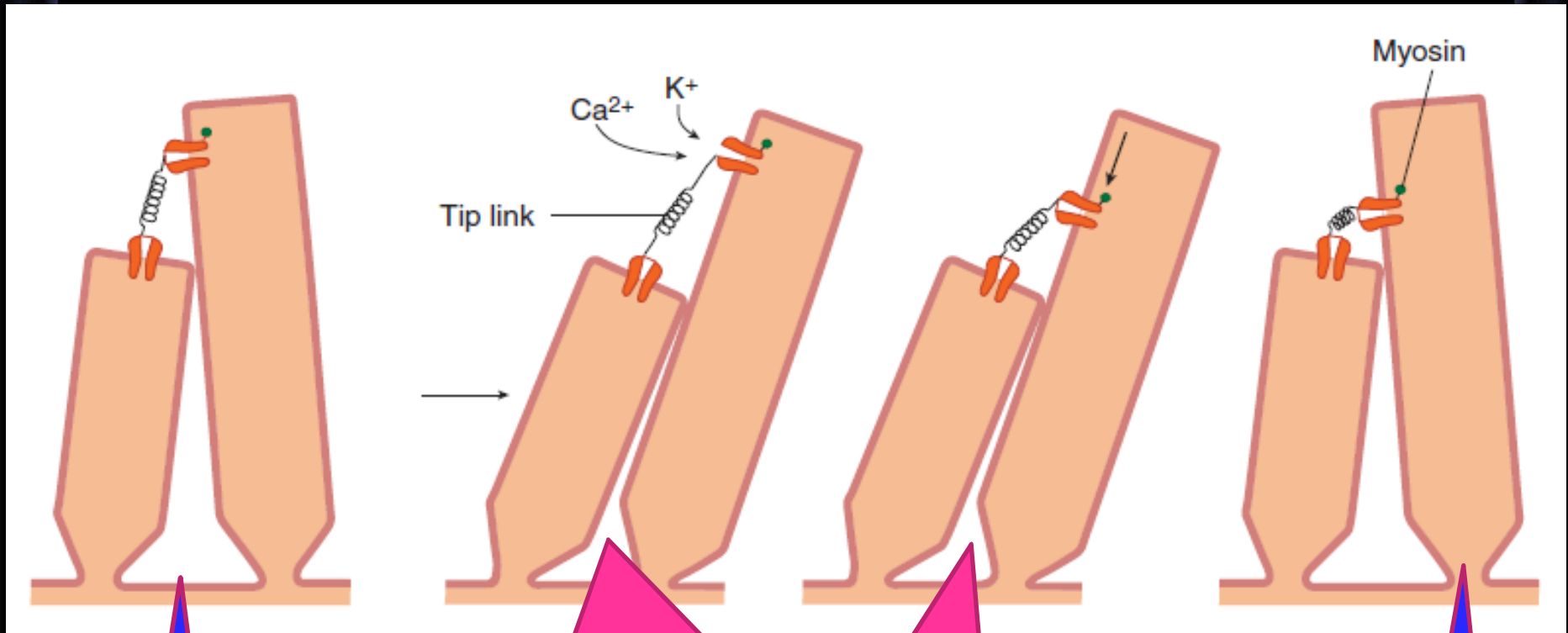


Otoliths (calcium carbonate crystals)

Otolithic Membrane



Role of tip links in responses of hair cells

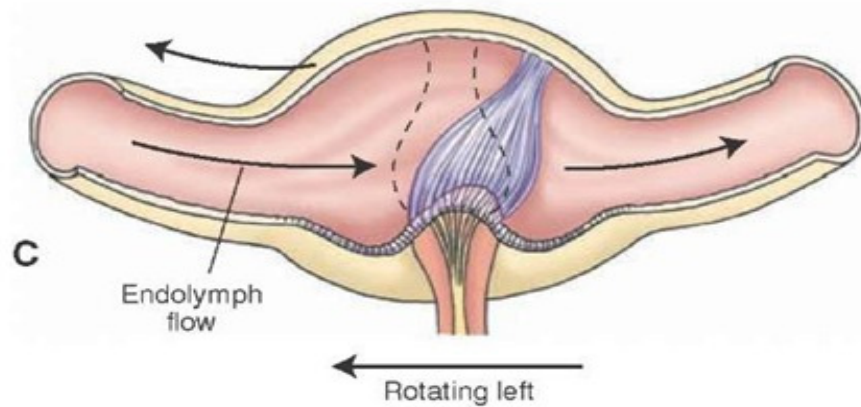
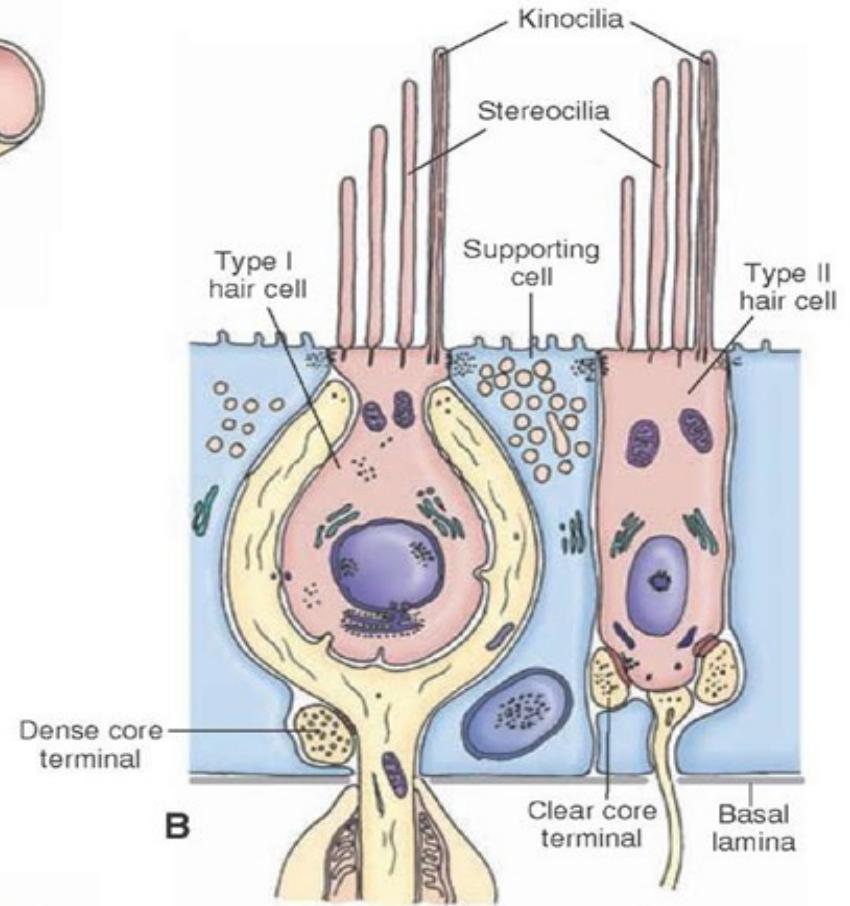
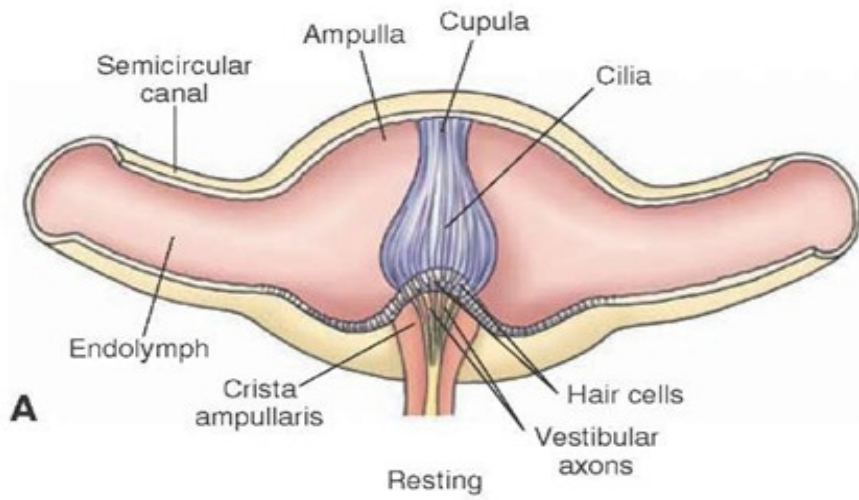


Resting position

Stereocilium is pushed toward a taller one, the tip link is stretched and opens an ion channel in its taller neighbor.

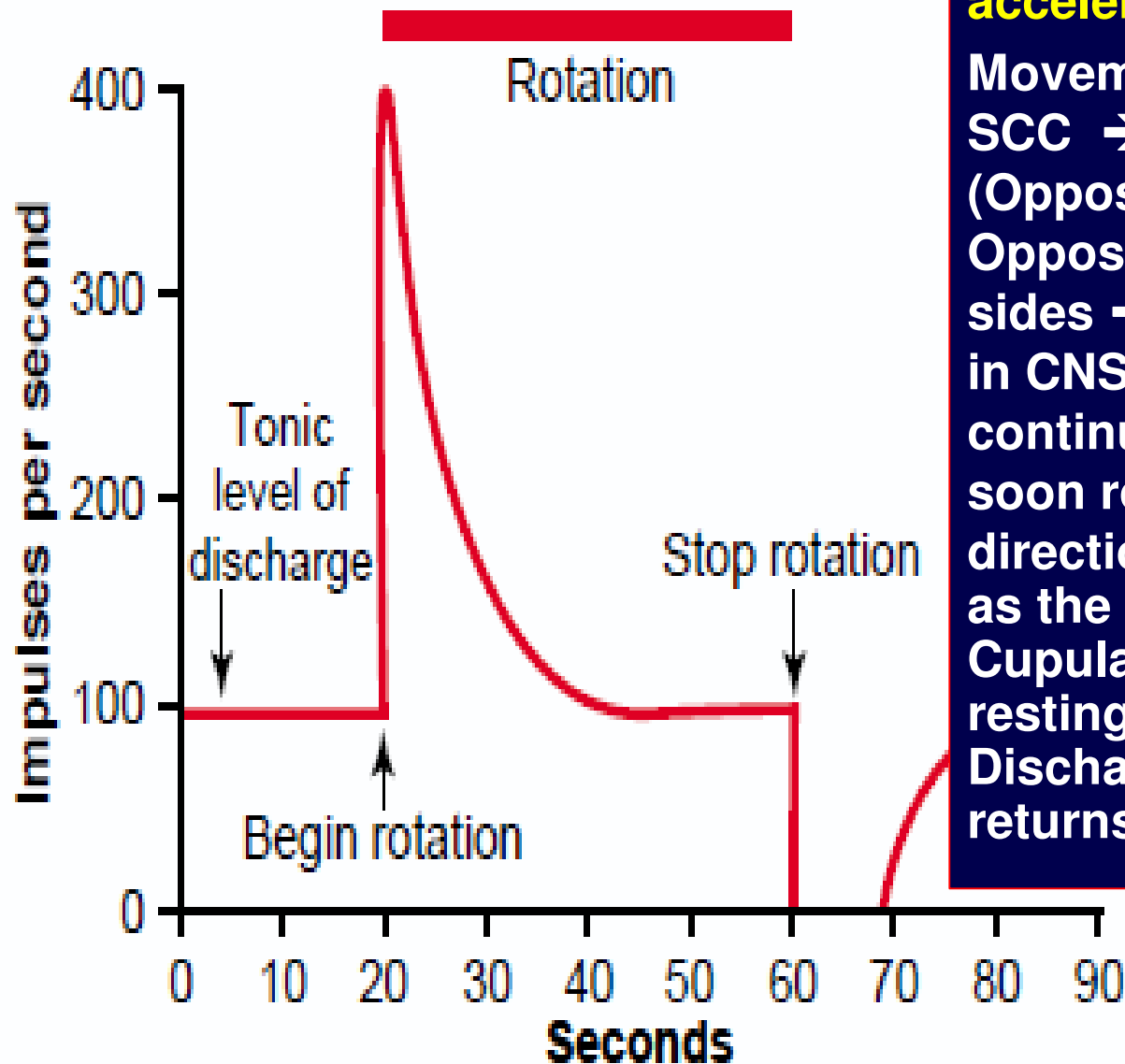
Channel moves down by molecular motor and release tension

Resting position



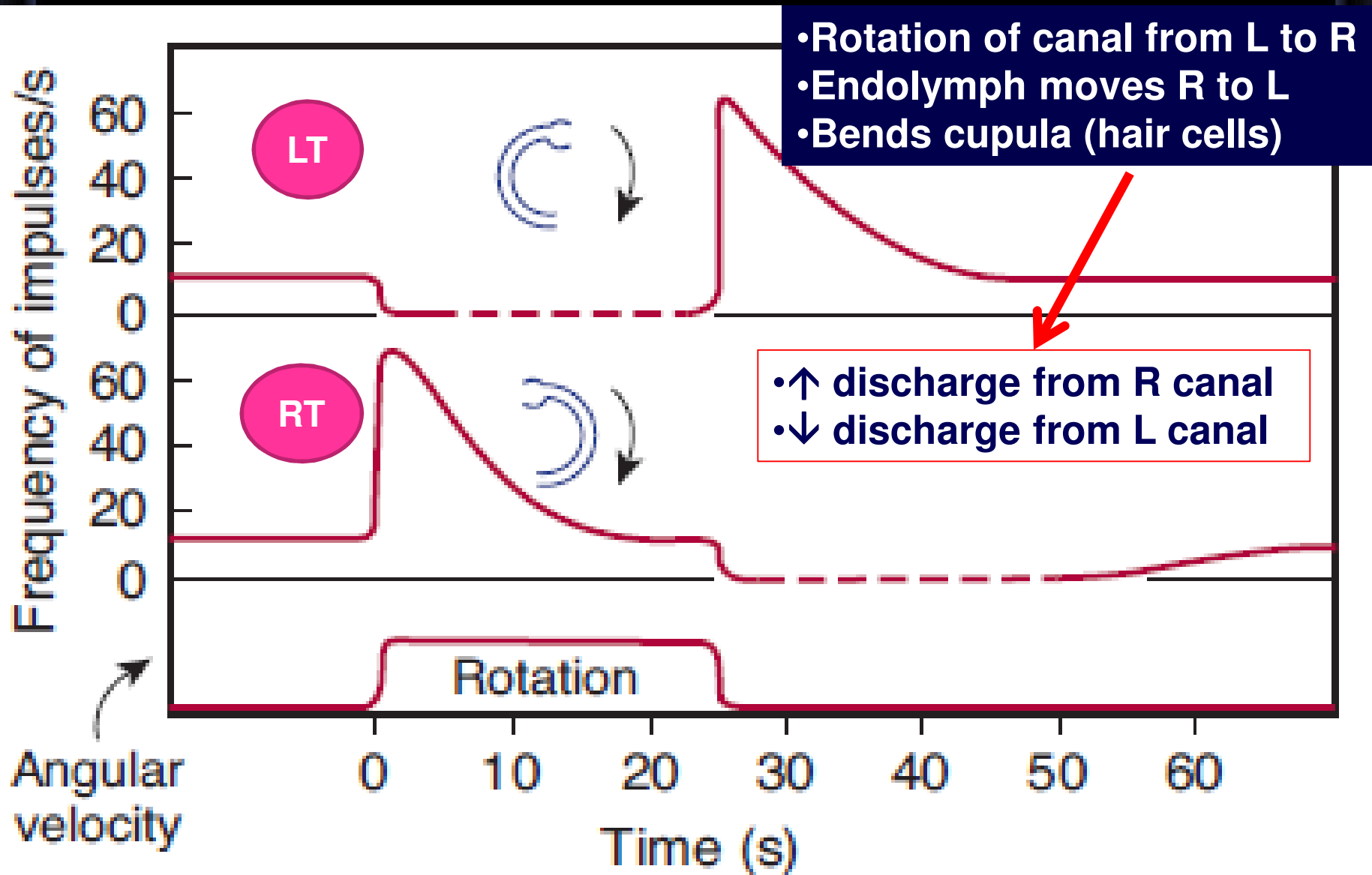
Angular (rotational) acceleration

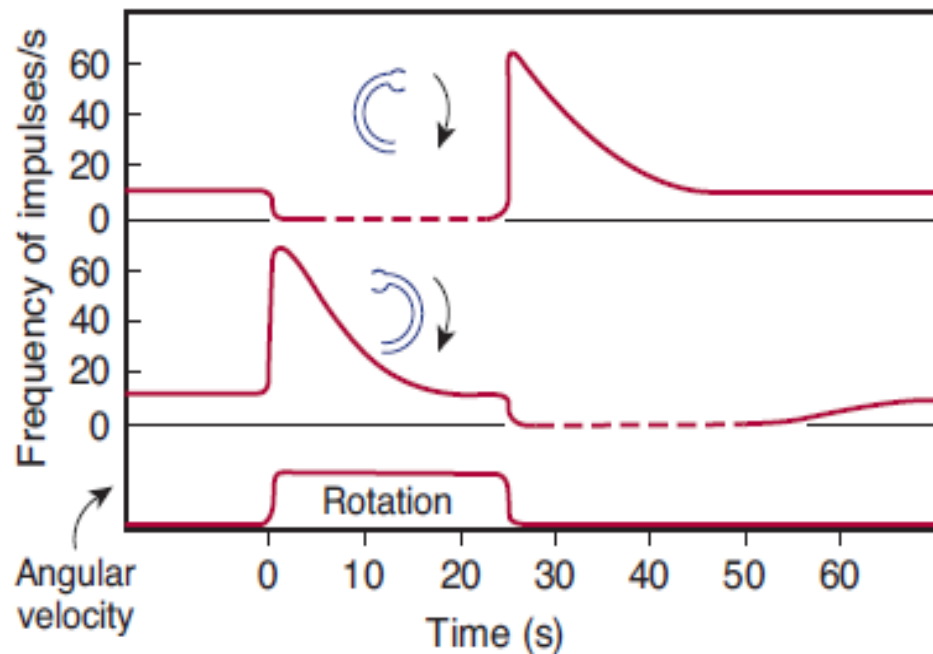
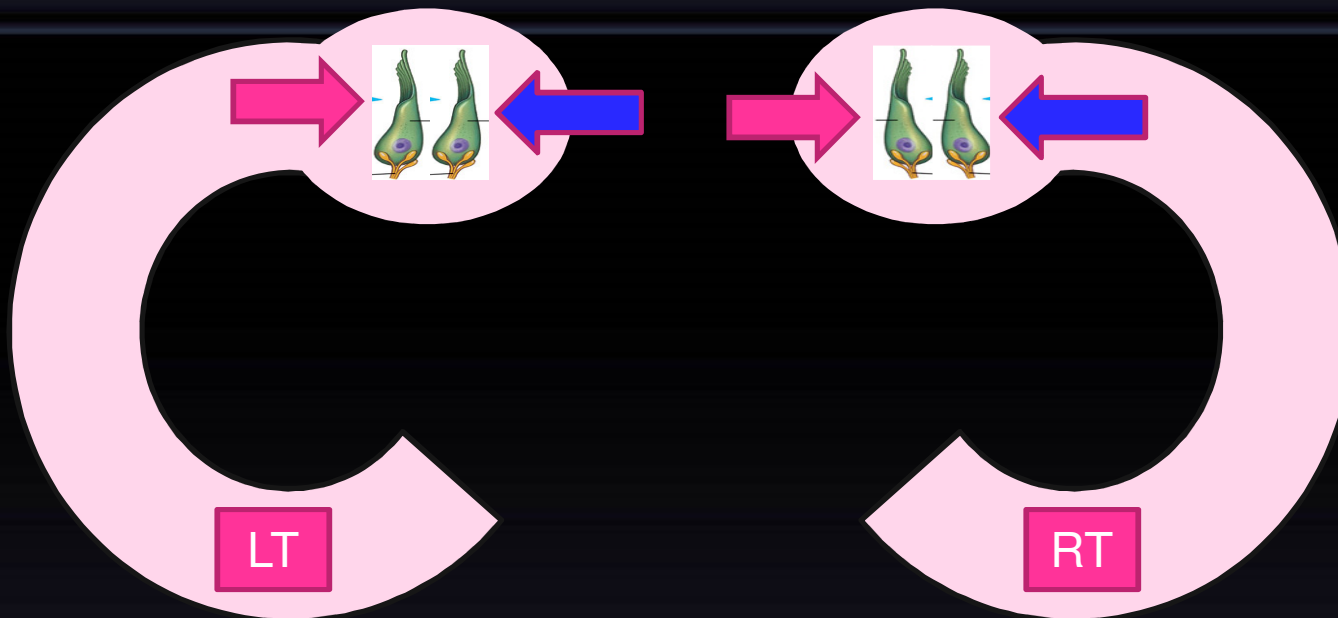
Movement of endolymph in SCC → Bending of hairs (Opposite on two sides) → Opposite discharge from two sides → Sensation of rotation in CNS → As rotation continues endolymph will soon rotate in the same direction (& speed) as the SCC → Cupula being elastic returns to resting position → Discharge from both sides returns to resting level



No sensation of rotation so long eyes are closed

Rotational Acceleration, Steady Rotation & Deceleration





- ↑ discharge from R canal
- ↓ discharge from L canal

- Rotation of canal from L to R
- Endolymph moves R to L
- Bends cupula (hair cells)

Start of rotation
 End of rotation
 Changes in rate of rotation

Function of the Semicircular Duct System in the Maintenance of Equilibrium

SCCs detect ANGULAR ACCELERATION:

- The beginning of rotation
- End of rotation
- Changes in rate of rotation (eg; Joy Riding)

& PREDICTIVE FUNCTION SCCs

Predict ahead of time that mal-equilibrium is going to occur → Send impulses to CNS for corrective measures before the start of the fall

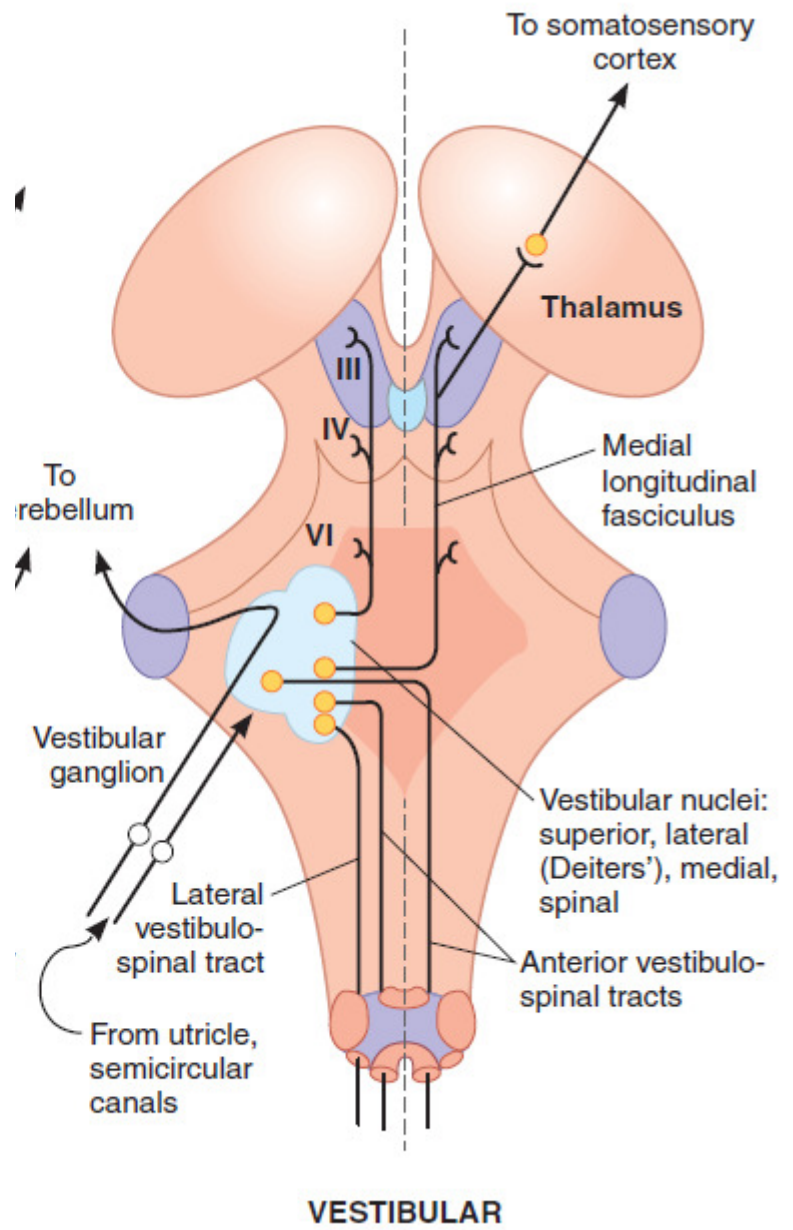
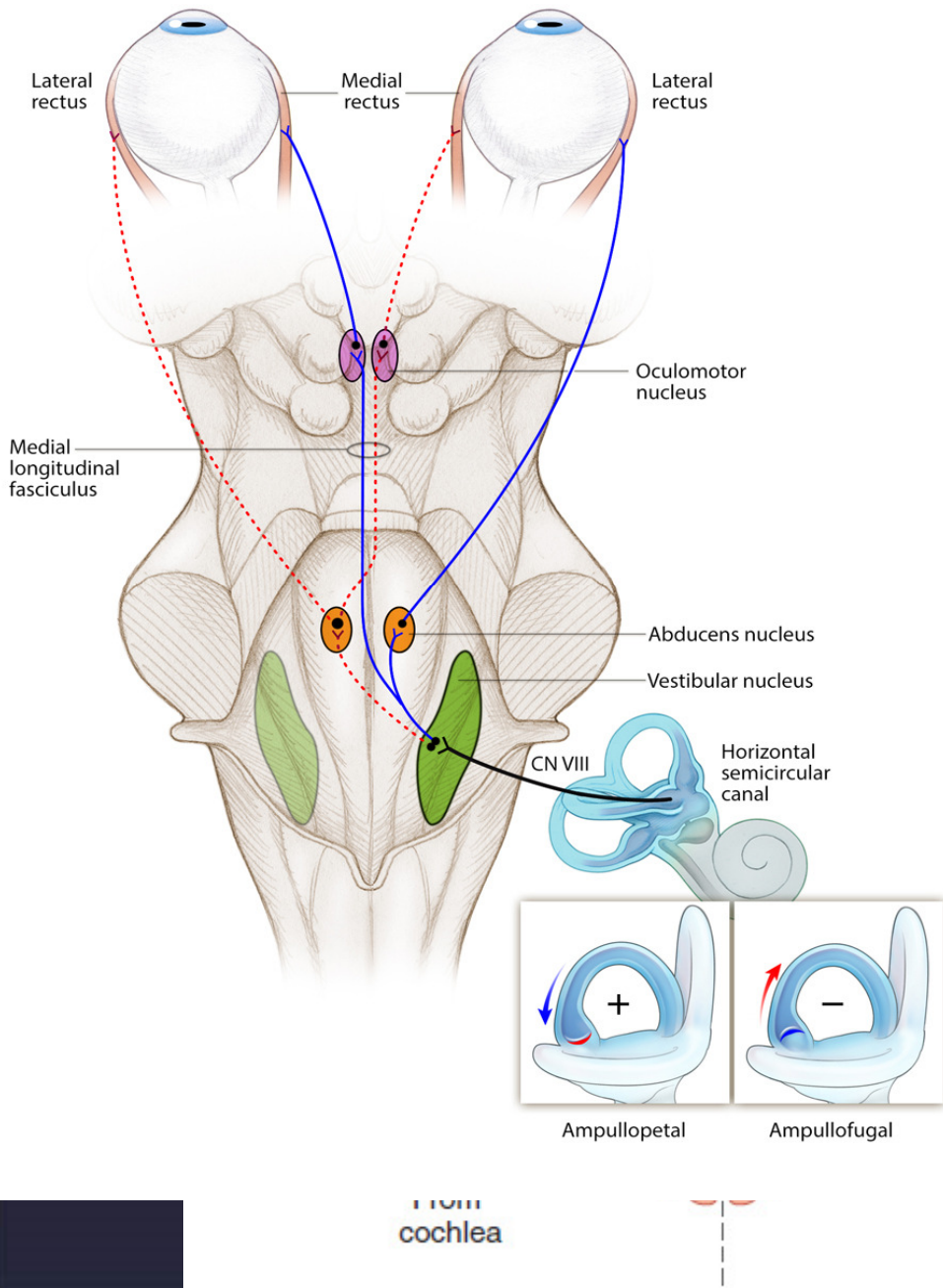
The maculae of the utricle and saccule cannot detect that the person is off balance in angular acceleration until after the loss of balance has occurred.

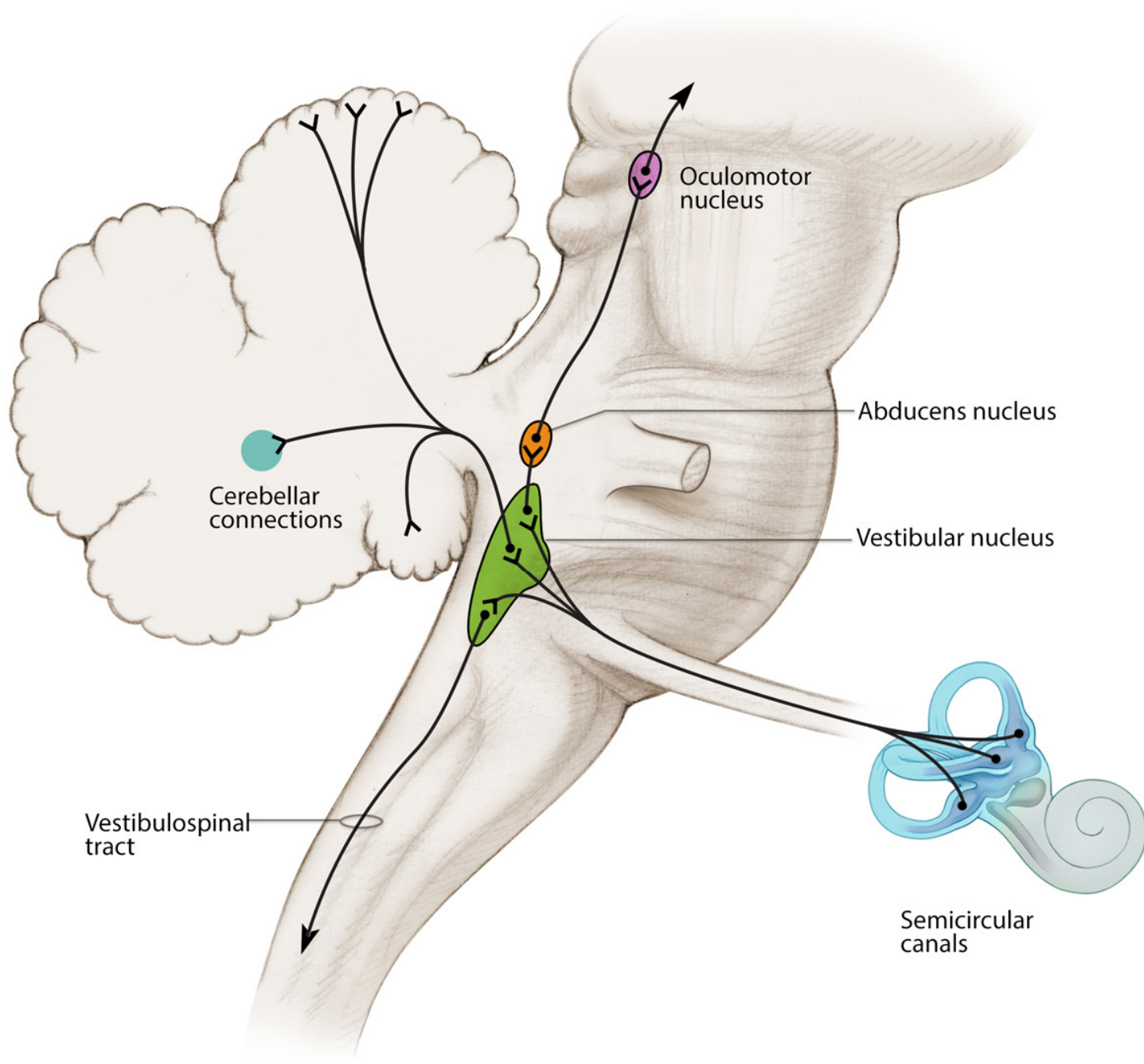
VESTIBULAR PATHWAY

Neural connections:

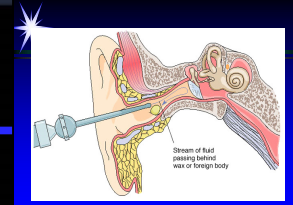
1. Cerebellum
2. Motor nuclei of CNs 3,4 & 6
3. Reticular formation (Spinal cord)**
4. Spinal cord (Vestibulo-spinal tract)**

** Impulses maintain equilibrium i.e. facilitate or inhibit the stretch reflex (regulate muscle tone)





Testing Vestibular system



1. Calorie test

The semicircular canals are stimulated by instilling warm (40°C) or cold (30°C) water into the external auditory meatus.

The temperature difference sets up convection currents in the endolymph, with consequent motion of the cupula.

In healthy subjects, warm water causes nystagmus that bears toward the stimulus, whereas cold water induces nystagmus that bears toward the opposite ear.

Mnemonic COWS (Cold water nystagmus is Opposite sides, Warm water nystagmus is Same side).

In the case of a unilateral lesion in the vestibular pathway, nystagmus is reduced or absent on the side of the lesion.

2. Rotation tests

To avoid nystagmus, vertigo, and nausea when irrigating the ear canals in the treatment of ear infections, it is important to be sure that the fluid used is at body temperature.

Vestibular Disorders (Motion Sickness)

Clinical signs:

1. Vertigo: feeling of rotation when body is not
2. Nystagmus

Clinical signs:

- Nausea
- Vomiting
- Bradycardia
- Hypotension
- Sweating

Mechanism: autonomic stimulation

Vertigo: feeling of rotation when body is not moving

Vestibular Disorders

- **Benign paroxysmal positional vertigo (BPPV)**
otoconia from the utricle separate from the otolith membrane and become lodged in the canal or cupula of the semicircular canal
- **Meniere disease** is an abnormality of the inner ear causing vertigo or severe dizziness, **tinnitus**, fluctuating hearing loss, and the sensation of pressure or pain in the affected ear lasting several hours.
- **Motion sickness** are produced by excessive vestibular stimulation
- **Space motion sickness** (in astronauts) develops when they are first exposed to microgravity and often wears off after a few days of space flight. Due to mismatches in neural input from vestibular apparatus and other gravity sensors

Canalith repositioning

Labyrinthine Sedatives (Meclizine)

Antihistamines or scopolamine, a cholinergic muscarinic receptor antagonist.