



# Inner ear in balance and equilibrium

## Objectives :

- ❖ Understand the sensory apparatus of the inner ear that helps the body maintain its postural equilibrium.
- ❖ The mechanism of the vestibular system for coordinating the position of the head and the movement of the eyes.
- ❖ The function of semicircular canals (rotational movements, angular acceleration).
- ❖ The function of the utricle and saccule within the vestibule (respond to changes in the position of the head with respect to gravity (linear acceleration)).
- ❖ The connection between the vestibular system and other structure (eye, cerebellum, brain stem)

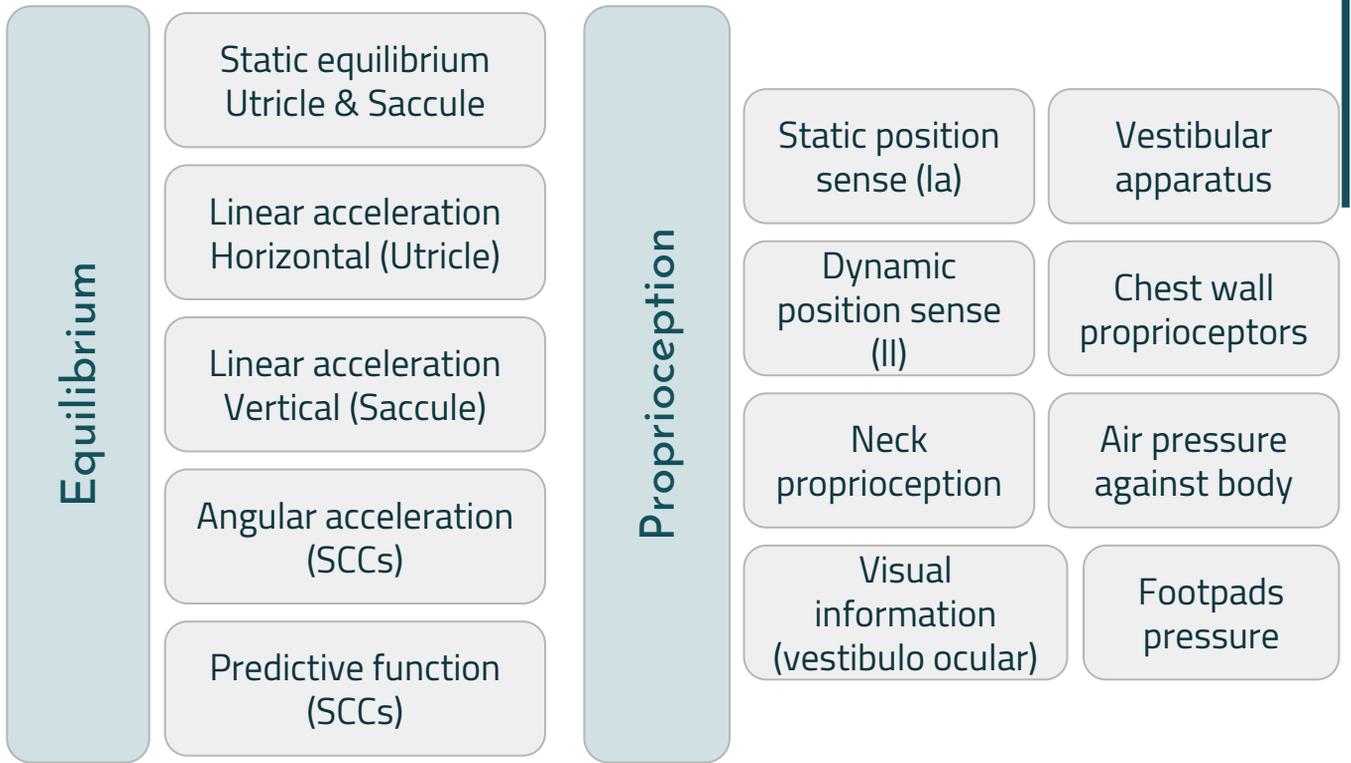
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### Colour index:

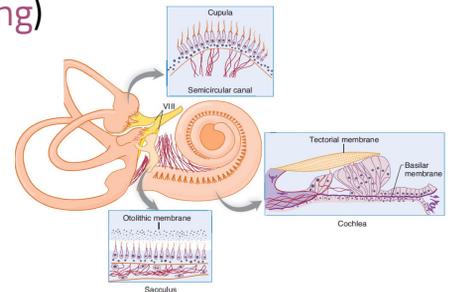
- Important
- Numbers
- Extra

## Overview of proprioception and balance

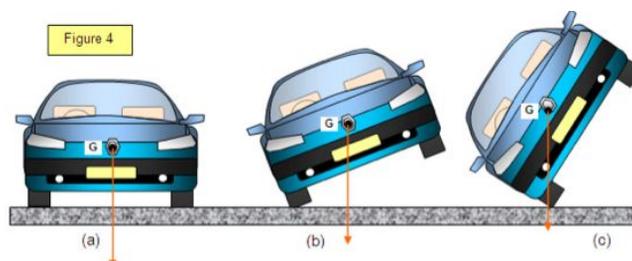


## Labyrinth components

1. Cochlea (**organ of corti** containing receptors for **hearing**)
2. Semicircular canals (**Crista ampullaris** containing receptors that respond to **head rotation**)
3. Utricle & Sacculle (**Macula** contain otolith organs and receptors that respond to **gravity and head tilt**).



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



## Balance and 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 for in unaccelerated 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 Equilibrium

Keep the body in a desired position. 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.

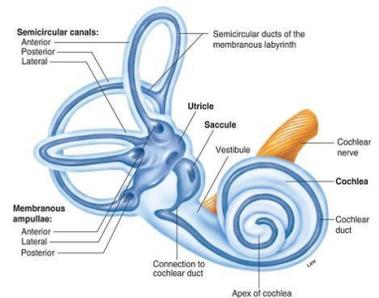
### Dynamic Equilibrium

To move the body in a controlled way. 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.

## Control of Equilibrium

Sensory inputs from:

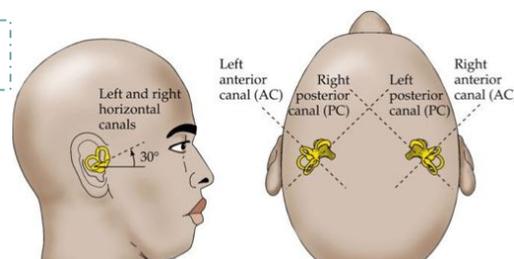
- Vestibular system
- Visual system
- Proprioceptive system
- Cutaneous sensations



## Vestibular labyrinth

How is the SCCs are arranged?

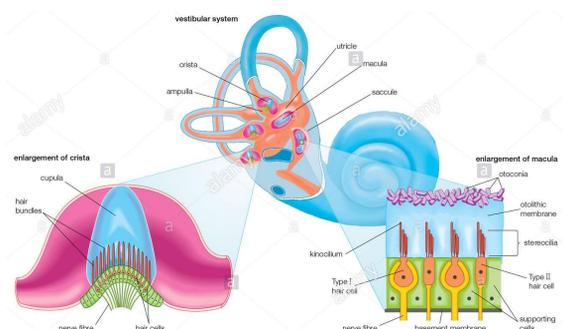
- Posterior canal shares plane with contralateral anterior canal.
- Horizontal canals share plane.



## Vestibular apparatus

Components: Three SCCs:

1. Anterior (superior)
2. Posterior (inferior)
3. Lateral
  - a. Vestibule (Utricle & Sacculle).
  - b. Vestibular nerve and nuclei.



# Maintaining Equilibrium

Semicircular canals (Ant., post., lat.)	Vestibule (Saccule & utricle)
<ul style="list-style-type: none"> <li>➤ <b>Crista ampullaris</b></li> <li>➤ Hair cells in each crista are oriented in the same direction</li> <li>➤ <b>Dynamic equilibrium and angular motion</b></li> </ul>	<ul style="list-style-type: none"> <li>➤ <b>Maculae</b></li> <li>➤ Hair cells in each macula are oriented in all direction</li> <li>➤ <b>Otoliths</b> (calcified carbonate crystals)</li> <li>➤ <b>Static equilibrium and linear acceleration</b></li> </ul>

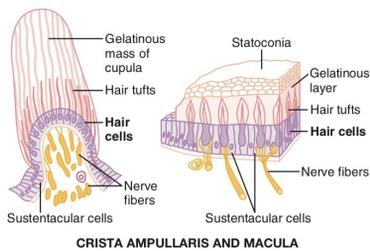
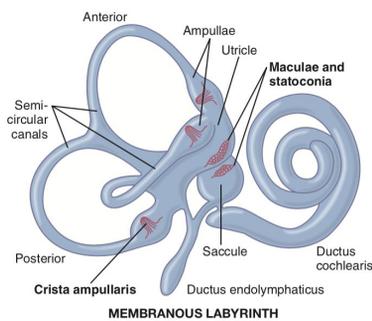


Figure 56-9. Membranous labyrinth and organization of the crista ampullaris and the macula.

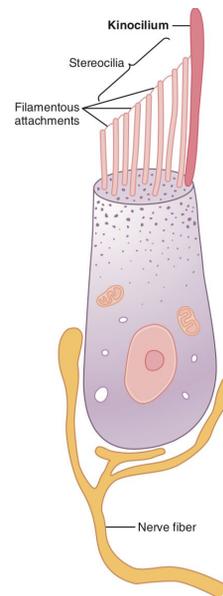
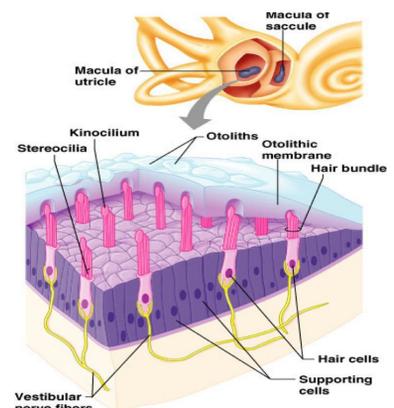
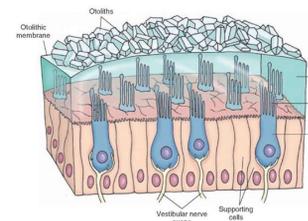


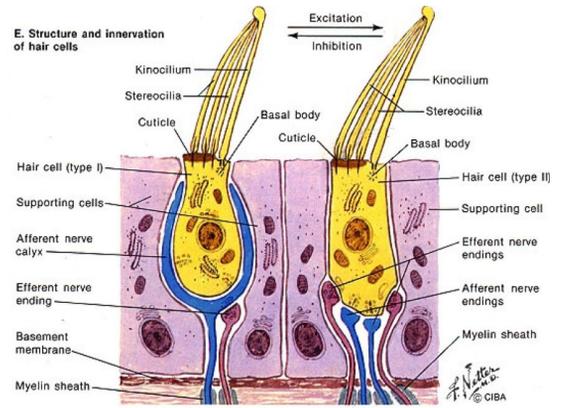
Figure 56-10. A hair cell of the equilibrium apparatus and its synapses with the vestibular nerve.

## Macula (otolith organs) of utricle and saccule

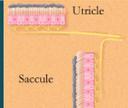
- ➔ hair cell synapse with endings of the vestibular nerve.
- ➔ Hair cell has 30-150 (stereocilia) and one large cilium called (kinocilium)
- ➔ Both connected with thin filamentous attachments "tip link"
- ➔ All cilium membrane has positive potassium channels
- ➔ Otolithes ( statoconia) of calcium carbonate suspended in gelatinous material.
- ➔ Macula of utricle is IN horizontal plane if the head is vertical , so cilia point upwards
- ➔ Stimulated when the head bends forward & backward & laterally



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



## Hair cells in utricle



## Hair cells in Saccule

Person in upright position: (Head vertical)

Person in upright position: (Head vertical)

Macula in horizontal plane

Macula in vertical plane

Hairs pointing upwards

Hairs pointing laterally

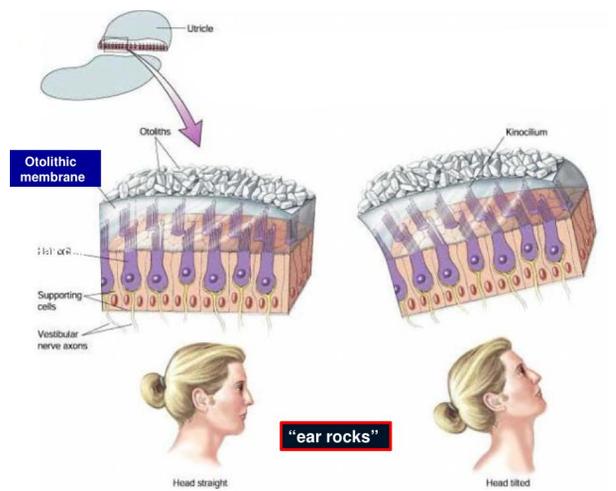
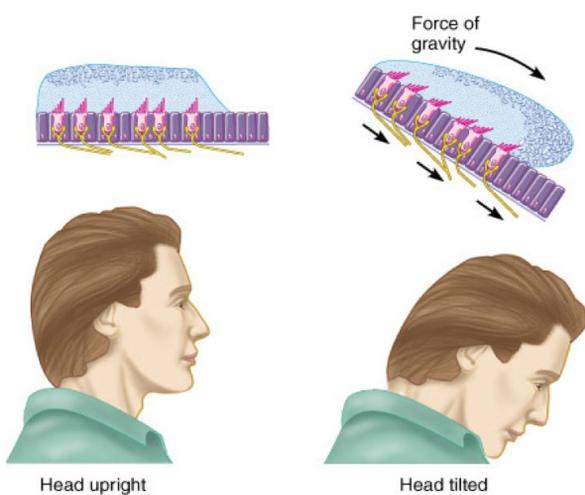
Hair cells signal head movements in any direction

Hair cells operate when one is lying down

Inform the brain of orientation of head in space

Utricle maculae defect > **horizontal** acceleration

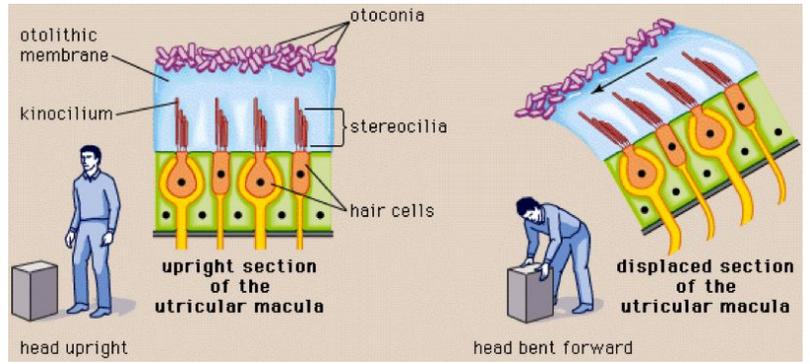
Saccular maculae defect > **vertical** acceleration



In macula: hair cells are oriented in different direction and tilt of head in any direction is signaled.

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

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.



## Functions of macula (*mainly the utricle*)

### 1. Orientation of head in space & maintenance of static equilibrium :

#### A. In erect upright position ( Vertical position واقف ) :

- RT & LT utricle impulses balance each other
- NO sensation of male-equilibrium

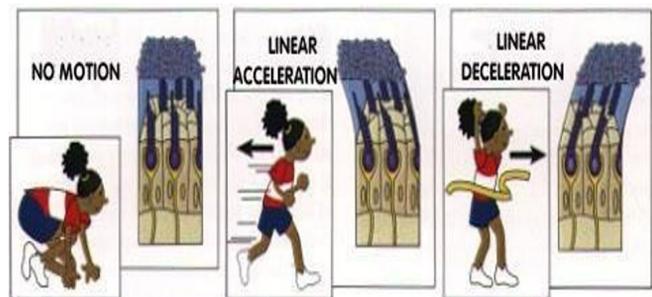
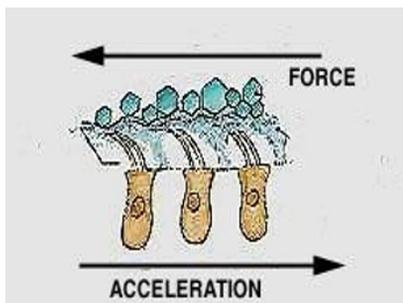
#### B. Bending head to one side :

- Statoconia crystals of hair cells fall to that Side by their weight → Pulls stereocilia to Move towards kinocilium → Depolarization (stimulation) occurs
- Stereocilia of the other side moves away from kinocilium → Hyperpolarization (inhibition) occurs



### 2. Detection of linear acceleration :

- **Linear acceleration** : As if you are running & standing in a bus
- At the beginning of movement statoconia lag behind by its inertia (القصور الذاتي) → Falls backwards → Cilia then moves backward → Person will feel he/she is falling backwards → Will try to correct this by leaning forward to shift statoconia & cilia anteriorly.

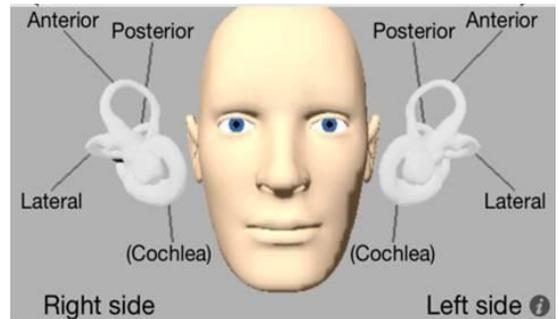
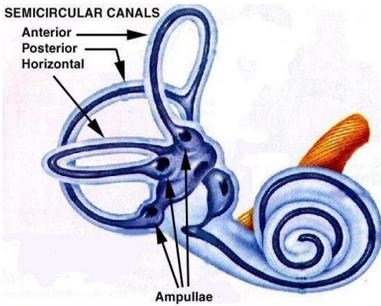
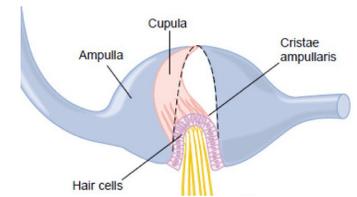
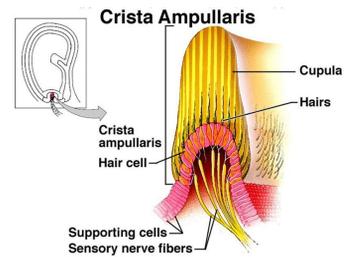


- At deceleration (runner try to stop) → statoconia moves forward by its **momentum** → Person will feel as if he/she is falling anteriorly.

# Semicircular canals

1. Horizontal ( Lateral ) *semicircular canal*
2. Anterior *semicircular canal*
3. Posterior *semicircular canal*

- They are perpendicular to each other
- Filled with **endolymph**
- Dilated end of each canal is called **Ampulla** (as macula) , cilia is embedded in a gelatinous mass called **Cupula**
- **Sensory organ: Crista ampullaris**
- **Detects angular changes**
- **Hair cells: oriented in same direction** unlike macula



## Function of Semicircular duct system in maintenance of equilibrium

### SCCs detect ANGULAR ACCELERATION:

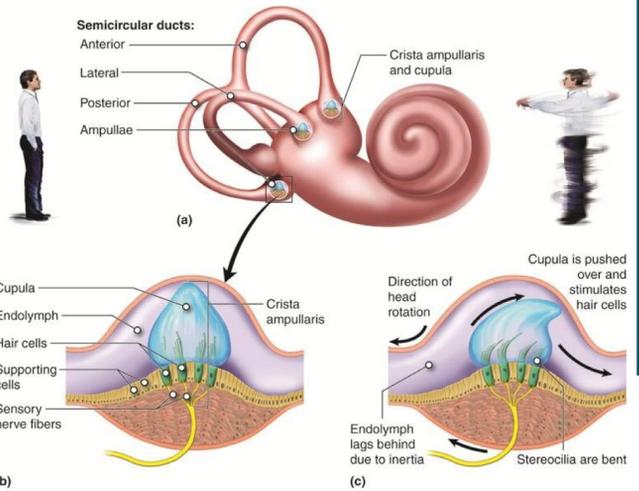
- the beginning of rotation
  - End of rotation
  - Changes in rate of rotation (e.g. Joy riding)
- & predictive function SCCs

Predict ahead of time that mal-equilibrium is going to occur -> send impulses to CNS for corrective measures before the start of all the fall.

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

# 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.**



## Angular (rotational) acceleration

Movement of endolymph → bending of hairs (opposite on two sides) → opposite discharge from two sides → Sensation of rotation in CSN

As rotation continues endolymph will soon rotate in the same direction (& speed) as the SCC → capsule being elastic returns to resting position → discharge from both sides returns to resting level.

★ No sensation of rotation as long as eyes are closed.

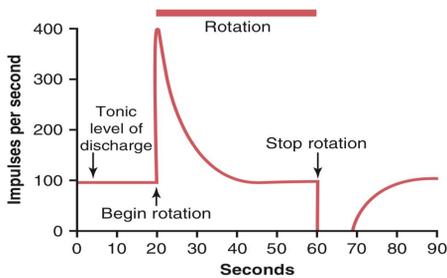
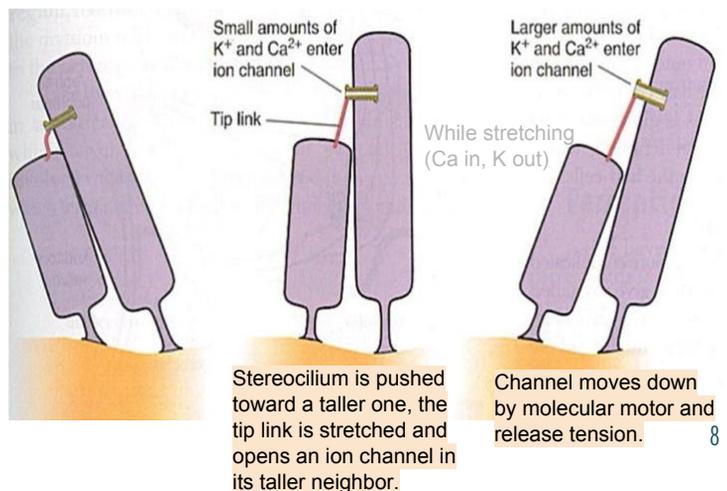
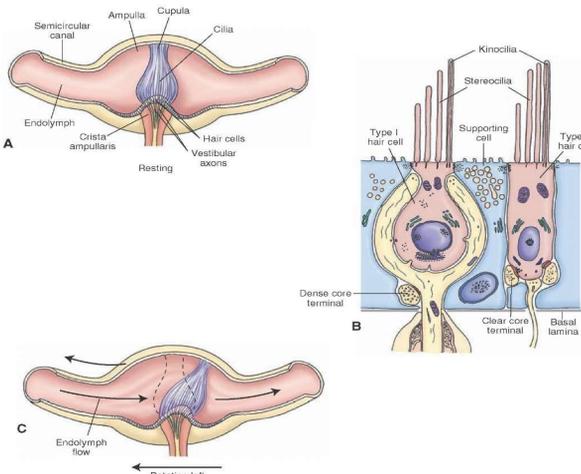
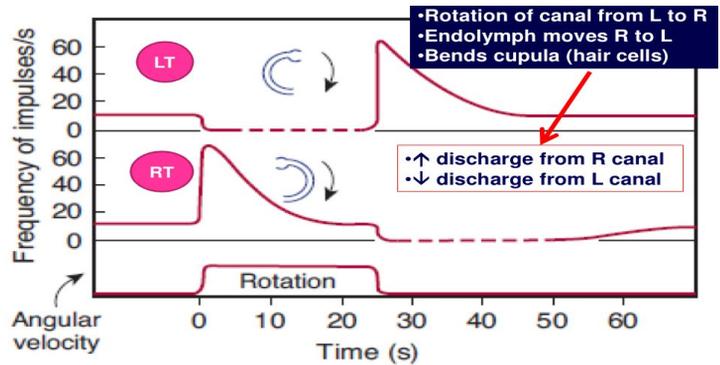


Figure 56-12. Response of a hair cell when a semicircular canal is stimulated first by the onset of head rotation and then by stopping rotation.

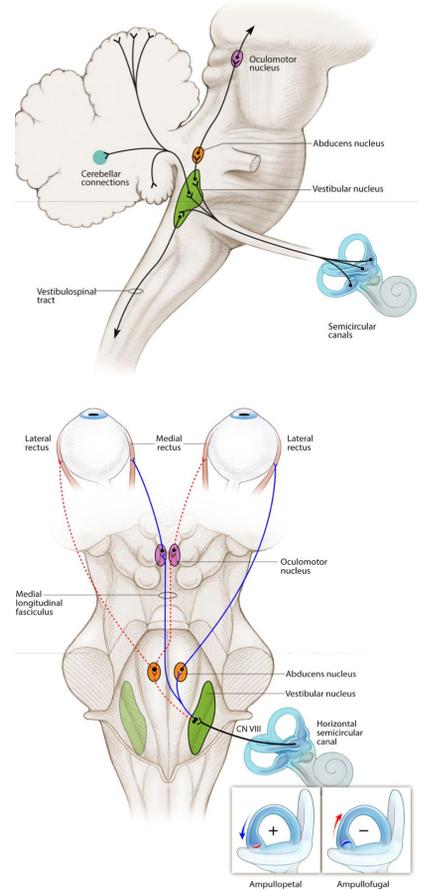


# VESTIBULAR PATHWAY

## Neural Connections:

- The vestibular nuclei on either sides of the brain stem send signal to:
  - Cerebellum.
  - Nuclei of cranial nerves III, IV, and VI
  - Reticular formation (spinal cord)\*
  - Spinal cord (vestibulospinal tracts)\*
  - Thalamus

\*impulses maintain equilibrium i.e. facilitate or inhibition 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 includes nystagmus that bears toward the opposite ear.

★ Mnemonic **COWS** (**C**old water nystagmus is **O**pposite sides, **W**arm water nystagmus is **S**ame side).

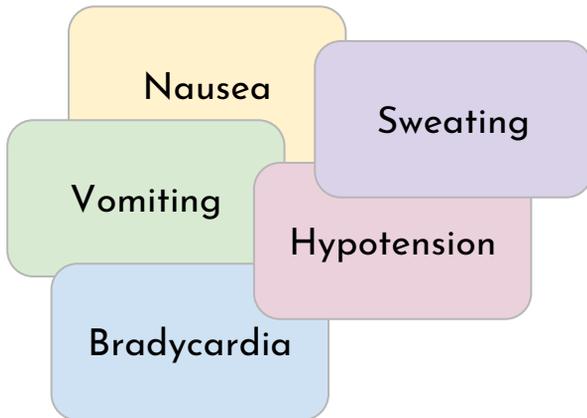
- In the case of unilateral lesion in the vestibular pathway, nystagmus is reduced or absent on the side of lesion.

### 2. Rotation test

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:



Clinical signs:

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

## Vestibular disorders

### Benign paroxysmal positional vertigo (BPPV)

Otoconia from the Utricle separate from otolith membrane and become lodged in the canal or cupula of the SCC.

- ★ Canalith repositioning

### Meniere disease

Abnormality of the inner ear causing vertigo or severe dizziness, tinnitus, fluctuating hearing loss & the sensation of pressure or pain in the affected ear lasting several hours.

- ★ Labyrinthine sedative (Meclizine)

### Motion sickness

Produced by excessive vestibular stimulation.

### Space motion sickness

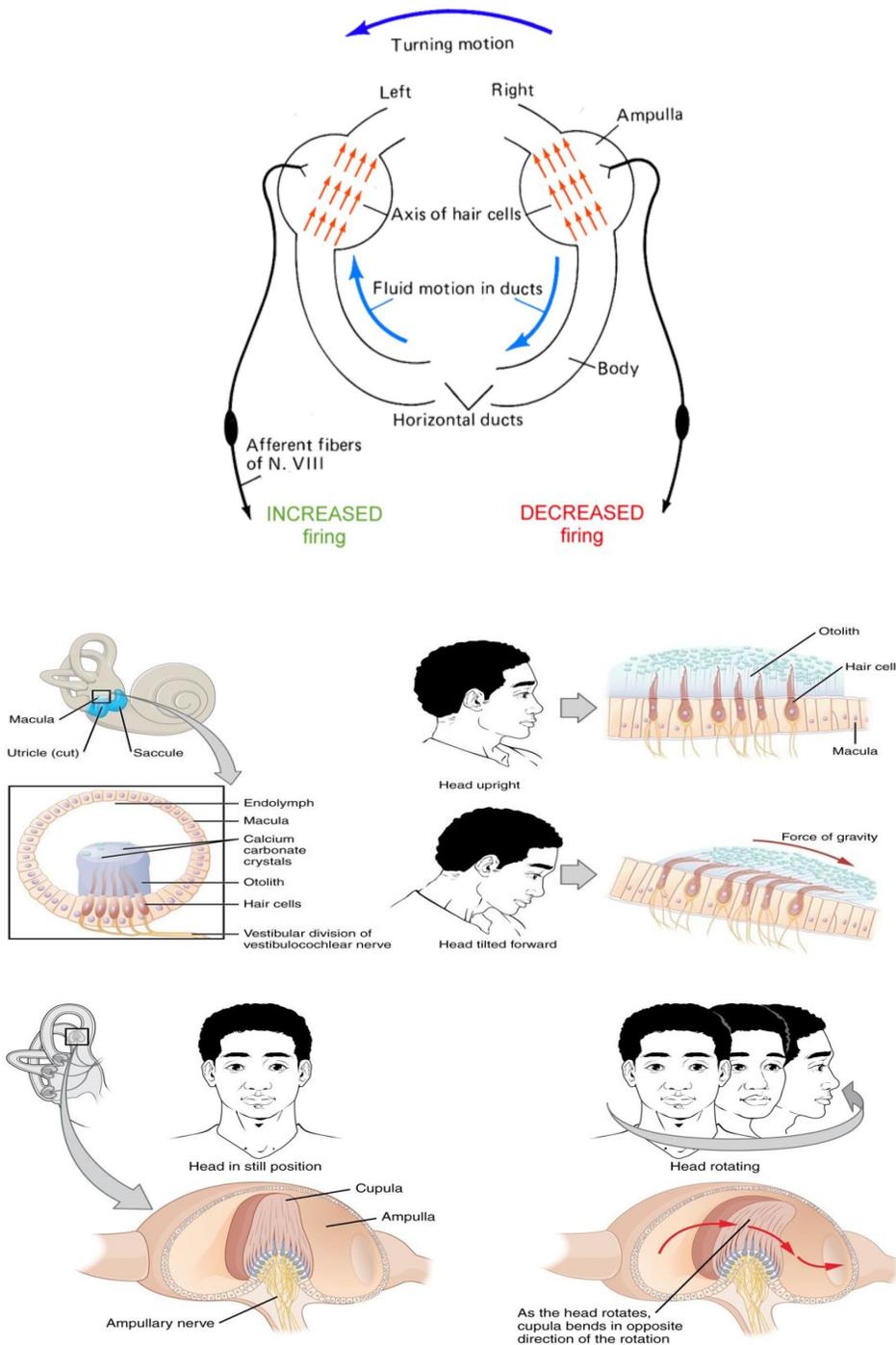
(In astronauts) develops when they are first exposed to microgravity and often wears off after a few days of spacing flight. Due to mismatches in neural input from vestibular apparatus and other gravity sensors.

- ★ Antihistamines or scopolamine, a cholinergic muscarinic receptor antagonist.

Important notes from Dr. Shahid:

- ★ Sensory organ of cochlea is known as Organ of Corti.
- ★ Sensory organ of SSCs is known as Crista ampullaris
- ★ Center of gravity is where all the forces are concentrated.
- ★ The resting membrane potential for hair cells is **-60 mV**.
- ★

Extra pic. To understand



# Summary

Cochlea	( <b>organ of corti</b> containing receptors for <b>hearing</b> )
Semicircular canals	( <b>Crista ampullaris</b> containing receptors that respond to <b>head rotation</b> ) Arrangement: <ul style="list-style-type: none"><li>- <u>Posterior canal shares plane with contralateral anterior canal.</u></li><li>- <u>Horizontal canals share plane</u></li><li>- <b>Sensory organ: Crista ampullaris</b></li><li>- <b>Hair cells: oriented in same direction</b> unlike macula</li></ul> Function: <b>SCCs detect ANGULAR ACCELERATION:</b> <ul style="list-style-type: none"><li>- the beginning of rotation</li><li>- End of rotation</li><li>- Changes in rate of rotation</li></ul>
Utricle & Saccule	( <b>Macula</b> contain otolith organs and receptors that respond to <b>gravity and head tilt</b> ).

1. Which one of the following is a sensory organ that respond to gravity and head tilt?

- A. Organ of corti
- B. Crista ampullaris
- C. maculla
- D. Tectorial membrane

2. Which one of the following structure in the vestibular apparatus is responsible for the detection of angular acceleration ?

- A. Macula
- B. Semicircular canal
- C. Sacculae
- D. Ampullae

3. Which one of the following is responsible of static equilibrium ?

- A. Vestibule
- B. Semicircular canal
- C. Ampullae
- D. cochlea

4. Which one of the following structures is maximally sensitive to linear head movement in the vertical line ?

- A. Macula of the utricle
- B. Macula of the sacculae
- C. Crista ampullaris of the anterior semicircular canal
- D. Crista ampullaris of the horizontal semicircular canal

5. Which one of the following structure detect rotation of the lateral movement of the head "anterior-posterior axis"?

- A. Utricle
- B. Anterior semicircular canal
- C. Posterior semicircular canal
- D. Horizontal semicircular canal

6. All the hair cells in the crista ampullaris of the horizontal semicircular duct have their stereocilia and kinocilium oriented according to which of the following patterns?

- A. Random pattern with progression from short to tall stereocilia such that the shortest is adjacent to the kinocilium
- B. Same pattern with progressive decrease in length of stereocilia from tallest to shortest, with the shortest located adjacent to the kinocilium
- C. Random pattern with random distribution of stereocilia of various lengths
- D. Same pattern with progressive increase in length of stereocilia from shortest to tallest with the tallest located adjacent to the kinocilium

7. Which one of the following is an effect of the semicircular canal in rotation?

- A. Hypertension
- B. Tachycardia
- C. Vertigo
- D. Decrease muscle tone in the same side of the rotation and increase muscle tone in the opposite site

8. Which one of the following disorder is produced by excessive vestibular stimulation?

- A. Meniere disease
- B. Motion sickness
- C. Deafness
- D. Ataxia

9. Which statement concerning the transduction mechanism in vestibular hair cells is correct?

- A. Movement that bends the stereocilia away from the kinocilium has a depolarizing influence on the hair cell
- B. The attachment of the stereocilia to the kinocilium is such that it activates voltage gated sodium channels in the membrane of the kinocilium
- C. Depolarization of the hair cell is achieved by inward movement of sodium from the endolymph
- D. Deflection of the cupula such that stereocilia move toward the kinocilium causes the hair cell to depolarize

10. Which one of the following happens when a person rotates toward the right?

- A. The endolymph in the left and the right horizontal SCC moves in the same direction.
- B. The stereocilia on the hair cell in the right posterior SCC bend inward the kinocilium.
- C. The hair cells in the right horizontal SCC become depolarized.
- D. The hair cells in the left posterior SCC become hyperpolarized.

Answers:

- 1.C
- 2.B
- 3.A
- 4.B
- 5.C
- 6.D
- 7.C
- 8.B
- 9.D
- 10.C