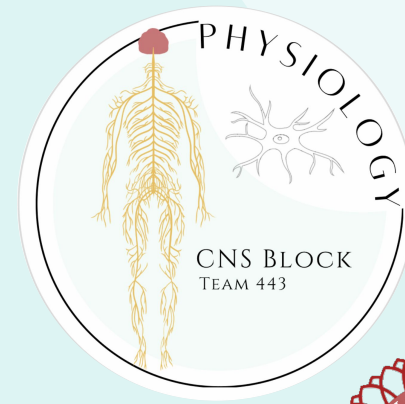


The inner ear in balance



Color Index:

- Main text
- **Important**
- Girls Slides
- Boys Slides
- Notes
- Extra

[Editing File](#)



Objectives:

- 1 Functional anatomy of the Vestibular Apparatus
- 2 Dynamic and static equilibrium
- 3 Role of Utricle and Saccule in linear acceleration
- 4 Role of Semicircular Canals in angular motion
- 5 Vestibular disorders



Overview of Proprioception & Balance:

components of Equilibrium

Utricle & Sacculle

Function:Static Equilibrium

Sacculle

Function: Linear Acceleration Vertical

SCCs

Function: Predictive Functions
when you jump of I stair on your feet, you do not fall

Utricle

Function: Linear Acceleration Horizontal
forward,backward,sideways

SCCs

Function:Angular Acceleration
when you rotate

dr shahid did not focus on proprioception

components of Proprioception

Static position sense (Ia)

Neck and Chest Wall Proprioceptors

Air pressure against body and Footpad pressure

Dynamic position sense (II)

Visual Information (vestibulo Ocular) and Apparatus

dr shahid:function of utricle and sacculle and SCCs is a possible MCQ



anatomy of the inner ear:

1

Bony labyrinth:
Bony cochlea & 3 semicircular canals.
Enclose the membranous labyrinth .

2

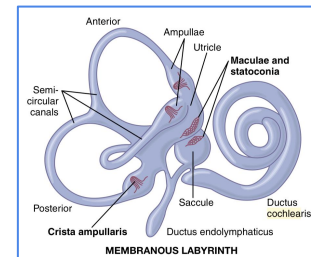
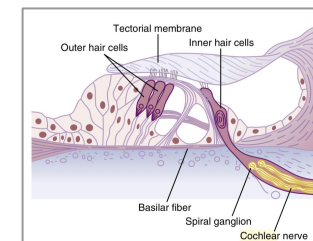
Membranous labyrinth :
-**Auditory** :cochlea **Organ of corti** containing receptors for hearing.
- **Non auditory for equilibrium:**
utricle & saccule(Macula contain otolith organ and receptors that responds to gravity and head tilt).

3

Semicircular canals:

1. **Anterior** (sense the forward & backward movement)
 2. **Posterior**(sense the up & down movement)
 3. **Horizontal/ lateral** (sense the left & right movement)
- Crista ampullaris** containing receptors that respond to head rotation

SVA: receptors are those of taste and smell (olfaction).
SSA: receptors are concerned with vision, audition, and balance or equilibrium.



Cranial nerve	Functional components	Nuclei	Distribution	Functions
VIII	SSA	Cochlear nuclei	Organ of corti in the cochlea of internal ear	Hearing
		Vestibular nuclei	Vestibular receptors in the semicircular ducts, utricle and saccule of internal ear	Equilibrium and balance



anatomy of the inner ear:

1

Vestibular apparatus (Non- auditory for equilibrium):
utricle, saccule, 3 semicircular canal:
1-Anterior (Superior)
2-Posterior (Inferior)
3- Lateral (horizontal)
, vestibular nerve and nuclei.

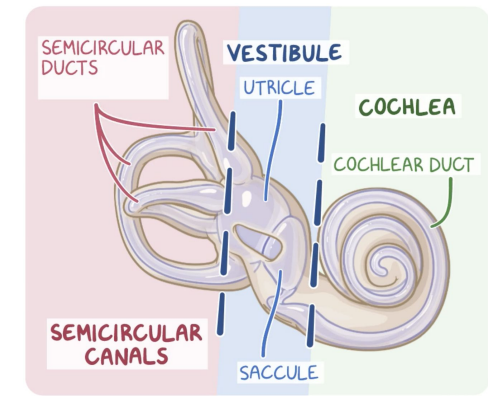
2

Posterior canal shares plane with contralateral anterior canal.

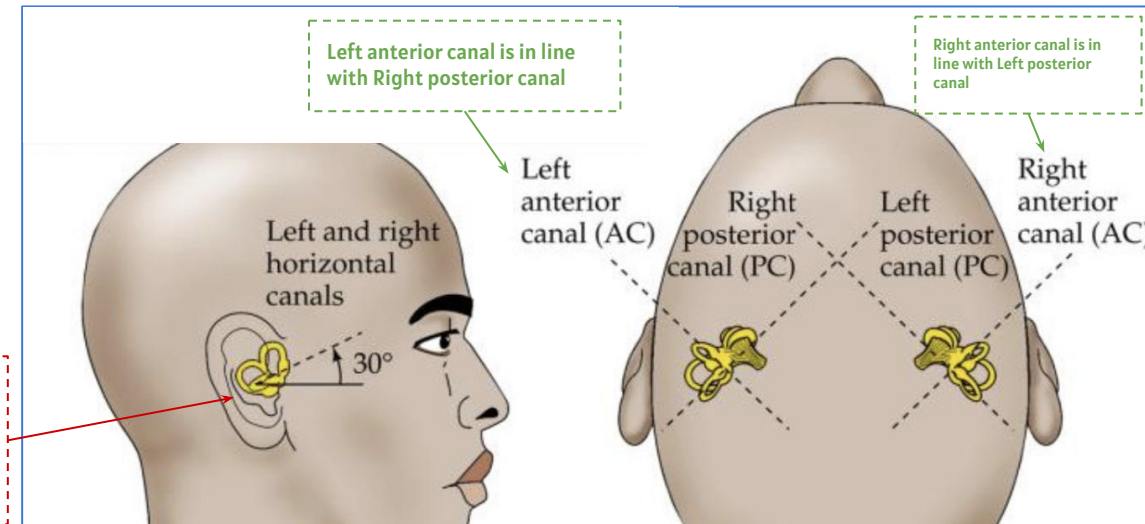
3

Horizontal canals share plane.

lateral canal is oriented at 30 degree
Dr:so if I asked you if you want to make your lateral canal on 0 axis in which direction you will tilt your head? down 30 degrees forward



Macula presents inside utricle and saccule and responsible for the sensation of our direction. It consists of type I & 2 hair cells and in between supporting cells, these hair cells have nerve fiber and stereocilia which is covered by gelatinous material (otolithic membrane) and on the top of that there are calcium carbonate particles (otoconia). The function of the otolithic membrane and otoconia is to sense and transmit any movement that the body does.



so now when one canal is stimulated, the other counterpart is inhibited



Balance and Equilibrium

Center of gravity of an object : the point at which weight is evenly dispersed and all sides are in balance. the point at which the entire weight of a body may be considered as concentrated so that if supported at this point he body would remain in equilibrium in any position

To balance the centre of gravity must be above the support point at which the weight is evenly dispersed. the higher the center of gravity -> less stability

Balance: the ability to maintain the equilibrium of the body.
Foot position affects standing balance.

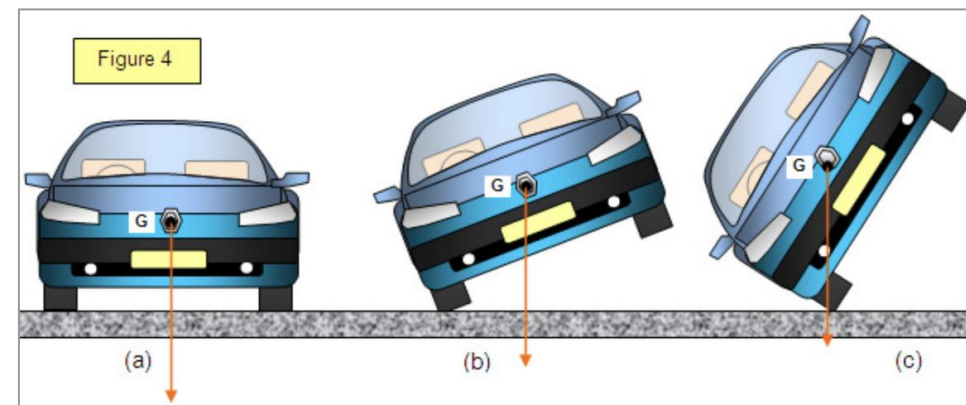
Equilibrium: the state of a body or physical system **at rest** or in unaccelerated motion in which the resultant of all forces acting on it is zero and the sum of all torques about any axis is zero.

Equilibrium: Reflexes maintain body position at rest & movement Through: receptors of postural reflexes

1-Proprioceptors.

2-Visual(retinal) receptors

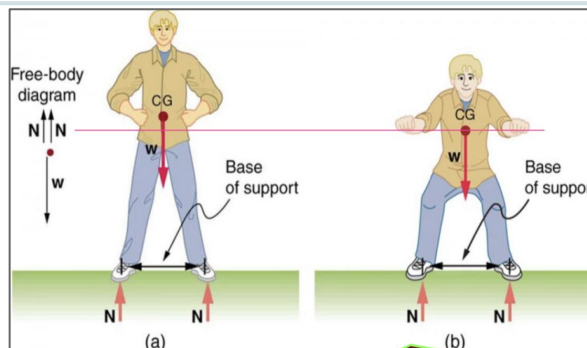
3-Non-auditory membranous labyrinth



Balance and Equilibrium

There are 2 types of Equilibrium

<p>Static</p>	<p>The equilibrium is maintained in FIXED POSITION, usually while standing on one foot or maintenance of body posture relative to gravity while the body is still. -keep the body in desired position</p>	<p>sense the position of the head, maintain stability and posture</p>
<p>Dynamic</p>	<p>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. <i>(move the body in controlled way)</i></p>	<p>balance the head during sudden movements</p>



Stability is increased by

Lowering the center of gravity

Stability is increased by

When the base is expanded by placing the feet farther apart



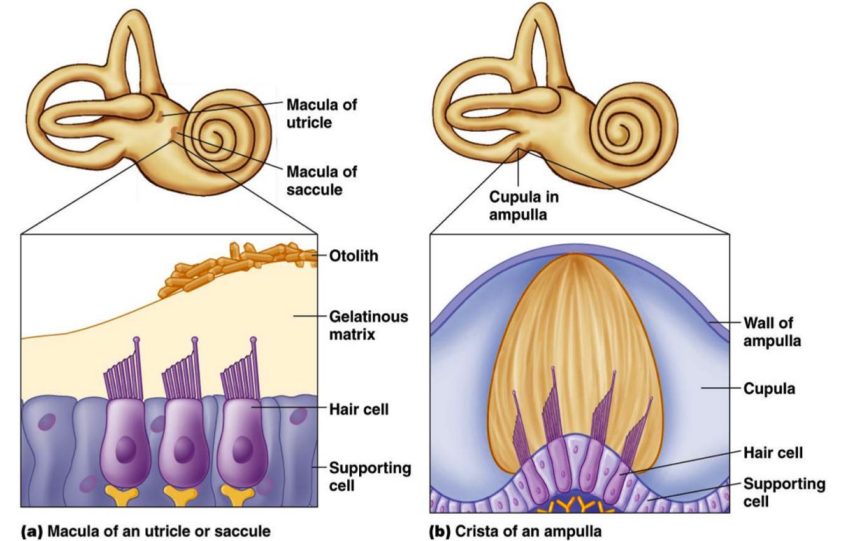
Balance and Equilibrium

Important

MCQ

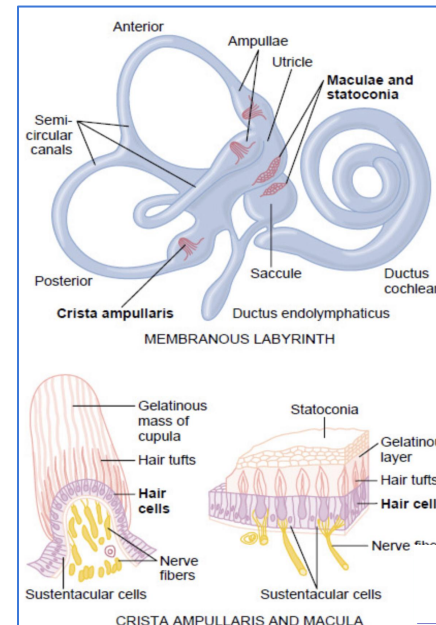
Maintaining equilibrium

SemiCircular Canals	Saccule and utricle (vestibule)
Crista ampullaris (sensory organ) : dilated end filled with endolymph	Macula (sensory organ)
Hair cells in each crista are oriented in the same direction (perpendicular)	Hair cells in each macula are oriented in all direction
No Otoliths	Otoliths (calcium carbonate crystals)
Dynamic Equilibrium and angular motion and changes	Static equilibrium and Linear Acceleration
Predictive function	No predictive function

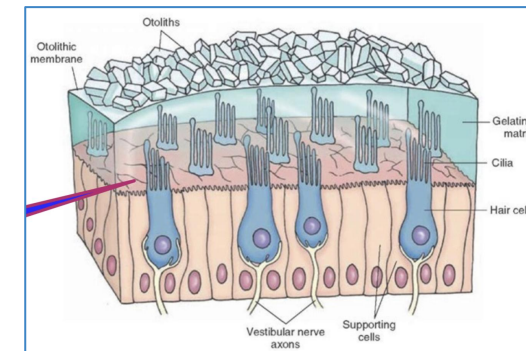


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Crista ampullaris



Macula





Three Semicircular Canals

1

Contain Endolymph

2

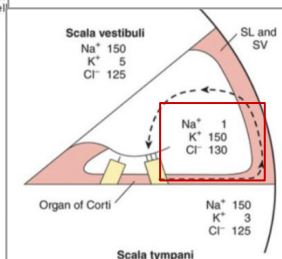
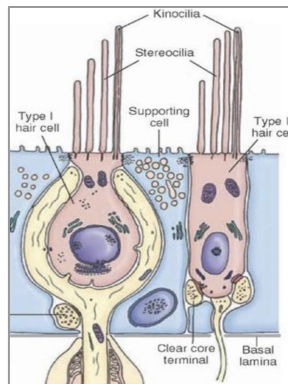
Each canal has a dilated end Ampulla

3

The ampulla **houses the sensory hair cells** (oriented in same direction unlike macula) covered by a gelatinous **mass/material** (Cupula)

**SENSORY ORGAN:
CRISTA AMPULLARIS**

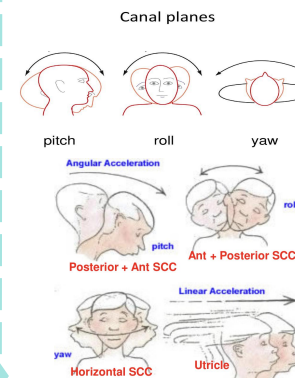
Pay attention that
**Na is low
K is high**



This part wasn't mentioned in the slide but it was in the picture

Plane of rotation & stimulated canal

Canal	Plane of rotation
Horizontal	Rotation of head in vertical axis
Anterior	Rotation of head in an oblique side (Anterolateral or Posterolateral)
Posterior	Rotation of head in anteroposterior axis (Move head laterally to Shoulder)

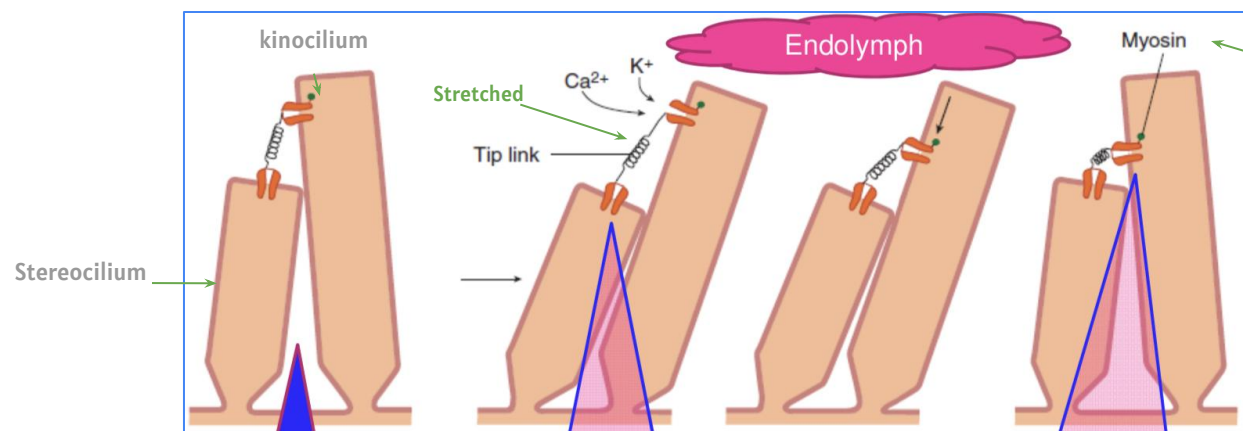


Pitch: Superior + Posterior
Roll: Posterior + Superior
Yaw: Lateral

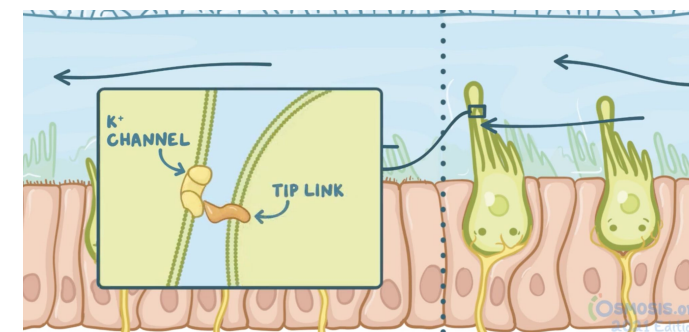


Hair Cells Mechanism of Action (tip link)

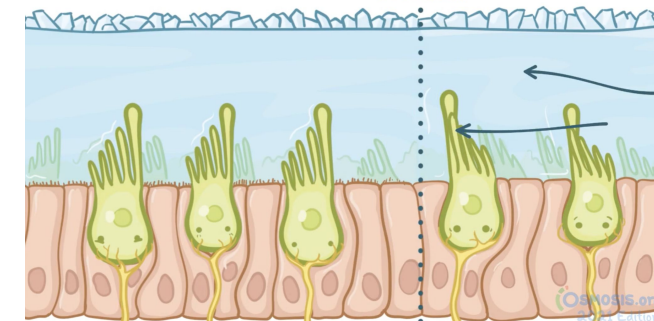
1. Bending of stereocilia **toward kinocilium** \Rightarrow depolarization, Ca^{2+} entry & neurotransmitter release \Rightarrow **increase** rate of impulses to 8th nerve fibers.
2. Bending of stereocilia **away from kinocilium** \Rightarrow hyperpolarization \Rightarrow **decrease** rate of impulses to 8th nerve fibers.



myosin will bring down the ion channel down to the resting position, so the channels will close and no more signals will go



STRIOLA



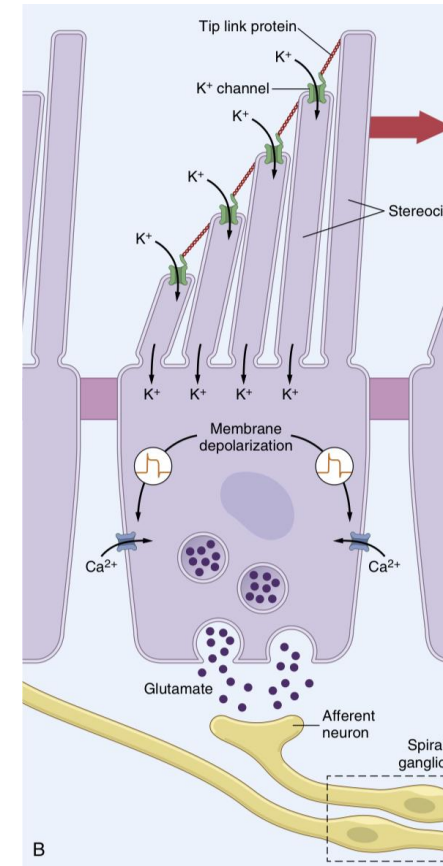
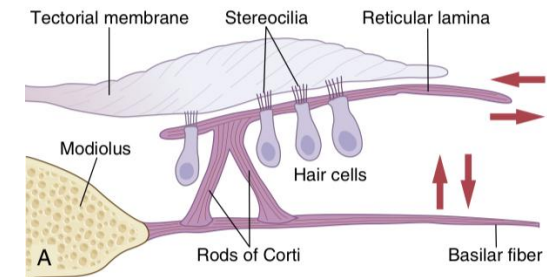
Hyperpolarized

Depolarized



Extra: tip links

- Upward movement of the basilar fiber rocks the reticular lamina upward and inward toward the modiolus. Then, when the basilar membrane moves downward, the reticular lamina rocks downward and outward. The inward and outward motion causes the hairs on the hair cells to shear back and forth against the tectorial membrane. Thus, the hair cells are excited whenever the basilar membrane vibrates.
- Transduction of mechanical energy into neural signals by the hair cells. When the stereocilia are bent in the direction of the longer ones, K⁺ channels are opened, causing depolarization, which in turn opens voltage-gated Ca²⁺ channels. The influx of Ca²⁺ augments the depolarization and elicits release of the excitatory transmitter glutamate, which depolarizes the sensory nerve



Extra

- The Figures shows the mechanism whereby vibration of the basilar membrane excites the hair endings



Macula

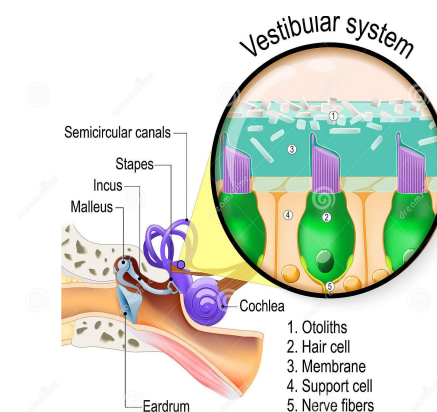
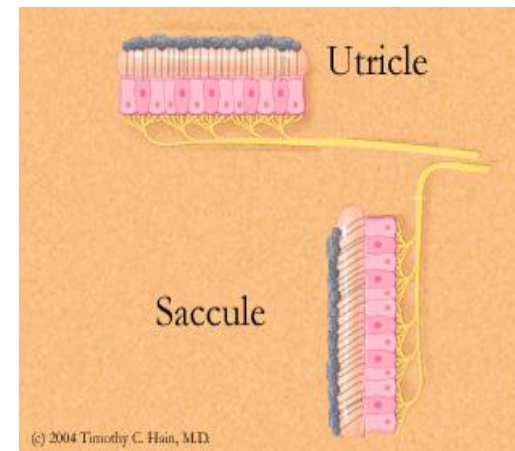
Characteristics of Hair cells:

1-Directional sensitivity

2-Slow adaptation

3-Highly sensitive to mechanical stimulation.

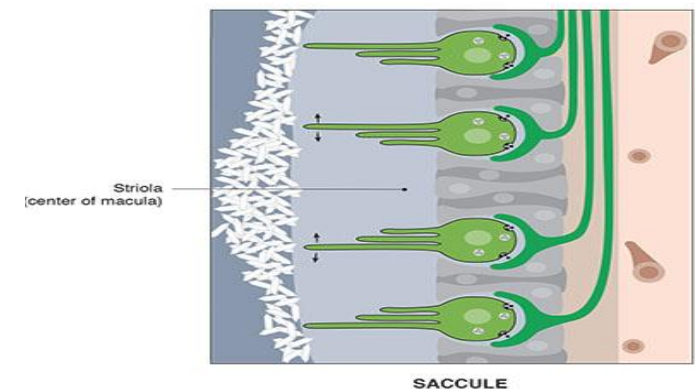
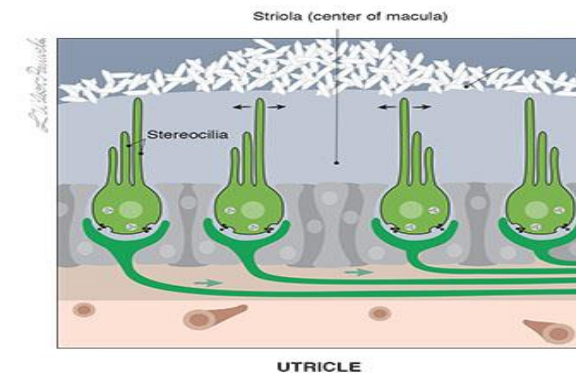
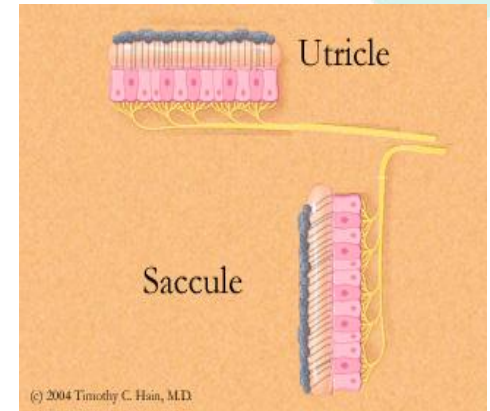
- Vestibule (between cochlea and semicircular canals) contains static equilibrium receptors called macula.
- Hair cell synapse with endings of the vestibular nerve.
- Hair cells are oriented in different direction and tilt of head In any direction is signaled.
- Hair cell has :One (large) kinocilium 30 to 150 (small) stereocilia Cilia connected by fine/thin filamentous attachments (tip links)
- All cilium membrane has positive potassium channels.
- Otolithes (statoconia) of calcium carbonate suspended in gelatinous material.
- 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.





Macula

Hair cells in Utricle	Hair cells in Saccule
in upright position (head vertical):	
hair (cilia) pointing upwards	hair pointing laterally
Hair cells signal head movements in any direction	Hair cells operate when one is lying down
Macula in horizontal plane	Macula in vertical plane
Macula detect linear acceleration of head	
macula detect :horizontal acceleration/ balance in horizontal direction	macula detect :vertical acceleration/ balance in horizontal and vertical direction
<ul style="list-style-type: none"> ● stimulated when the head bends forward & backward & laterally ● Inform the brain of orientation of head in space (at all times) 	





Function of utricle and saccule

Detection of linear acceleration (for example someone standing in a bus)

Sudden acceleration ⇒ at beginning of movement statoconia lag behind movement by its inertia

⇒ **Falling backwards** ⇒ **Otoliths falls back on hairs** ⇒ cilia moves backward ⇒ **sensation of mal-equilibrium** (Feels like he is falling backwards) ⇒ **Correction by leaning forward** to shift statoconia & cilia anteriorly.

at deceleration (runner try to stop) ⇒ statoconia move forwards by its momentum ⇒ person feels falling anteriorly .

Detection of static tilt

- Upright vertical position: Impulses from both utricle macula balance each other.
- if Body tilts to one side: Two maculae send signals informing brain of new position of:
 - Head in space .
 - Sensation of imbalance.

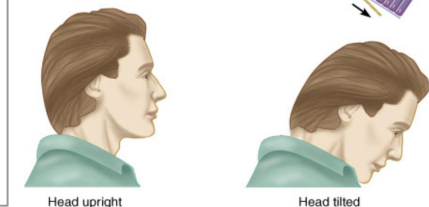
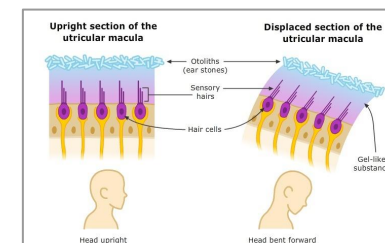
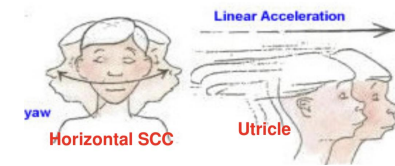
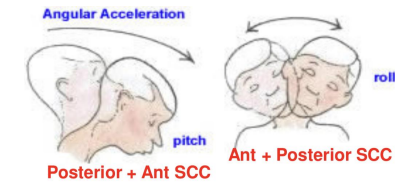
What events will occur to maintain balance if the bus suddenly stops?

you will lean forward, detected by utricle

dr shahid questions:

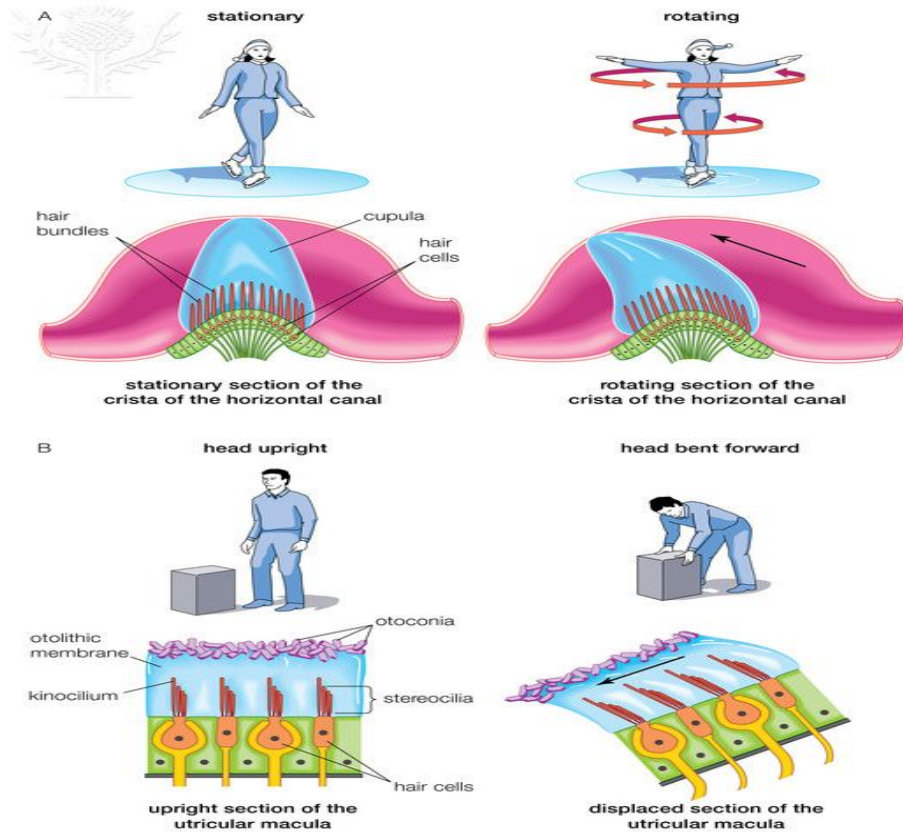
1-what event will occur if the bus suddenly stops?

2-what event will occur if the bus suddenly accelerate?





Linear acceleration (detection of static tilt)



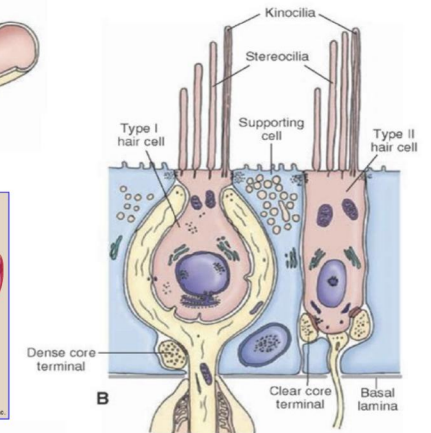
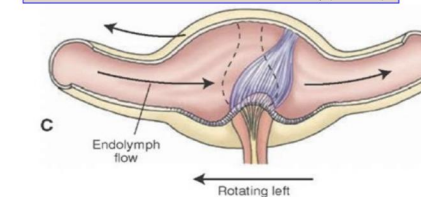
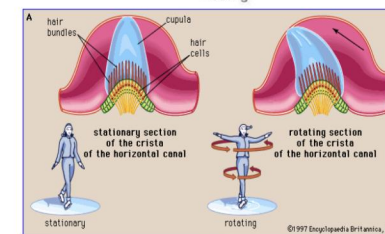
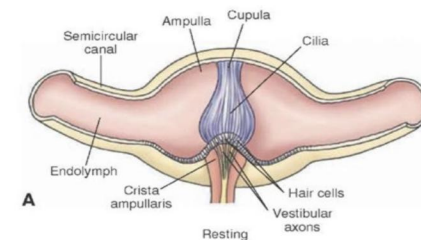
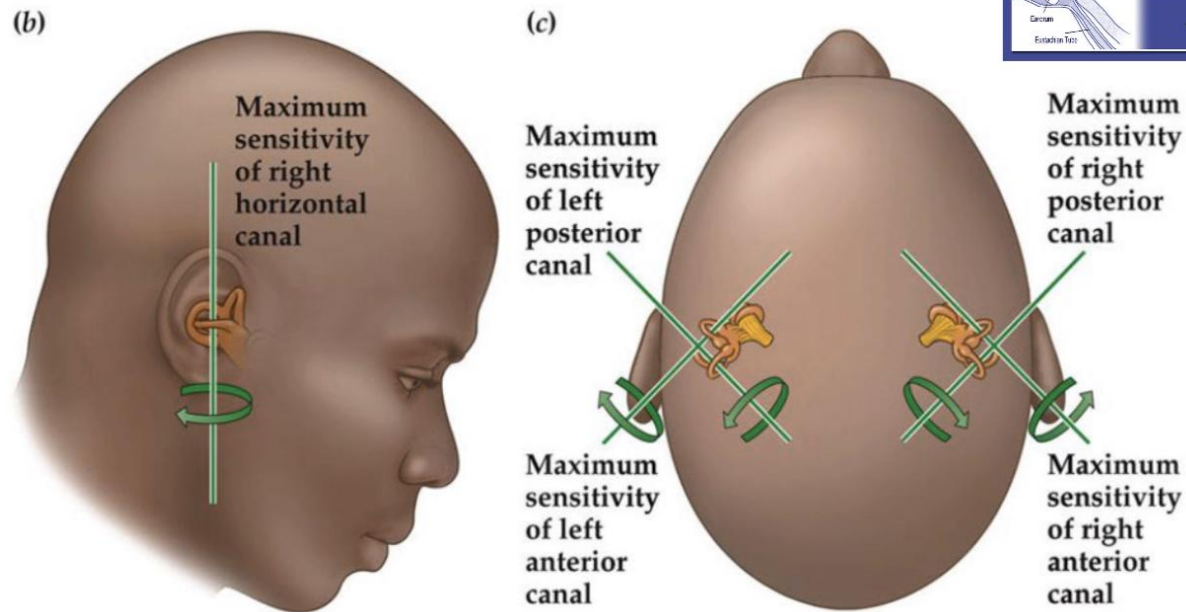
Girls doctor explanation:

- At rest, the otoconia exert similar pressure on all surface of the macula.
- If we are standing on a bus and it suddenly moves forward the gelatinous material will move backward and otoconia move backward further, then hair cells present in the back on the macula will give action potential in the nerve fiber due to the pressure of the gelatinous material & otoconia. This gives us the sensation of falling backward, so we will try to correct our position by moving forward a little bit.
- When the bus stop the gelatinous material & otoconia will move forward pressing the hair cells in the front of the macula. This gives the sensation of falling forward and then backward reflux movement occurs.



3D Orientations of SCCs & Head rotations

- Each semicircular canal works in concert with a partner located on the other side of the head, which has its hair cells aligned oppositely. (if one canal is stimulated the other will be inhibited)
- **Head rotation** deforms the cupula in **opposing directions** for the two partners, resulting in opposite changes in their firing rates (head rotation will make the sensitivity of the two canals are opposite)
- the hair cells in the canal towards which the head is turning are **depolarized**, while those on the **other side are hyperpolarized**.
- The pair whose activity is modulated is in the rotational plane, and the member of the pair whose activity is increased is on the side toward which the head is turning.

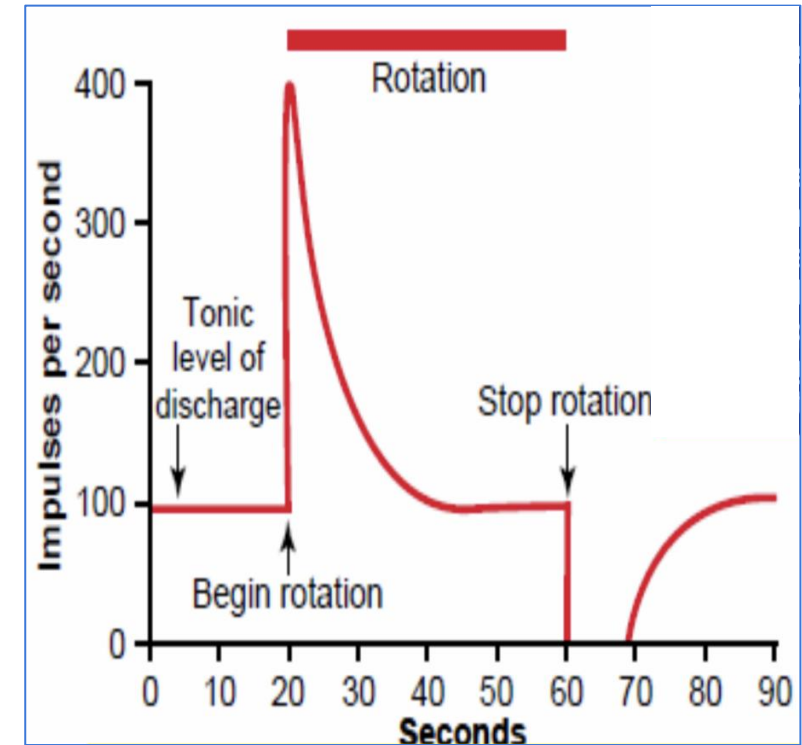




Function of the Semicircular Duct System in the Maintenance of Equilibrium

1. During rest : equal discharge from SCC on both.
2. Detect & maintain posture during head rotation in any direction.
3. (angular acceleration) rotation.
 - **SCCs detect Angular Acceleration:**
 - ❖ **The beginning of rotation**
 - ❖ **End of rotation**
 - ❖ **Changes in rate of rotation** (e.g. Joy riding)
 - **SCCs Predictive Function:**
 - **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.



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 for the SCC > Cupula being elastic returns to resting position > Discharge from both sides returns to resting level



SCC Events in an Example of Clockwise Rotation (i.e. Left to Right)

1 Endolymph -->>>move to the opposite direction by inertia (from right to left)

2 the cilia of right side bent by endolymph towards the kinocilium >towards the utricle.

3 it will cause depolarization>impulses from right side increase.

4 impulses from left side decrease as cilia bent away from kinocilium.>>>>it will cause sensation of rotation to right
dr shahid :before stopping fluid will move in the same direction eventually

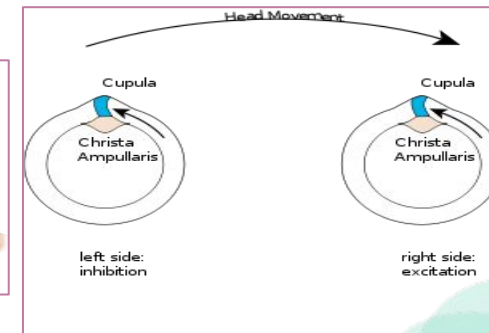
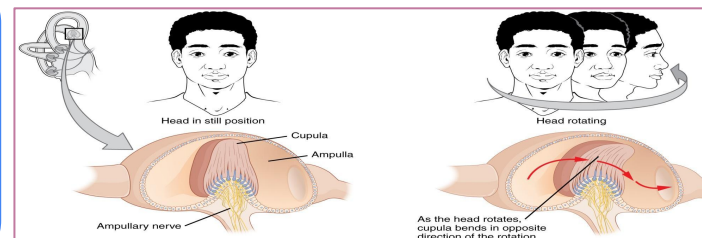
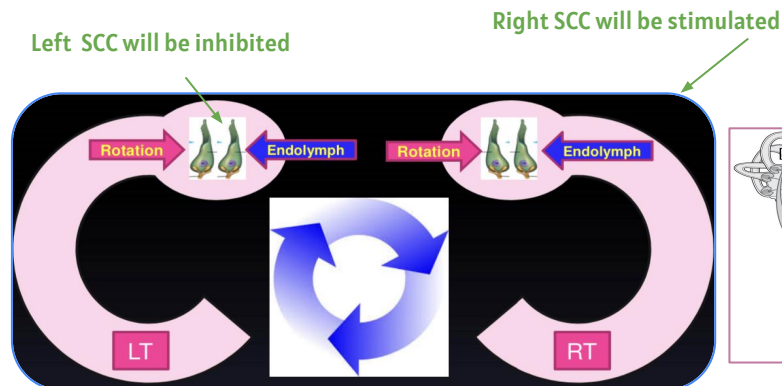
Effects of stimulation of S.C.C (rotation)

1. Vertigo: this false sensation of counter-rotation at end of rotation
2. Nystagmus
3. Bradycardia & hypotension
4. Increased muscle tone on same side of rotation to support the body & decreased muscle tone on the opposite side

SCC detect:

- 1.Start of rotation
- 2.End of rotation
- 3.Changes in rate of rotation

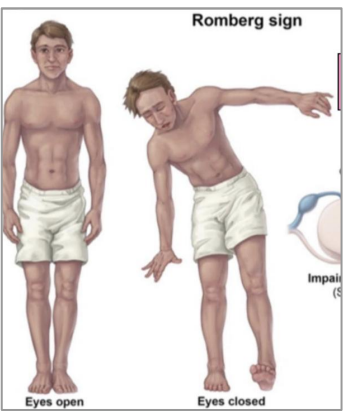
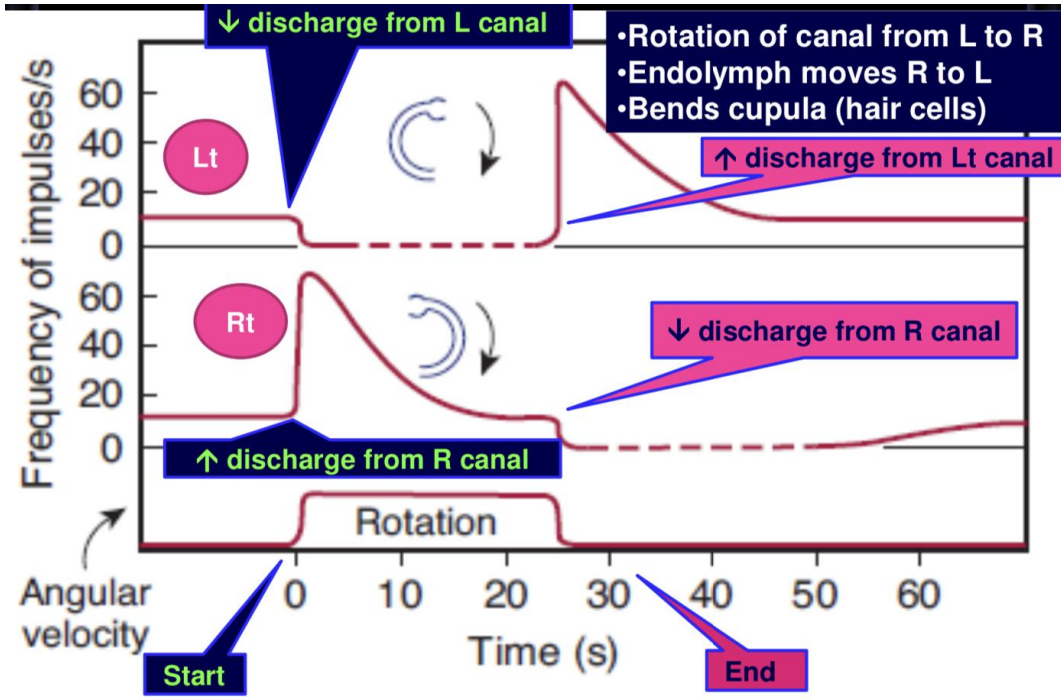
- Rotation of canal from L to R
- Endolymph moves R to L
- Bends cupula (hair cells)





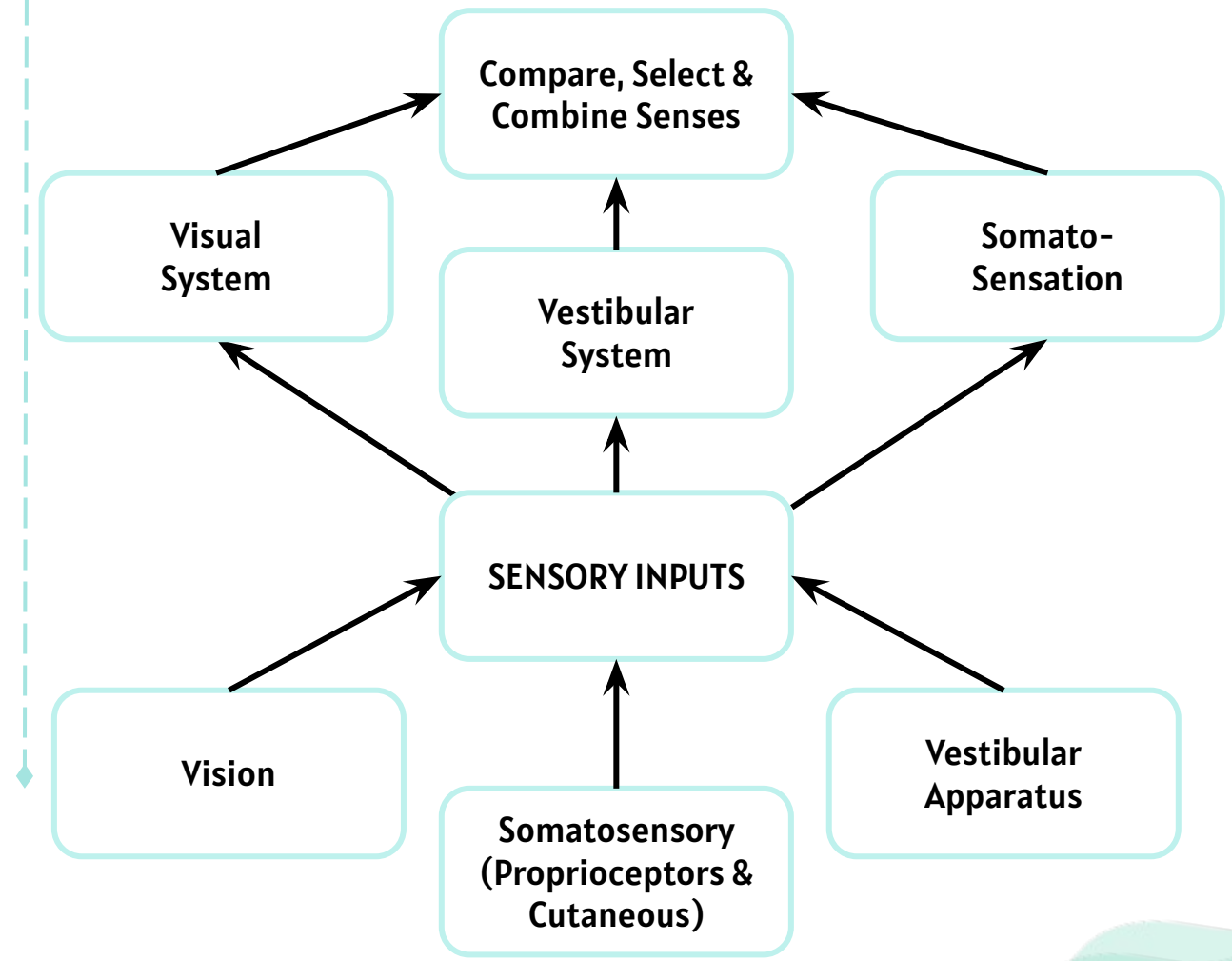
SCC Events in an Example of Clockwise Rotation (i.e. Left to Right)

Rotation from left to right



A Romberg test / Romberg's sign is a simple physical test to see if you have balance problems that are related to impaired proprioception (Dorsal Column)

systems work together to maintain balance





Vestibular Pathway (Neural connections)

Nervous connections of vestibular apparatus:-
Nerve fibers from maculae & cristae ampularis
>> Vestibular nerve >> ipsilateral vestibular nucleus to :-

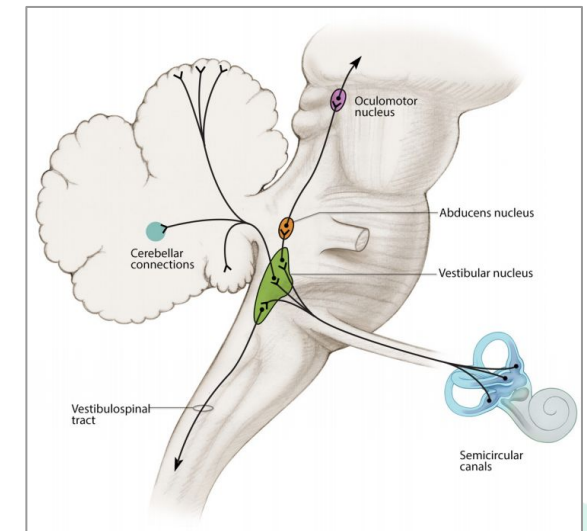
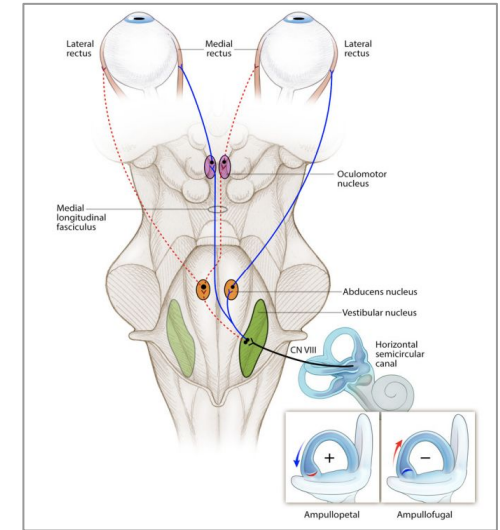
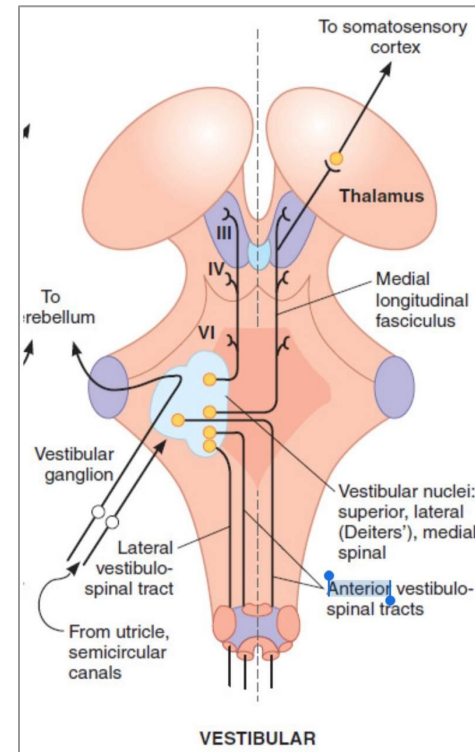
1 Cerebellum (Flocculonodular lobe)

**2 Motor nuclei of CNs 3,4 & 6
(To lateral & medial rectus)**

3 Reticular formation (Spinal cord)*

4 Spinal cord (Vestibulospinal tract)*

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





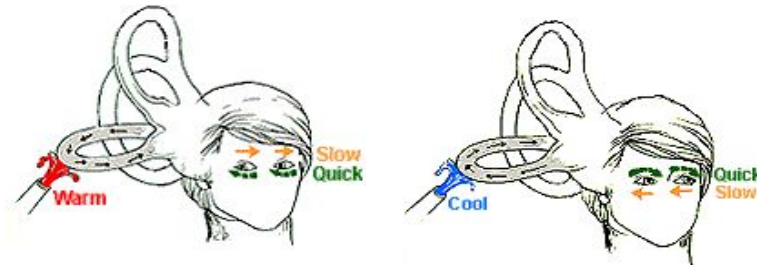
Testing Vestibular System

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 includes nystagmus that bears toward the opposite ear.
- Mnemonic COWS** (Cold 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 (Rotary Chair)

- 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.
- Remember:** When nystagmus is seen at rest, it is a pathology sign.



NOTE: Nystagmus direction is not the direction of the eye!. Nystagmus is more like a tremor of the eye





Vestibular Disorders

disorder	description	treatment
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	Canalith repositioning
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.	Labyrinthine Sedatives (Meclizine)
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	Antihistamines or scopolamine, a cholinergic muscarinic receptor antagonist.



TEST YOURSELF !

which of the following will occur during movement of stereocilia towards kinocilium?

A)depolarization

B)repolarization

C)local potential

D)subthreshold stimuli

which of the following is a presenting feature of SCC stimulation?

A)vertigo

B)hypertension

C)increase muscle tone in the opposite side

D)sympathetic stimulation

which part of SCC responsible for moving head on vertical axis?

A)superior

B)posterior

C)lateral(horizontal)

D)A+B

which of the following has predictive function?

A)me

B)sacculle

C)utricle

D)SCC



SAQ

what are the function of utricle and saccule?

Page 3

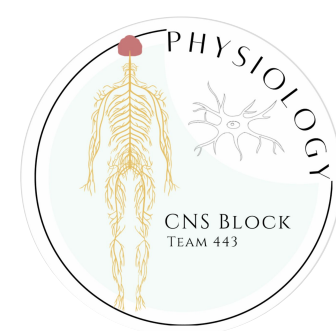
if you are standing inside a moving bus, what event will occur if the bus suddenly stopped? the movement that will happen is detected by what?

you will lean forward, detected by utricle

mention three nerve connections of vestibular apparatus?

- 1- Cerebellum: flocculonodular lobe
- 2- Spinal cord (vestibulospinal tracts)
- 3- Reticular formation

Team Leaders



Aseel Alsaif



Aldanah Alghamdi



Huda bin Jadaan



Sultan Albaqami



Fahad Almughaiseeb



Hamad Alziyadi

Team Members

Bayan Alenazi
Renad alshehri
Layan Alruwaili
Norah Alhazzani
Haya Alzeer
Huda bin Jadaan
Haya Alajmi
Reena alsadoni
AlJoharah AlWohaibi

Rahaf Alslimah
Jana Alshiban
Razan Alsoteehi
Lena Alrasheed
Layan Aldosary
Shahad Alzaid
Norah Almanian
Lama Almutairi
Raghad Alhamid

Layla Alfrhan
Farah Aldawsari
Manar Aljanubi
Waad Alqahtani
Salma Alkhlassi
Shoug Alkhalifa
Sarah Alajajii
Sarah Alshahrani
Wafa Alakeel
Reemaz Almahmoud
Sarah Alshahrani

Hamad Alyahya
Mishal aldakhail
Ziyad Alsalamah
Omar Alamri
sultan almishrafi
Mohammad Alzahrani
Khalid Alanezi
sami Mandoorah
Abdullah alzamil
Mohammed Alqutub
Mohammed Bin Manee

Salmam Althunayan
faisal alzuhairy
Mohammed Alarfaj
Ryan alghizzi
Mohammed Maashi
Zeyad Alotaibi
Nazmi Adel Alqutub
Faisal Alshowier
Ziad Alhabardi
Osamah almubbadel

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✉️ med443physioteam@gmail.com