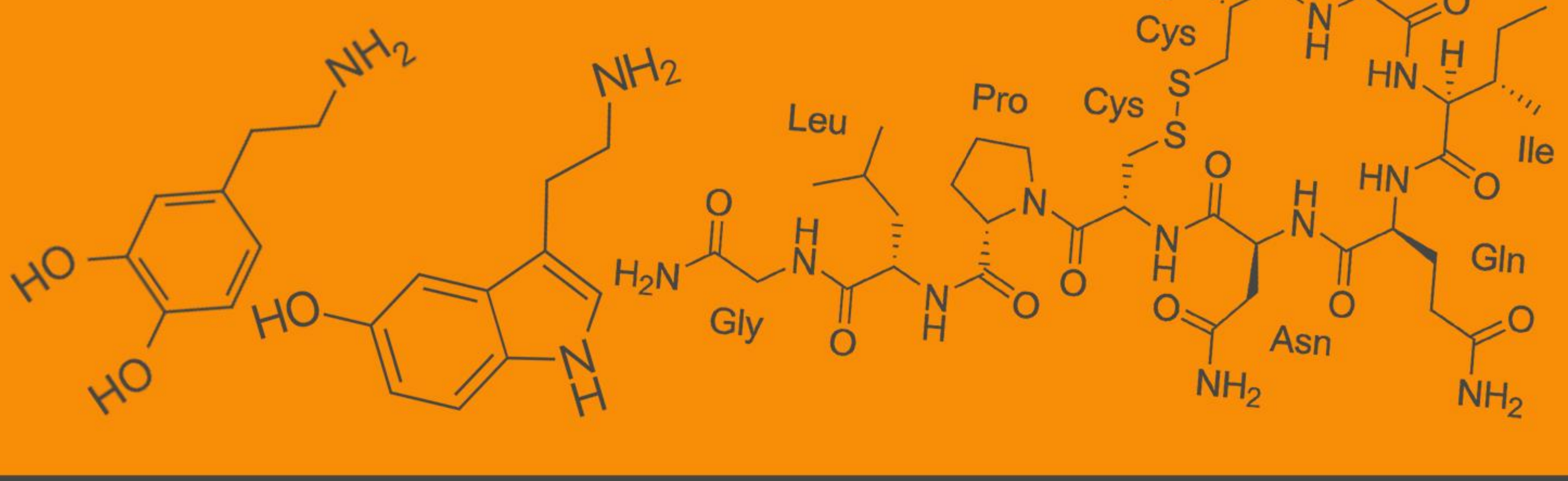


MEDICINE438's CNS PHYSIOLOGY

LECTURE XIX: Inner Ear in Balance & Equilibrium

EDITING FILE GSLIDES

IMPORTANT MALE SLIDES EXTRA FEMALE SLIDES LECTURER'S NOTES

1 Inner Ear in Balance & Equilibrium

Lecture Nineteen

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)

Equilibrium

Reflexes maintain body position at rest and movement through *receptors of postural reflexes*

1. Proprioceptors
2. Visual "retinal" receptors (photoreceptors)
3. Non auditory membranous labyrinth (macula & crista)

Labyrinth

- **Bony labyrinth** (filled with perilymph) enclosing the membranous labyrinth.
  a. bony cochlea
  b. Three bony semicircular canals
- **Membranous labyrinth** (filled with endolymph):
  a. Auditory (cochlea for hearing)
  b. Non auditory for equilibrium (Vestibular apparatus)

Labyrinth components

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

To balance the center of gravity must be above the support point at which the weight is evenly dispersed. The center of gravity of an object is the point at which weight is evenly dispersed & sides are in balance

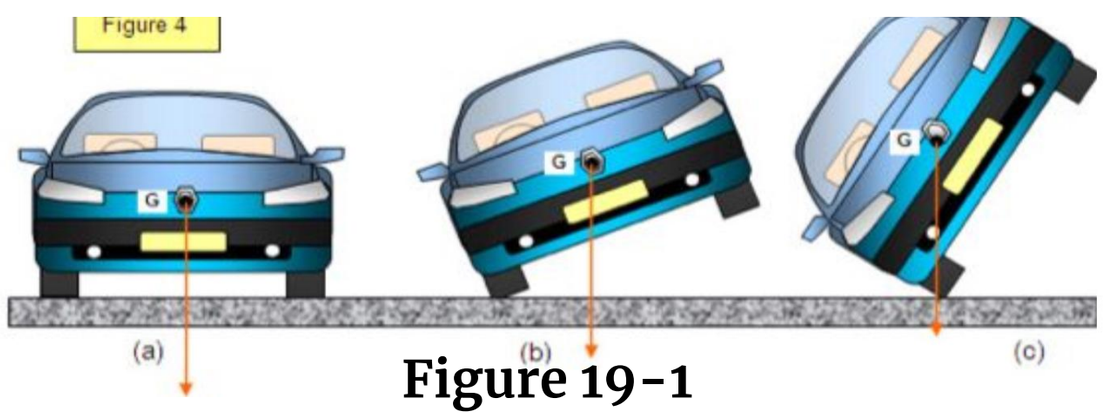


Figure 19-1

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 unaccelerated motion in which the **resultant of all forces acting on it is zero** & the sum of **all torques** about any access is **zero**.

There Are Two 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.

Semicircular Canals

1. Posterior canal shares plane with contralateral anterior canal.
2. Horizontal canals share plane.

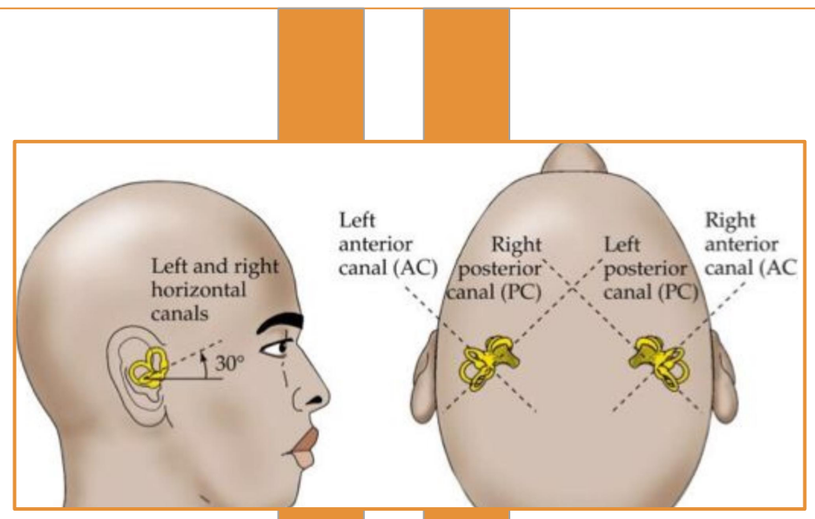


Figure 19-2

Vestibular apparatus

Components: Three Semicircular canals:

1. Anterior (superior)
2. Posterior (inferior)
3. Lateral
    a. Vestibule (BOX 19-1) (Utricle & Saccule)
    b. Vestibular nerve and nuclei.

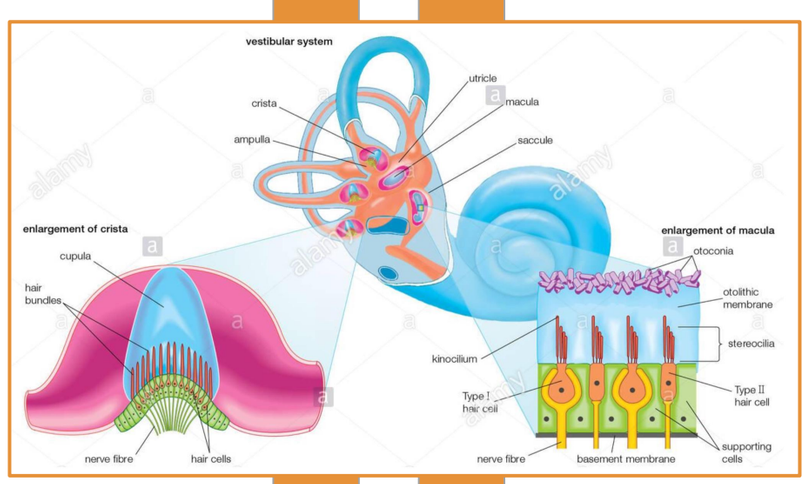
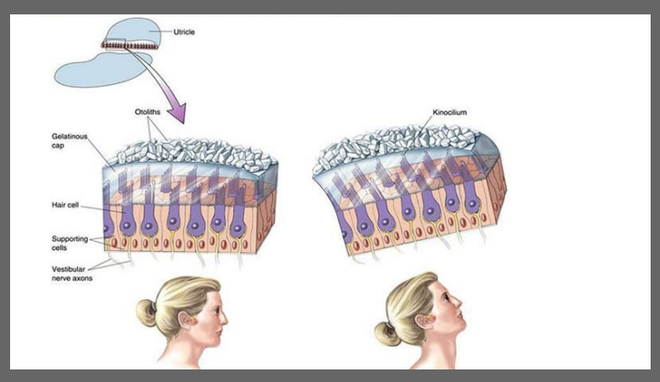


Figure 19-3

BOX 19-1: NEUROSCIENCE: EXPLORING THE BRAIN

Each otolith organ (saccule and utricle) contain a sensory epithelium called macula, this macula is composed of specialized epithelium called hair cells. These hair cells have cilia which are projected into gelatinous substance “gelatinous cap” as can be seen in the figure. This gelatinous cap is topped by specialized crystals called otoliths, or otoconia, these otoconia have higher density than the endolymph which fills the vestibule.

- When the head position changes these otoconia move with head movement, this exerts a force on the gelatinous cap which bends the cilia of hair cells. So basically otoliths control movements of hair cells through the gelatinous cap, now note, that this increased density of otoliths is a protective mechanism against excess stimulation. We will see in later slides a condition called Benign Paroxysmal Positional Vertigo, in this condition these otoconia are detached from the gelatinous cap, causing excess stimulation of hair cells and consequent feeling of spinning whenever the head moves.
- Because vestibular sensations function to keep an image in focus in the retina. If there is excess stimulation of vestibular sensations, then there is uncoordinated eye movement which will inevitably result in an unfocused image on the retina and a consequent feeling of spinning.



Maintaining equilibrium

Semicircular canals (Anterior, posterior, lateral)

- Crista ampullaris
- **Hair cells** in each crista are oriented in the **same direction**
- **Dynamic** equilibrium & **angular motion**
- Predictive function (BOX 19-2)

Vestibule (Saccule & utricle)

- Maculae[1]
- **Hair cells** in each macula are oriented in **all direction**
- Otoliths (calcified carbonate crystals)
- **Static** equilibrium & **linear** acceleration
- **No** predictive function

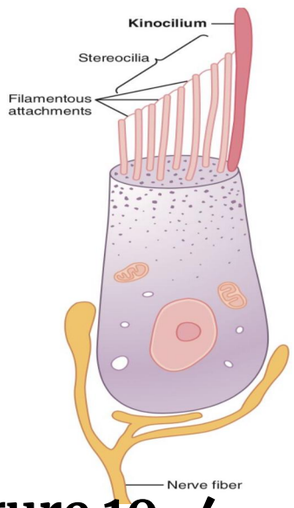


Figure 19-4

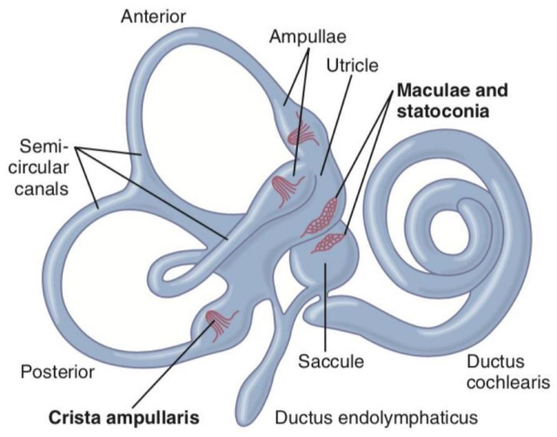


Figure 19-5

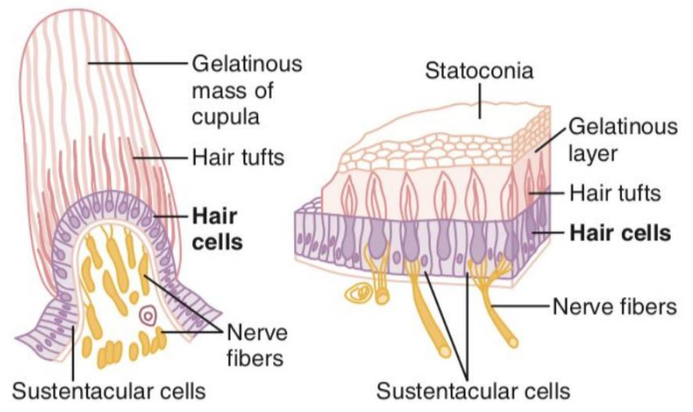


Figure 19-6

Macula (otolith organs) of Saccule & utricle

- Hair cells synapse with endings of the vestibular nerve.
- Hair cell has **30-150 stereocilia**[2] & **1 large** cilium called (**kinocilium**)
  - Both connected with thin filamentous attachments "tip link"
  - All cilium membrane has **positive potassium channels**
- Otolithes (**statoconia**) of **calcium carbonate crystals** suspended in **gelatinous material** (these crystals are heavy & they pull the gelatinous material) otoliths membrane enhance the sensitivity of stereocilia.
- Macula of **utricle** is in **horizontal plane** if the head is vertical, so cilia point upwards.
- Stimulated when the head bends forward & backward & laterally.

Movement of stereocilia **toward** Kinocilium —> **de**polarize it
Movement of stereocilia **away** from Kinocilium —> **hyper**polarize it

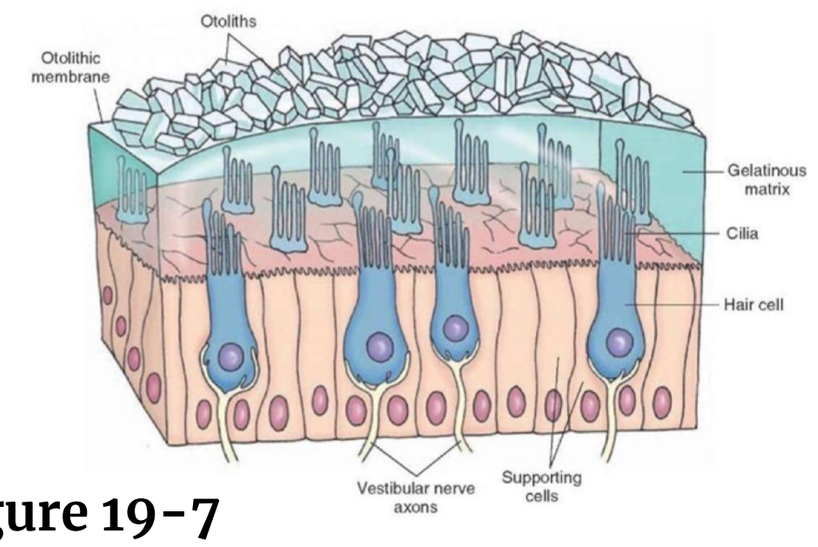


Figure 19-7

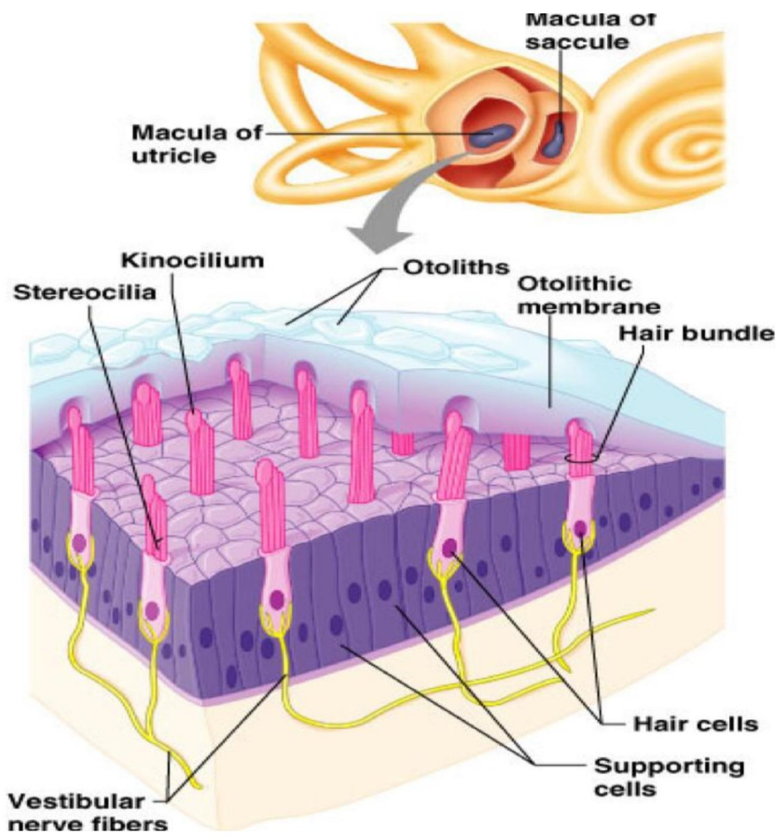


Figure 19-8

FOOTNOTES

1. Inside of the saccule and utricle is a special detector or a sensory epithelium called maculae.The sensory epithelium of the utricle is on the floor with the hair cells "stereocilia" pointing up. In the saccule, the sensory epithelium is on the wall with the stereocilia pointing out.
2. Above the the cilia, there is a gelatinous material called otoliths membrane and lodged into this membrane, calcium carbonate crystals "otoconia, otoliths"

4 Inner Ear in Balance & Equilibrium

Lecture Nineteen

- The doctor focused on the following features of hair cells:

1. Slow adaptation[1]
2. Directional sensitivity
3. Highly sensitive to mechanical stimulation

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

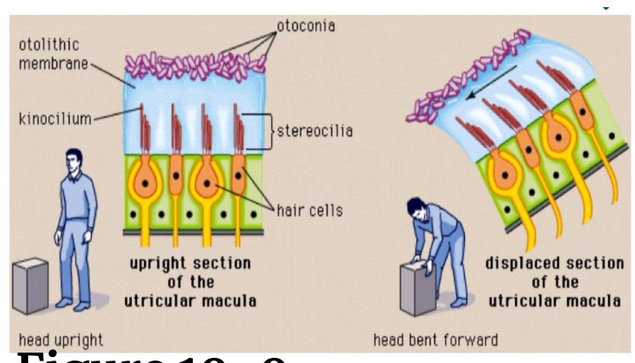


Figure 19-9

Functions of macula (Utricle & Saccule)

1 Orientation Of Head In Space & Maintenance Of Static Equilibrium:

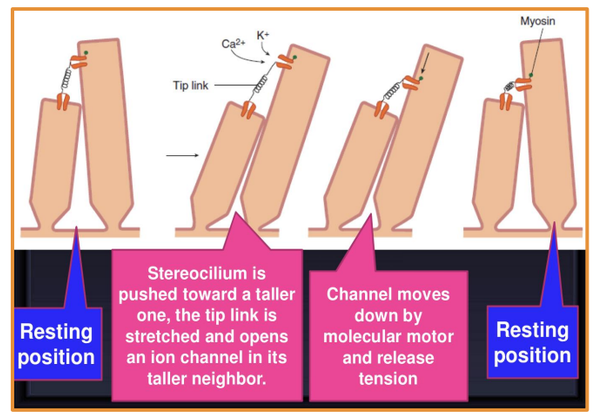


Figure 19-10

- In upright position (**Vertical** position)
  - Impulses from both utricle balance each other
- 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. entry of Ca & neurotransmitter release → increase rate of impulses to 8th nerve fibers
  - **Stereocilia** of the other side moves **away from kinocilium** → Hyperpolarization (inhibition) occurs → decrease rate of impulses to 8th nerve fibers

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 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 & cillia anteriorly

Cilia Sense changes in position & then stimulate reflexes to correct it.

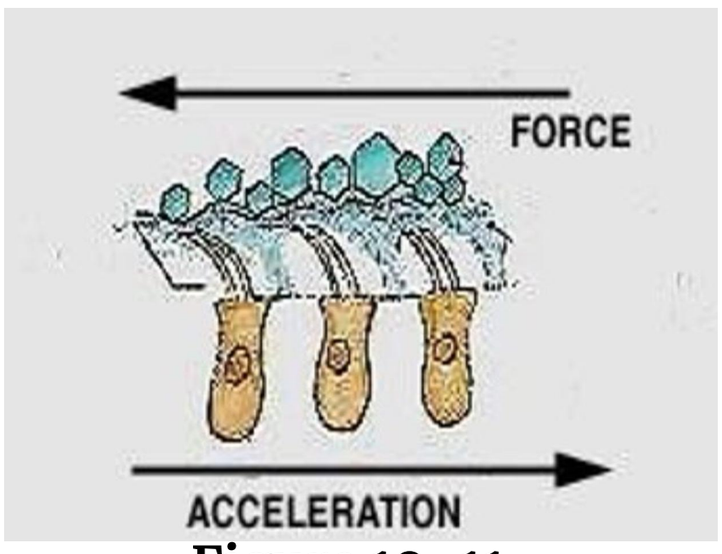


Figure 19-11

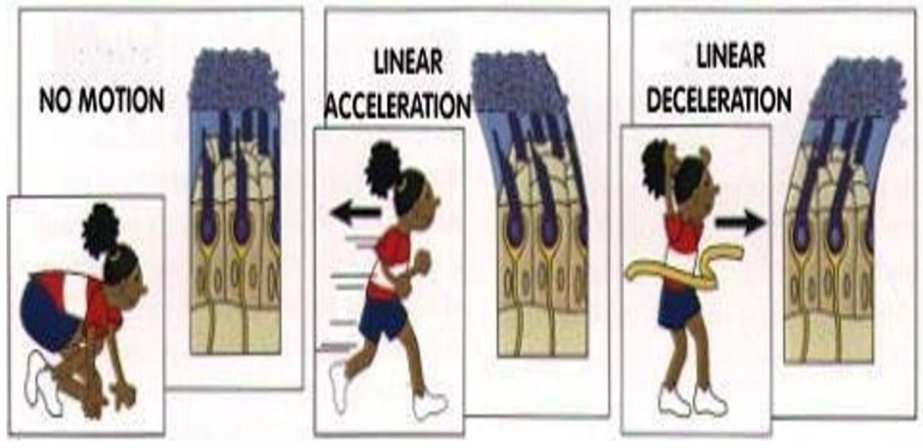


Figure 19-12

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

FOOTNOTES

1. The hair cells of the vertebrate inner ear convert mechanical stimuli to electrical signals. Two adaptation mechanisms are known to modify the ionic current flowing through the transduction channels of the hair bundles: a rapid process involves Ca2+ ions binding to the channels; and a slower adaptation is associated with the movement of myosin motors. Slow adaptation is most prominent in vestibular hair cells that sense spatial movement and less in cochlear hair cells that detect auditory signals.

BOX 19-2: NEUROSCIENCE: EXPLORING THE BRAIN & GUYTON AND HALL

The Vestibular System and Cerebellum Predictive Functions

Cerebellum provides the vestibular system with a predictive function, this happens in the following way:

- Suppose a person is running in a marathon, and was faced with a sharp turn that caused his head to turn. This stimulates the semicircular canals which will stimulate the vestibular nuclei with consequent correction of eye movement through connections between vestibular nuclei and extraocular muscles (medial longitudinal fasciculus). This will cause the eyes to move with head movements, thus maintaining a focused image on the retina and preventing the sensation of spinning.
- After head movement, signals are relayed to the cerebellum through vestibulocerebellar system into the flocculonodular lobe, the cerebellum becomes aware of the head position in space from the vestibular nuclei, however signals are also relayed to the cerebellum by the spinocerebellar tract which inform the cerebellum of the current body position, the cerebellum also receives signals from the cortex through pontocerebellar fibers, which inform the cerebellum of the upcoming movement (note that the dorsal spinocerebellar tract relays proprioceptive impulses from the body into the vermis and paravermis of cerebellum, the vermis and paravermis contain the topological representations of the trunk and limbs, yes even the cerebellum and other nuclei have topological representation. Which is why a lesion in the vermis will cause truncal ataxia). Receiving signals about intended movements from the cortex and about current movements through spinocerebellar tract allows the cerebellum to calculate the corrections required to achieve equilibrium.
- The cerebellum will detect that the head moved however the limbs and trunk position are still in mismatch with head movement, cerebellum then "predicts" the movements required to correct body position. This is made by sending corrective signals to the cortex through ventral lateral nucleus of thalamus, and to the red nucleus to inform them about the movement required to maintain equilibrium.

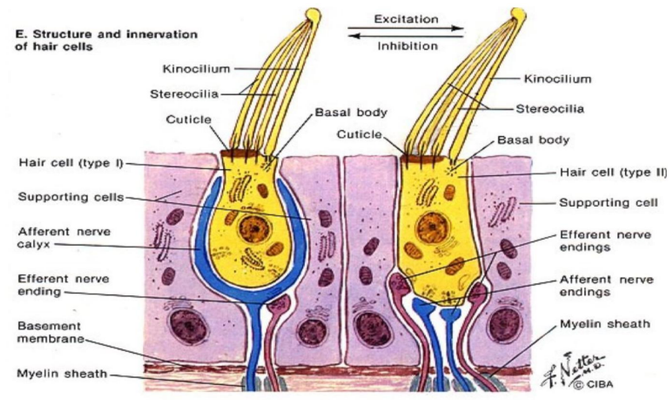


Figure 19-13

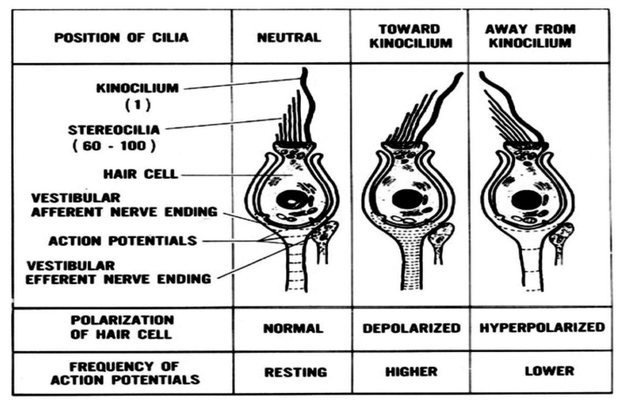


Figure 19-14

Hair cells in Utricle[1]	Hair cells in Saccule
Person in upright position: (Head vertical)	
Macula in horizontal plane	Macula in vertical plane
Hairs pointing upwards (bc they are in the **floor** of utricle)	Hairs pointing laterally(bc they are in the **wall** of saccule)
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 detect linear acceleration in horizontal axis & head tilt (for example when you're in a car)	Saccular maculae detect linear acceleration in vertical axis (for example when you're in an elevator going up or down)
Detect balance in horizontal direction	Detect balance in horizontal & vertical direction

Table 19-1

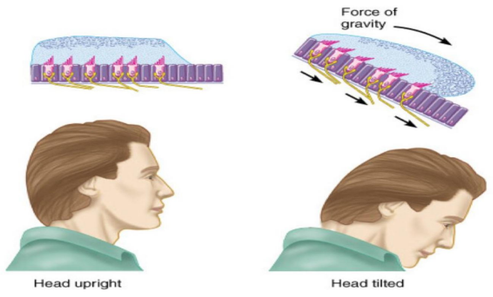


Figure 19-15

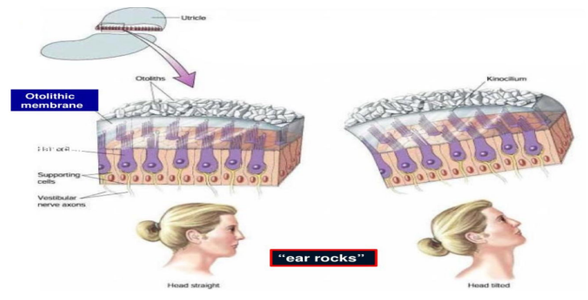


Figure 19-16

- In macula: hair cells are oriented in different direction & tilt of head in any direction is signaled.
- Macula of Utricle or Saccule are concerned with ***linear acceleration*** of head.

FOOTNOTES

1. if head moves forward, calcium carbonate crystals will pull the gelatinous membrane forward, causing the stereocilia to move, and if they move in the direction of the kinocilium, the channels open, K and Ca influx > electrical stimulation, high action potentials will be sent down the nerve endings.
- If head moves backwards, the otoconia will pull the otolithic membrane backwards, causing the stereocilia to move away from the kinocilium, little or no APs.
- When head is stationary, the APs are constant.
- If head tilts rightward, calcium carbonate crystals move to the right and as they move, it cause the stereocilia to beat towards the kinocilium increasing the APs.
- If head tilts leftward, calcium carbonate crystals will pull the stereocilia to the opposite direction, little or no APs.

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.

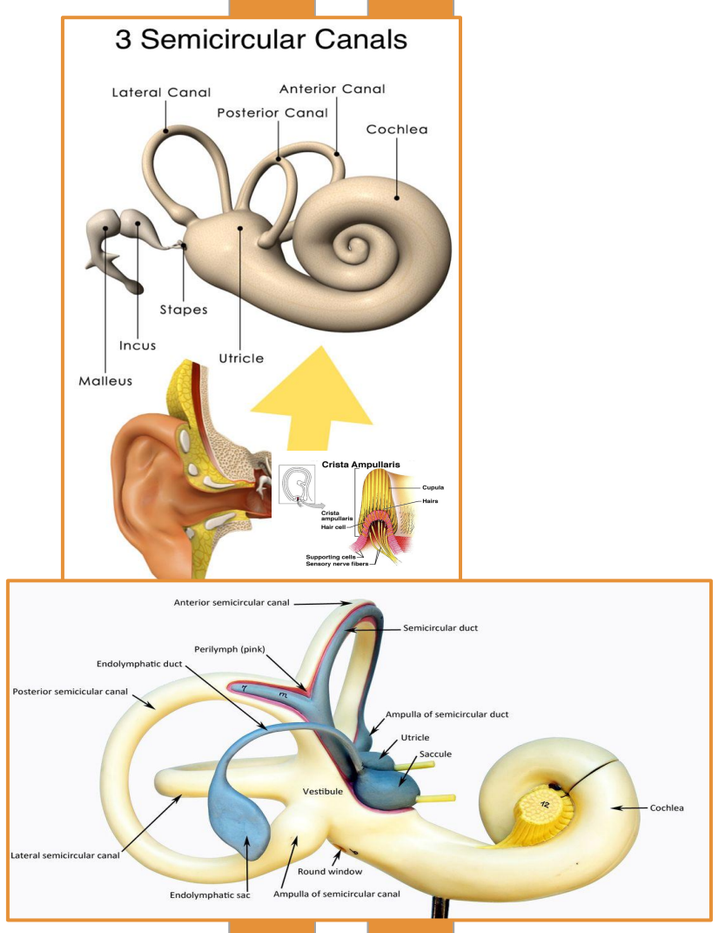


Figure 19-17

PLANE OF ROTATION

Determines the canal to be stimulated

Horizontal:	Rotation of head on vertical axis.
Posterior:	Lateral movement of head (AP axis) (approximate head to shoulder).
Superior:	Anterolateral or posterolateral head movement (oblique axis).

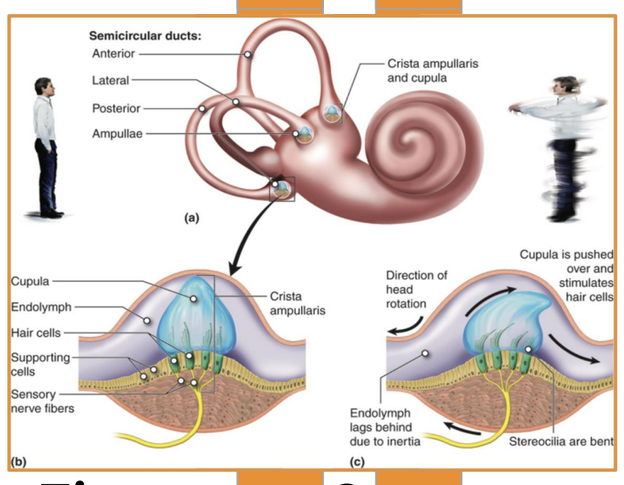


Figure 19-18

Function Of Semicircular Duct System

- During rest: equal discharge from SCC on both.
- Detect & maintain posture during head rotation in any direction
- **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 all the fall.

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

BOX 19-3: NEUROSCIENCE: EXPLORING THE BRAIN & GUYTON AND HALL

How Semicircular Canals Detect Motion

The semicircular canals are uniquely arranged, with each canal communicating with the vestibule through termination (at one end only) called the ampulla, which contain the crista ampullaris. Therefore there are three semicircular canals, with three ampullae.

- Let's say the head was rotated to the right, what happens is that the semicircular canal itself on both the right and left side are rotated to the right as well.
- This endolymph however remains stationary within the canal due to inertia, which is defined as the resistance of a body to motion, this endolymph is then approached by the cupula of the moving semicircular canal. The cupula is bended by the static endolymph. Within the right semicircular canal (remember in our scenario the head is rotated to the right) the endolymph pushes the cupula in the opposite direction of rotation, therefore the cupula and hair cells within them are bended to the left (stereocilia bends first followed by kinocilia) . This causes depolarization of hair cells and signals being relayed to CNS.
- The left semicircular canal is also rotated to the right, however their rotation causes the endolymph to push the copula in a direction that causes hyperpolarization (kinocilia bends first) . Because remember, the semicircular canals in each side are mirror images of each other, whatever happens in one side will happen oppositely in the other side. The combination of this depolarization and hyperpolarization causes the CNS to decipher the impulses as head rotation. And corrective measures will begin. Different planes of rotations will stimulate different canals.

ANGULAR (ROTATION) ACCELERATION

Movement of endolymph › 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.

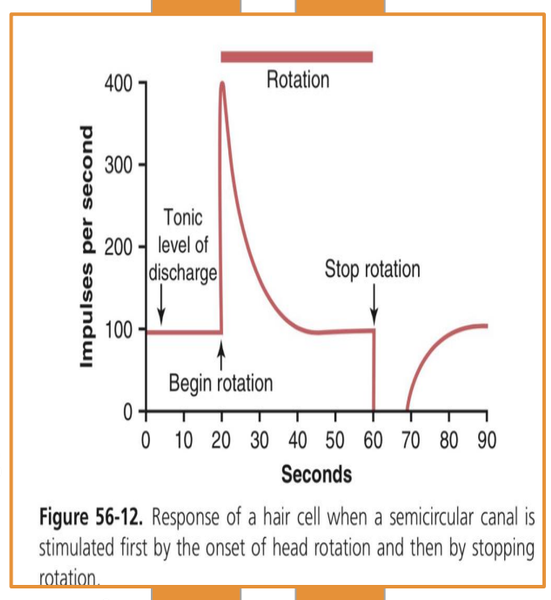


Figure 56-12. Response of a hair cell when a semicircular canal is stimulated first by the onset of head rotation and then by stopping rotation.

Figure 19-19

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

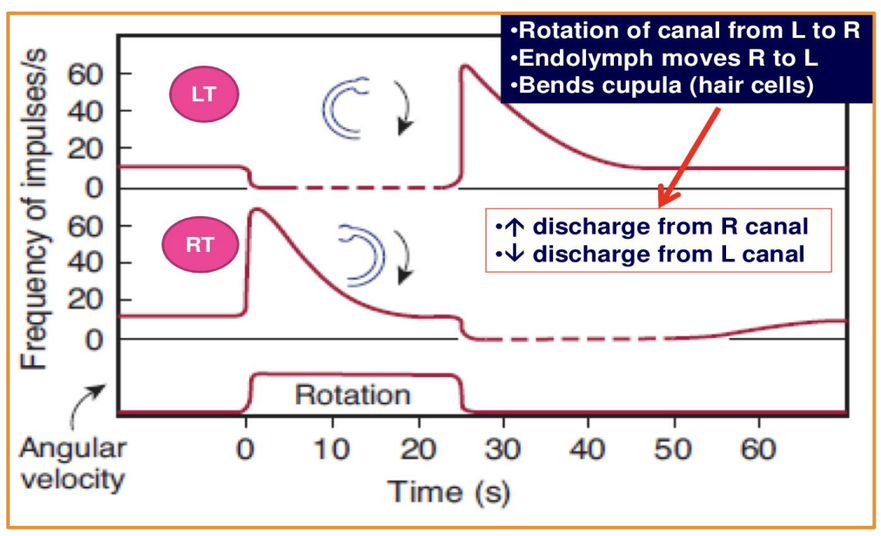


Figure 19-20

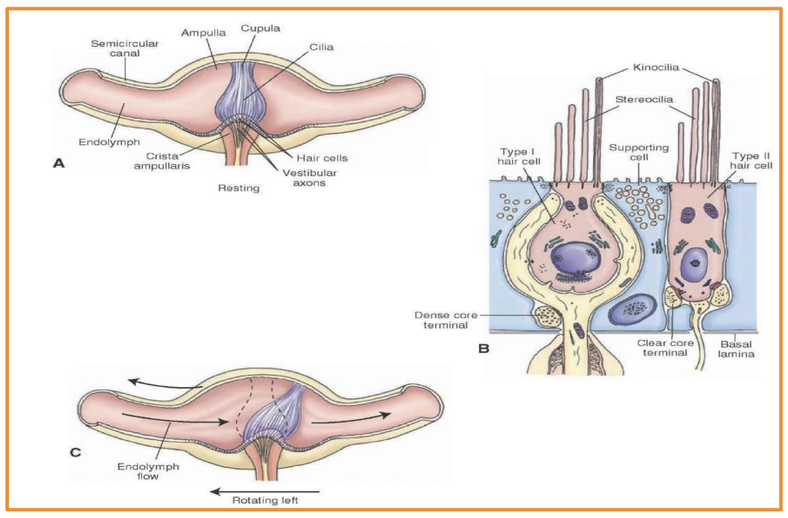


Figure 19-21

- When you move your head **rightward**, the cristae on **right** side will be stimulated "depolarized", it means the stereocilia are bending towards the kinocilium. While the cristae on the **left** semicircular canal is hyperpolarized.
- Whenever in space your head is having *Angular movement*, the rate of movement of fluid within the semicircular duct alters. This changes the bending of the cristae which alters the electrical signals that are transmitted to the brain.

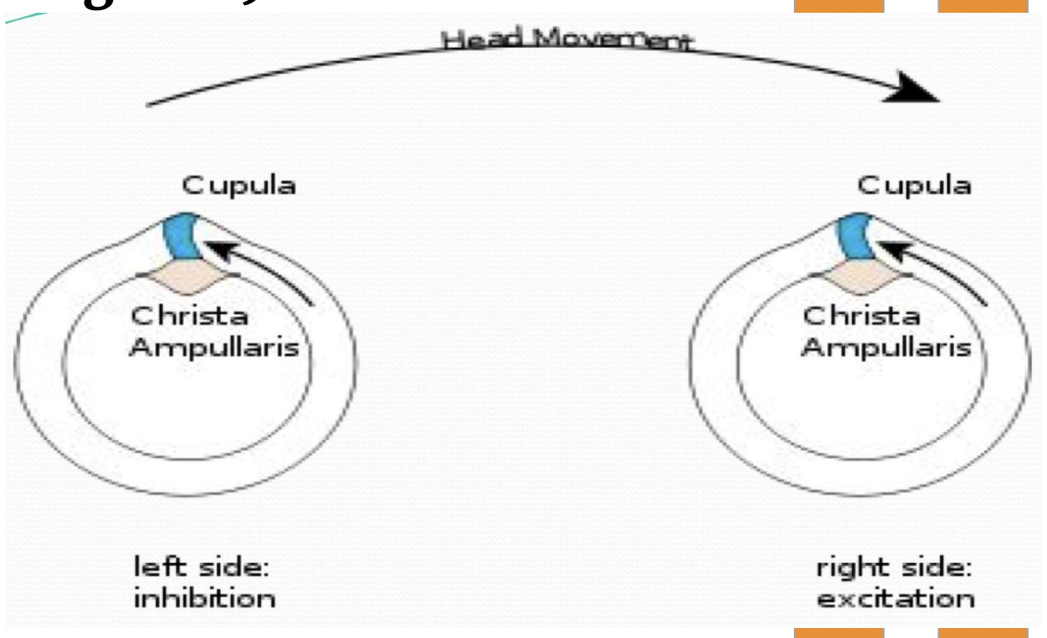


Figure 19-22

VESTIBULAR PATHWAY

Neural Connections:

- Nerve fibers from maculae & cristae ampullaris ➔ Vestibular nerve ➔ ipsilateral vestibular nuclei on either sides of the brainstem send signal to:

1. Cerebellum: flocculonodular lobe
2. Motor nuclei of cranial nerves III, IV, and VI (to lateral & medial rectus)
3. Reticular formation (spinal cord)*
4. Spinal cord (vestibulospinal tracts)*

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

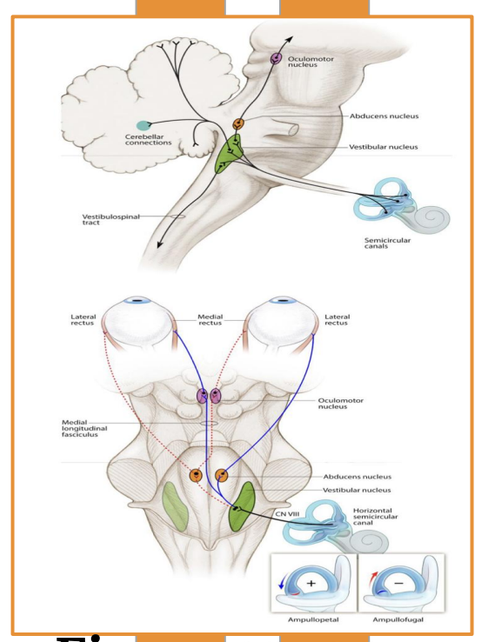


Figure 19-23

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

2. Rotation test

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

★ 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 DISORDER

Benign paroxysmal positional vertigo (BPPV)(BOX 19-1)

2

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

★ Canalith repositioning.

Motion sickness

1

- Produced by excessive vestibular stimulation.

Meniere disease

3

- 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).

Space motion sickness

4

- (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.

Effects of stimulation of semicircular canals (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

QUIZ

MEDICINE438's
CNSPHYSIOLOGY

1. Utricle detect balance in:
A) Horizontal direction
B) Vertical direction
C) Horizontal & vertical

2. Which one of the following respond to gravity and head tilt?
A) Macula
B) Organ of corti
C) Crista ampullaris

3. Macula of saccule detect balance in which direction?
A) Horizontal
B) Vertical
C) Both A&B

4. Which one of the following structure detect rotation of the lateral movement of the head “anterior-posterior axis”?
A) Anterior semicircular canal
B) Posterior semicircular canal
C) Horizontal semicircular canal

5. Disorder produced by excessive vestibular stimulation:
A) Meniere disease
B) Motion sickness
C) Deafness

SHORT ANSWER QUESTIONS

1) Mention 3 differences between utricle & Saccule

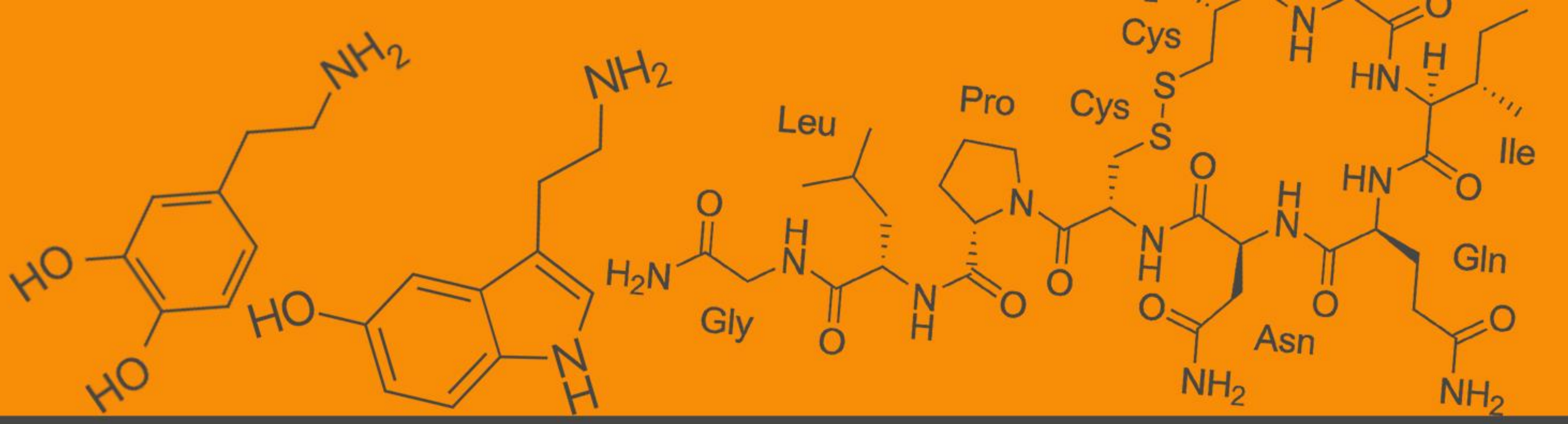
2) The vestibular nuclei on either sides of the brain stem send signal to:

3) Mention 3 of vestibular disorders :

1) Table in page 5
2)
- Cerebellum.
- Nuclei of cranial nerves III, IV, and VI
- Reticular formation (spinal cord)
- Spinal cord (vestibulospinal tracts)
- Thalamus

3) Motion sickness, Meniere disease, Benign paroxysmal positional vertigo (BPPV)

ANSWER KEY: A, A, C, B, B



THIS LECTURE WAS DONE BY

Sarah Alhelal, Nouf Alhumaidhi

FEMALE PHYSIOLOGY CO-LEADERS

Maha Alnahdi, Ghaliah Alnufaei

MALE PHYSIOLOGY CO-LEADERS

Nayef Alsaber, Hameed M. Humaid

PRESENTED BY

MEDICINE438's CNSPHYSIOLOGY

REFERENCES

- Guyton and Hall Textbook of Medical Physiology
- Ganong's Review of Medical Physiology