



بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

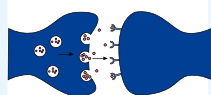


الجهاز الدهليزي Vestibular System

MID | Lecture 9

﴿ إِنِّي تَوَكَّلْتُ عَلَى اللَّهِ رَبِّي وَرَبِّكُمْ مَا مِنْ دَابَّةٍ إِلَّا هُوَ آخِذٌ بِنَاصِيَتِهَا إِنَّ رَبِّي عَلَى صِرَاطٍ مُسْتَقِيمٍ ﴾

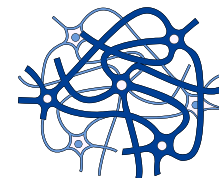
تدقيق: المثني خليل



كتابة: منيب العربيات
مازن النشاش



Physiology



رحلة اليقين مع سورة يس

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

وَعَايَةٌ لَهُمُ اللَّيْلُ نَسَلَخُ مِنْهُ النَّهَارَ فَإِذَا هُمْ مُظْلِمُونَ ﴿٣٧﴾

أي: {وَأَيَّةٌ لَهُمْ} على نفوذ مشيئة الله، وكمال قدرته، وإحيائه الموتى بعد موتهم. {اللَّيْلُ نَسَلَخُ مِنْهُ النَّهَارَ} أي: نزيل الضياء العظيم الذي طبق الأرض، فنبدله بالظلمة، ونحلها محله {فَإِذَا هُمْ مُظْلِمُونَ} وكذلك نزيل هذه الظلمة، التي عمتهم وشملتهم، فتطلع الشمس، فتضيء الأقطار، وينتشر الخلق لمعاشهم ومصالحهم.

Neurophysiology

Vestibular system

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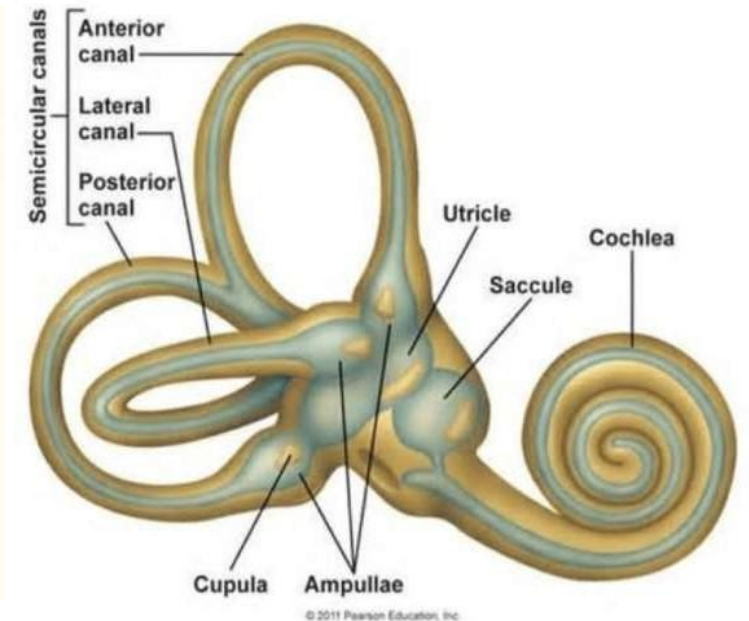
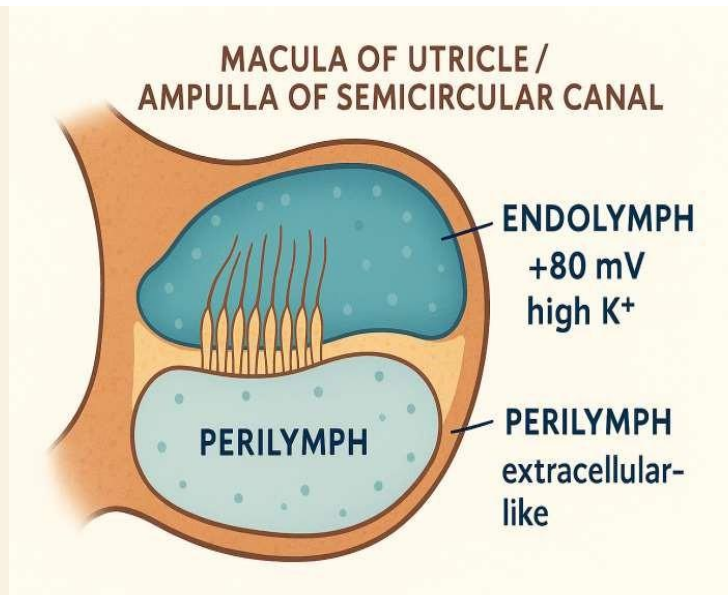
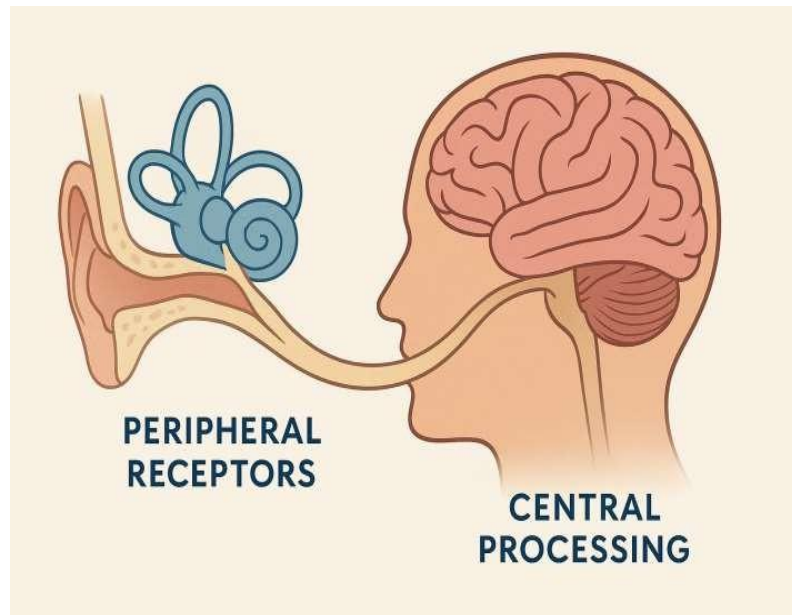
Vestibular System Physiology

- Balance • Motion • Gaze Stability



Functions of the Vestibular System

- Balance
- Spatial orientation
- Stable vision during movement



Introduction to the Physiology of the Vestibular System

The vestibular system provides continuous sensory inputs that allow the body to maintain balance, ensure spatial orientation, and keep vision stable during head movement. When dysfunction occurs in the vestibular system, it can produce symptoms such as vertigo, imbalance, and nausea.

1. Components of the Vestibular System

The vestibular system consists of two main components:

Peripheral sensory receptors: Located in the inner ear.

Central processing centers: Located in the brainstem and the cerebellum.

2. Fluids of the Inner Ear

The inner ear relies on two distinct types of fluid for its function:

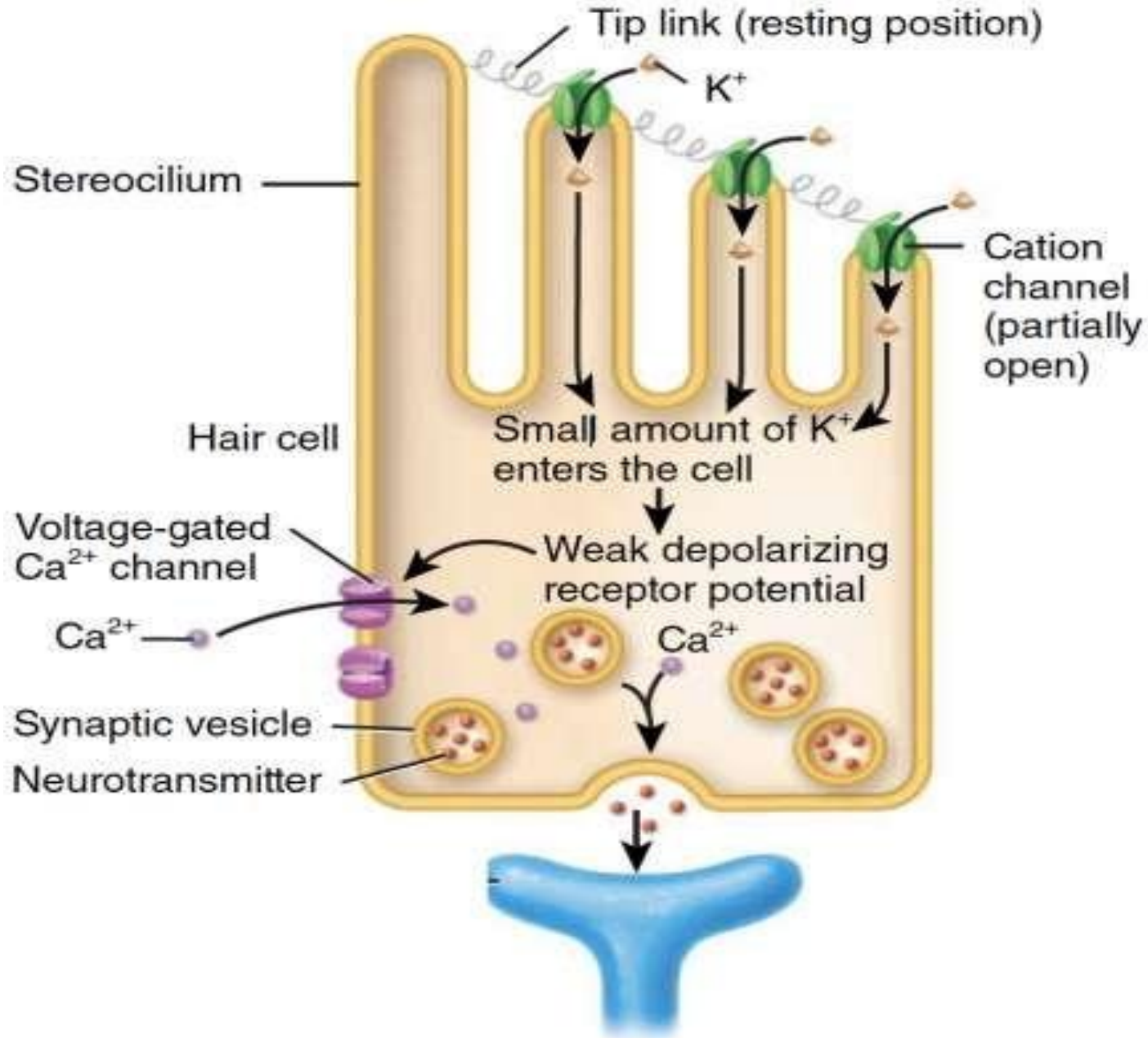
Endolymph: Found within the membranous labyrinth; it is rich in potassium.

Perilymph: Surrounds the membranous labyrinth (within the bony labyrinth); it is a fluid similar to the extracellular fluid.

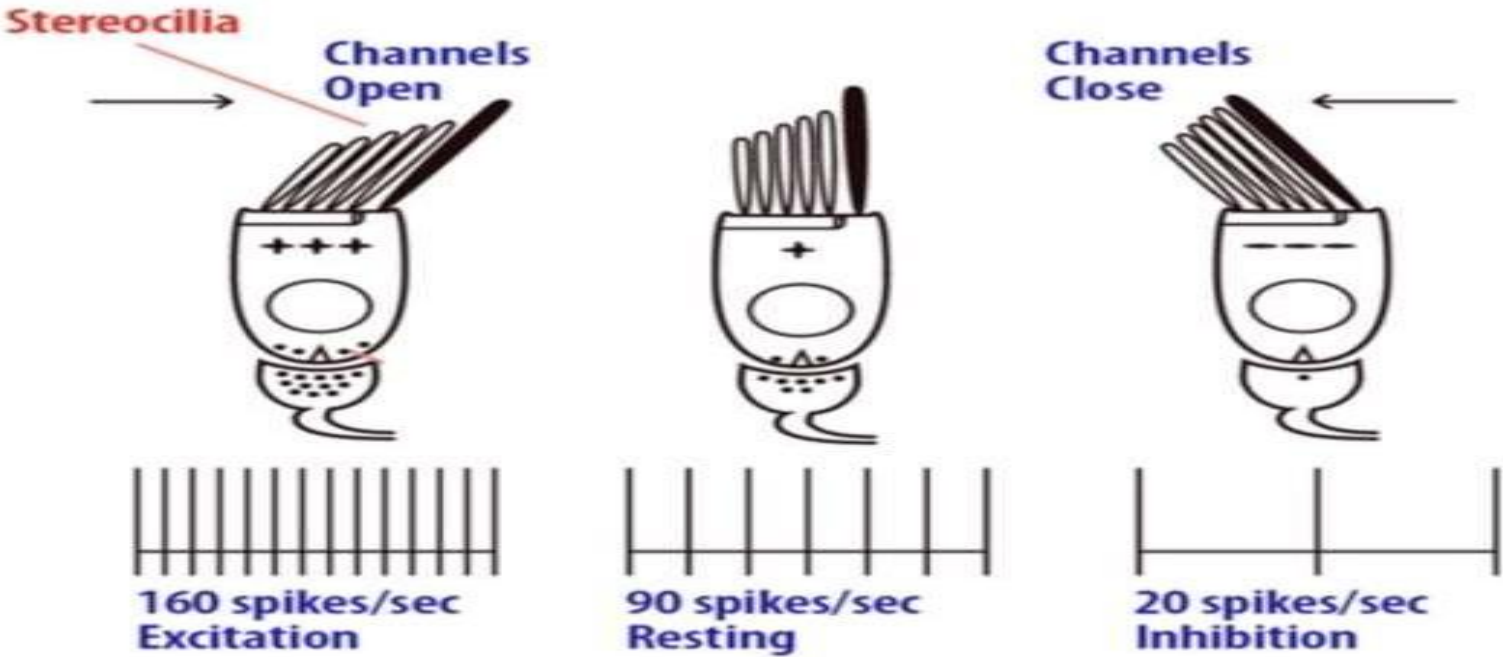
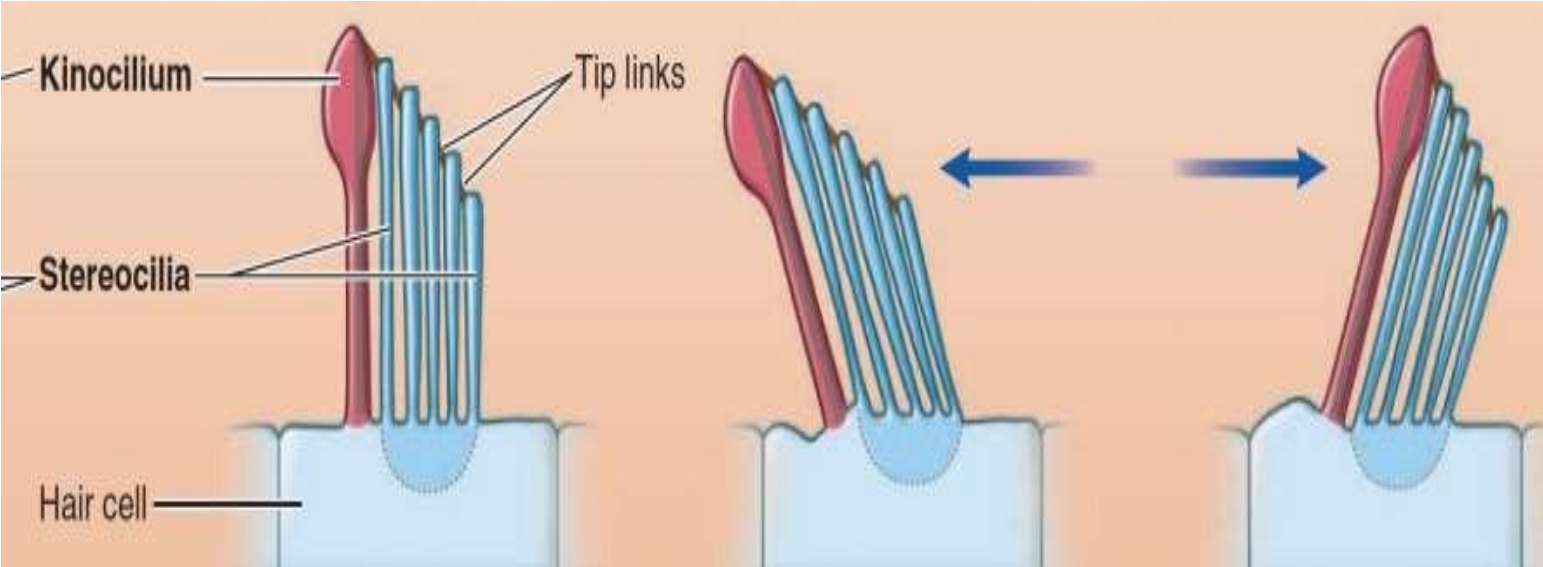
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Hair Cell Mechanotransduction

سبحان الله وبحمده سبحان الله العظيم



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Vestibular Sensory Organs and Hair Cell Physiology

1. Vestibular Sensory Organs

The vestibular system relies on specific structures to detect different types of movement:

Three Semicircular Canals: Detect angular acceleration (rotation).

Two Otolithic Organs: Include the **Utricle** and **Saccule**, which detect linear acceleration and head tilt.

2. Vestibular Hair Cells (Mechanoreceptors)

These cells are the functional units of the vestibular system. Their structure is specialized for detecting mechanical force:

Structure: They contain multiple **stereocilia** arranged in ascending height and a single, tallest hair called the **kinocilium**.

Directionality: The position of the kinocilium is crucial as it determines the **excitatory direction** of the cell.

3. Electrochemical Gradient

The activation of these cells depends on the unique electrical environment of the inner ear:

Potentials: The **endolymph** has a positive potential of about **80 millivolts**, while the **interior of the hair cells** is negative.

Driving Force: This significant difference creates a strong **electrochemical gradient** that favors the entry of **potassium** into the hair cells.

4. Mechanism of Hair Cell Activation

The firing of the vestibular nerve is controlled by the physical bending or deflection of the stereocilia:

Depolarization (Excitation): Deflection of stereocilia **toward** the kinocilium opens mechanically gated potassium channels. This causes **depolarization** and leads to an **increase** in vestibular nerve firing.

Hyperpolarization (Inhibition): Deflection of stereocilia **away from** the kinocilium closes mechanically gated potassium channels. This causes **hyperpolarization** and leads to a **decrease** in vestibular nerve firing.

5. Baseline Activity of Vestibular Afferents

It is important to note that vestibular nerves are always firing, even when no sound is detected:

Resting State: Vestibular afferents fire **continuously at rest**, which is known as the baseline firing rate.

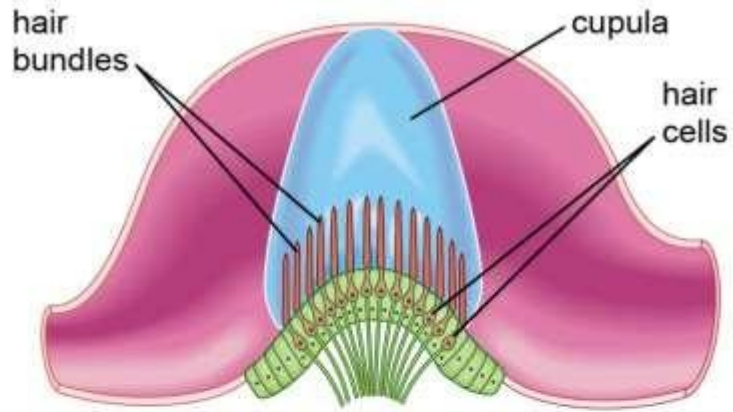
Encoding Movement: Head movement is encoded by **changes** in the firing rate relative to the baseline. This means movement is perceived through either an **increase** or a **decrease** in the firing rate.

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Semicircular Canals

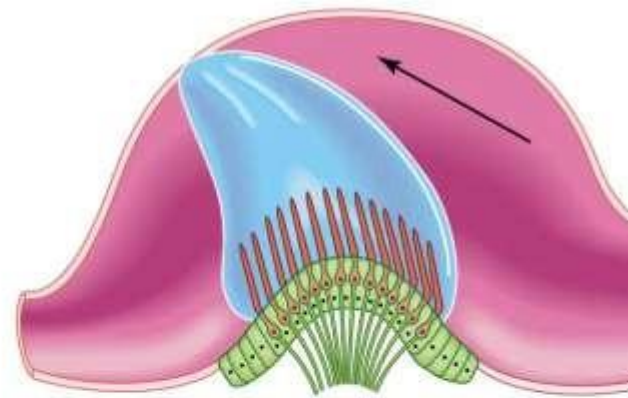
- Detect angular acceleration



stationary section
of the crista
of the horizontal canal



stationary



rotating section
of the crista
of the horizontal canal



rotating

Function of the Semicircular Canals

1. Detection of Angular Movement

- The semicircular canals are specialized to detect **angular (rotational) acceleration and deceleration**.
- **The Receptor Site:** The receptor cells are located in a specific area called the **ampulla**.
- **Internal Structure:** Inside the ampulla, the cilia of the hair cells are embedded in a gelatinous material called the **cupula**, which is entirely surrounded by **endolymph**.

2. Baseline Condition (No Stimulation)

At baseline, the system remains in a state of equilibrium:

- When the head is **stationary** or moving at a **constant velocity**, the hair cells are not stimulated.
- As a result, they fire at their steady **baseline rate**.

3. Effect of Head Rotation

When the head begins to rotate in a certain direction, the following mechanical sequence occurs:

- **Inertia:** The endolymph lags behind the movement of the canal due to its inertia.
- **Bending:** This lagging fluid causes the **cupula to bend** in the opposite direction of the head rotation.
- **Deflection:** The bending of the cupula leads to the **deflection of the stereocilia** of the hair cells.
- **Response:** This deflection results in a **change in the firing rate** (either an increase or decrease) of these cells.

4. Adaptation During Continued Rotation

As the rotation continues at a steady pace:

- The endolymph gradually **catches up** with the movement of the canal.
- The cupula returns to its **resting (stationary) position**, and the firing rate returns toward the baseline.

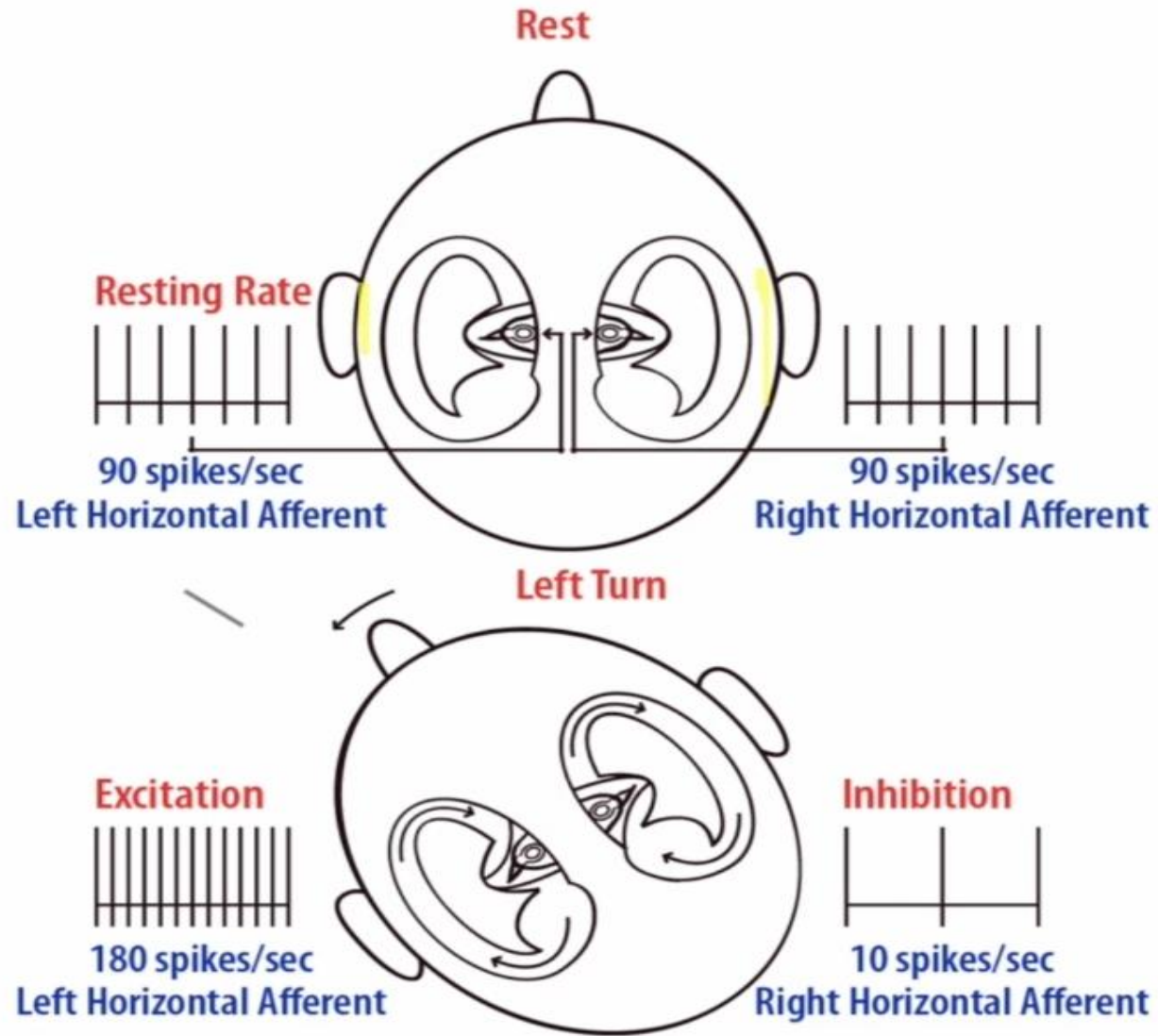
5. End of Movement

When the head suddenly stops moving:

- **Continued Flow:** The endolymph continues moving briefly due to inertia.
- **Reverse Bending:** This causes the cupula to bend in the **original direction** of the head movement.
- **Final Change:** This secondary bending again changes the firing rate of the hair cells, signaling to the brain that the movement has stopped.

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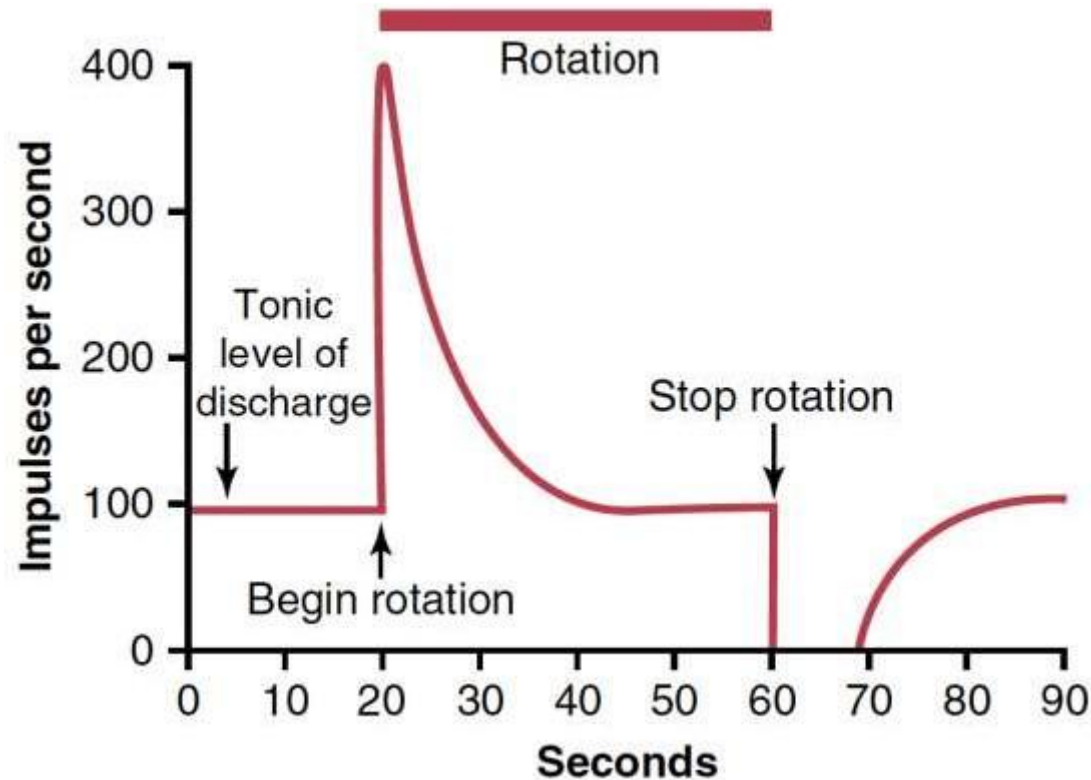


- Remember that we have **two inner ears**, and each one contains **three semicircular canals** that are oriented in space **perpendicular to each other**. These semicircular canals work in **functional pairs**, meaning that **movement excites one side while inhibiting the opposite side**, allowing **precise detection of head rotation**.
- At **rest**, the **horizontal semicircular canal on the right side** is not stimulated, so the **spikes represent the baseline firing rate** of the hair cells located in the **ampulla**. Similarly, the **hair cells in the ampulla of the left horizontal semicircular canal** are also at rest and therefore **fire at the same baseline rate**.
- As shown in the *diagram in the slide before*, when the **head turns to the left**, this movement causes **bending of the hair cells in the left horizontal semicircular canal**, resulting in **excitation and an increase in the firing rate**. On the **opposite side**, the **hair cells in the right horizontal semicircular canal** show a **decrease in their firing rate**, which represents **inhibition of the signal from that side**.
- Because **one side increases its firing rate while the other side decreases**, the **central nervous system is able to detect the direction of head rotation accurately**.

See next slides

Canal Adaptation

- Respond to acceleration, Not constant velocity.



Chronological Sequence of Canal Adaptation

1. Baseline State (Tonic Discharge)

Condition: The head is stationary (no movement).

- **Neural Activity:** Hair cells are not "silent"; they fire at a steady, constant baseline rate.
- **Example:** In the diagram, this is shown as a **Tonic level of discharge at 100 impulses per second.**

2. Initiation of Movement (Angular Acceleration)

Condition: The head begins to rotate suddenly.

- **Mechanism:** Due to **inertia**, the endolymph fluid lags behind the canal's movement, causing the **cupula to bend.**
- **Neural Activity:** There is a sharp **increase in the discharge rate** of the hair cells (e.g., jumping from 100 to 400 impulses per second).

3. Sustained Rotation (Adaptation Phase)

Condition: Rotation continues at a **constant speed** (constant velocity).

- **Mechanism:** The endolymph gradually "catches up" with the canal, and the cupula returns to its resting position.
- **Neural Activity:** The discharge rate **gradually decreases back to baseline** (100 impulses/sec), even though the rotation is still happening. This phenomenon is called **Canal Adaptation**.

4. Sudden Stop (Deceleration)

Condition: The rotation stops abruptly.

- **Mechanism:** The endolymph continues to move briefly due to momentum, causing the cupula to bend in the **opposite direction**.
- **Neural Activity:** A change in discharge occurs again, but this time in the **opposite direction** (dropping below the 100 baseline). This conflict causes **post-rotatory vertigo**.

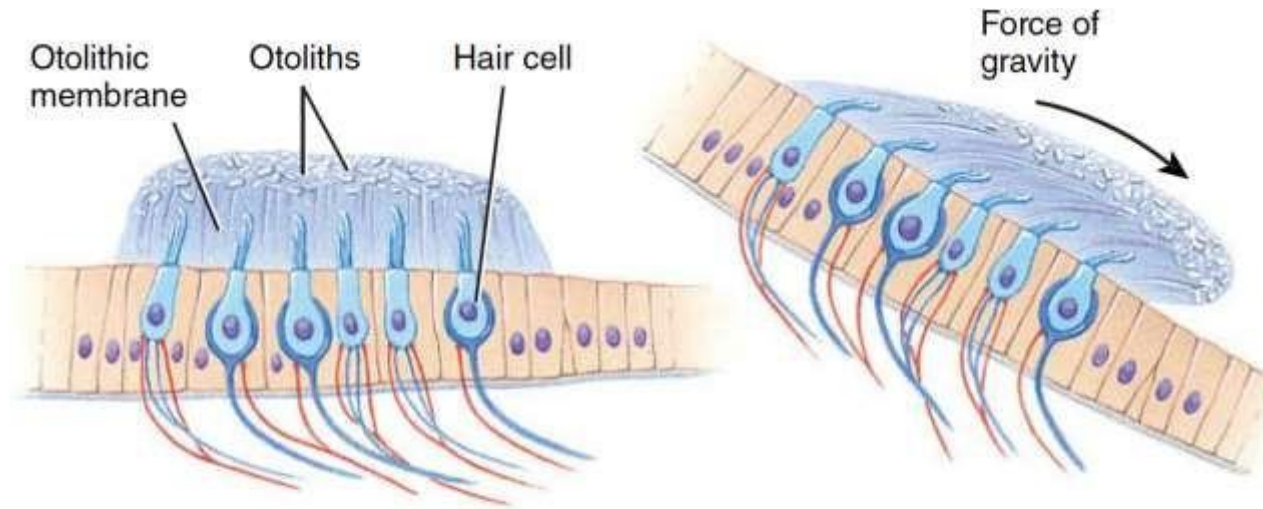
5. Recovery

Condition: The head remains stationary after the stop.

- **Neural Activity:** The firing rate gradually returns to the **baseline rate** as the fluid settles.

See next slide

Otolith Organs



Head upright



Head tilted forward

The Otolith Organs: Utricle and Sacculle

While the semicircular canals detect rotation, these organs are specialized to detect **linear acceleration** and **head position relative to gravity**.

1. Key Structures

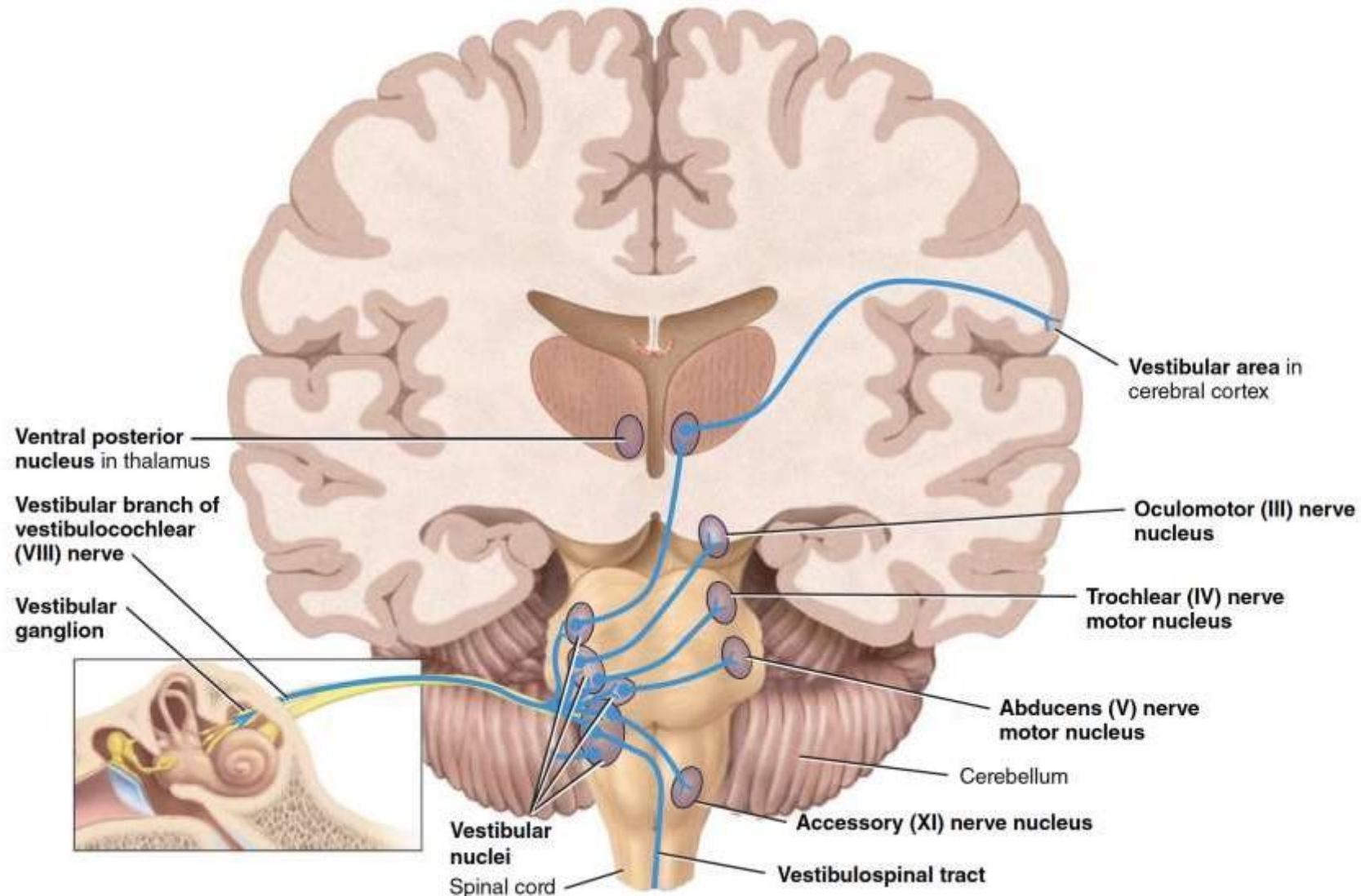
- **Macula:** The specific sensory area where the hair cells are located.
- **Otolithic Membrane:** A gelatinous layer covering the hair cells in which the stereocilia are embedded.
- **Otoliths:** Calcium carbonate crystals located on the surface of the membrane that provide the necessary mass to respond to gravity.

2. Mechanism of Action

- **Upright Position:** When the head is straight, the hair cells remain upright within the membrane.
- **Head Tilt:** When the head tilts (e.g., downward), the force of **gravity** acts on the heavy **Otoliths**.
- **Signal Transduction:** This causes the membrane to drag and **bend the stereocilia**, which changes the **firing rate** of the hair cells to signal the new head position to the brain.

See next slides

Central Vestibular Processing



Processing Vestibular Signals (1)

1. Signal Origin and Transmission

The vestibular system in the inner ear generates the initial signals. The **Semicircular canals** detect head rotation, while the **Otolithic organs**, specifically the **Utricle** and **Saccule**, detect linear movement and head tilt. These signals travel through the vestibular branch of the vestibulocochlear nerve until they reach the **Vestibular nuclei** located in the brainstem.

2. Sensory Integration in the Vestibular Nuclei

The **Vestibular nuclei** are clusters of neurons in the brainstem that act as a processing center. To create a complete picture of your position in space, vestibular information is integrated with other sensory inputs:

Visual inputs from the eyes.

Proprioceptive inputs from the muscles, joints, and skin.

Processing Vestibular Signals (2)

3. The Role of the Cerebellum

A portion of these signals is sent to the **Cerebellum**, which is crucial for coordinating physical responses.

4. Functional Importance

This complex integration system is vital for three main reasons:

Perception of motion: It allows you to know exactly how your head and body are oriented.

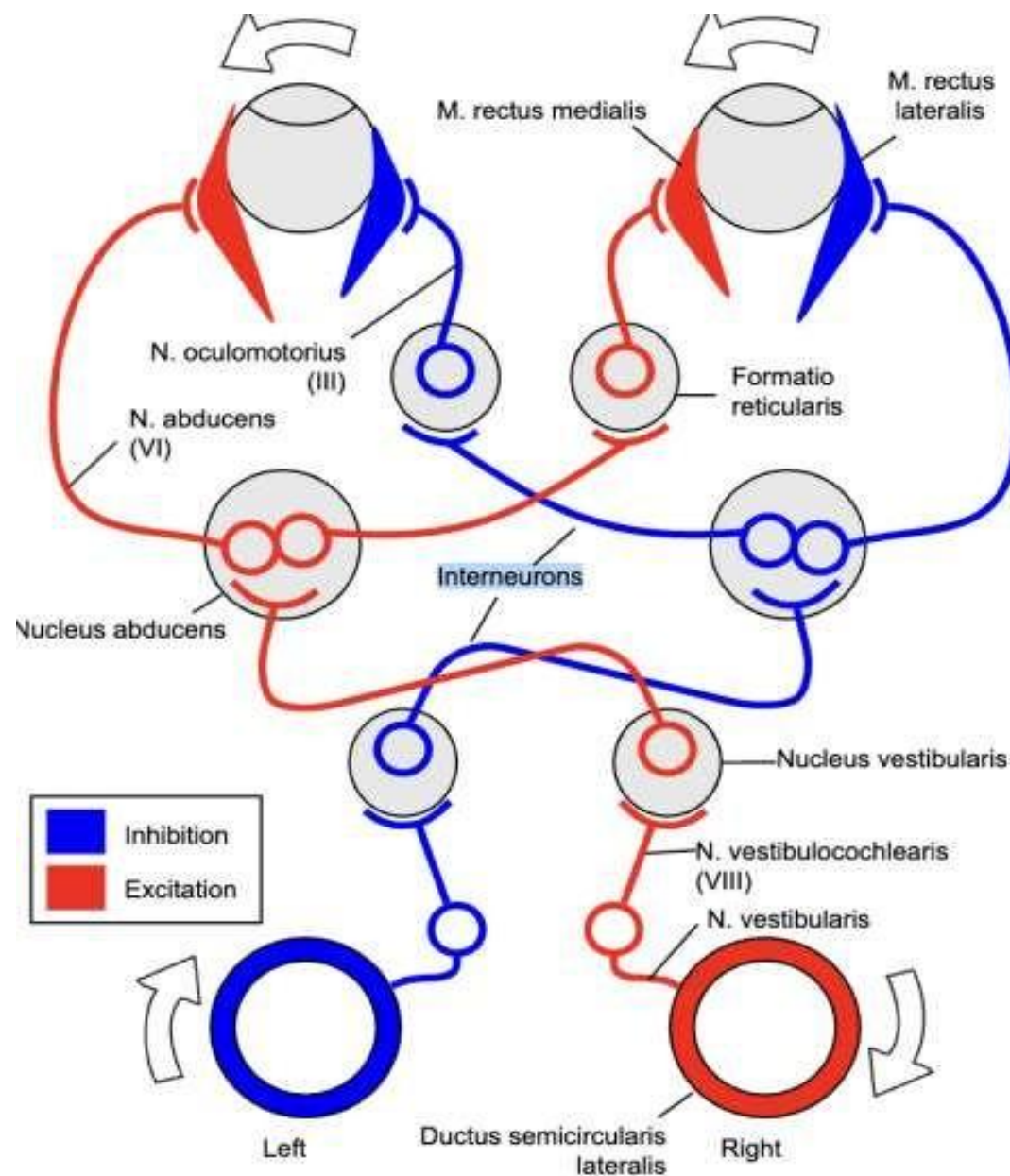
Balance maintenance: It helps you stay upright.

Gaze stability: It keeps your vision stable and focused even when the head moves.

Vestibulo-Ocular Reflex

See next slide

- Stabilizes vision



- The **vestibulo-ocular reflex (VOR)** stabilizes vision by producing eye movements **equal in magnitude** and **opposite in direction** to head movements.
- In this example, the **red color** represents **excitation** while the **blue color** represents **inhibition**. When the head rotates to the right side, the **right horizontal semicircular canal** becomes **excited**, and this excitation is transmitted to the **vestibular nucleus** on the **right** side. The vestibular nucleus then sends signals to the **left abducens nucleus** in the brainstem, which **excites** the **abducens nerve**, leading to **contraction** of the **left lateral rectus** muscle. It also sends signals that **activate** the **medial rectus** muscle in the **right** eye, allowing coordinated movement of the eyes.
- At the same time, because the head rotates to the right, the **left horizontal semicircular canal** is **inhibited**. From the **left vestibular nucleus**, inhibitory signals are sent that reach the **medial rectus** of the **left** eye and the **lateral rectus** of the **right** eye.
- As a result, rotation of the head to the right side causes the eyes to rotate to the left side. This reflex is very important because it allows gaze fixation, maintaining focus on a specific object even while the head is rotating, which prevents the visual world from appearing blurry or shaky during everyday movements, and it also helps maintain overall body balance

Vestibulospinal Reflexes

- Posture
- Extensor tone

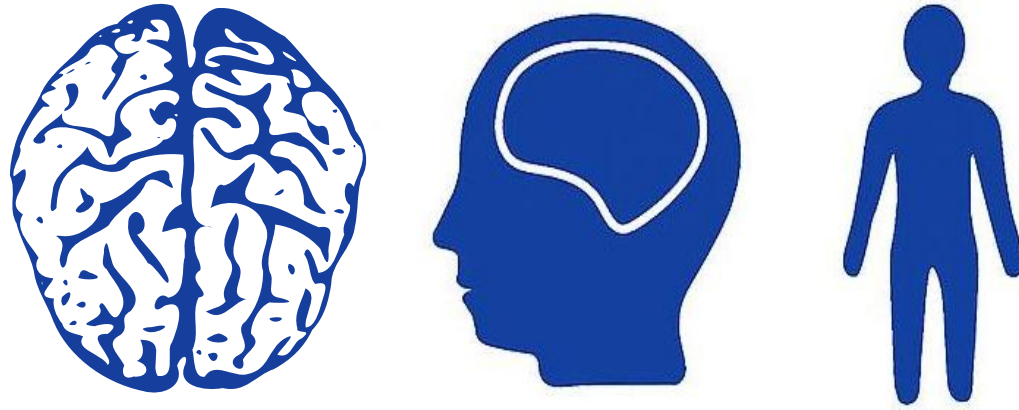
The **vestibulospinal pathways or reflexes** regulate **extensor muscle tone** and help maintain an **upright posture**. These reflexes trigger **compensatory body movements** to prevent falling when the **head tilts** or the **body sways**. They also **increase anti-gravity muscle tone**, particularly in the **legs and trunk**, to keep the body upright against the **constant pull of gravity**. If the body is **pushed**, the **vestibulospinal reflex** initiates a strategy to **quickly reposition the center of gravity**. Additionally, these reflexes **stabilize the head on the neck**, preventing it from wobbling while walking or running. More details about these reflexes are covered in **motor physiology**.

Key Clinical Principle

- Asymmetry = vertigo

Most **vestibular symptoms** result from **asymmetry in vestibular firing**, which the brain interprets as **movement**. Patients typically complain of **vertigo**, a specific type of dizziness characterized by a **false sensation of motion or spinning**.

Thank You



**PHYSIOLOGY
QUIZ
LECTURE 9**

رسالة من الفريق العلمي

اللهم إن عمر عطية في ذمتك وحبل جوارك، فقه من فتنة القبر وعذاب النار، أنت أهل الوفاء والحق، فاغفر له وارحمه إنك أنت الغفور الرحيم.

باب ما يقال عند الصباح والمساء:

روي في " صحيح البخاري " عن شداد بن أوس رضي الله عنه، عن النبي صلى الله عليه وسلم قال: " سَيِّدُ الْإِسْتِغْفَارِ: اللَّهُمَّ أَنْتَ رَبِّي لَا إِلَهَ إِلَّا أَنْتَ، خَلَقْتَنِي وَأَنَا عَبْدُكَ وَأَنَا عَلَى عَهْدِكَ وَوَعْدِكَ مَا اسْتَطَعْتُ، أَعُوذُ بِكَ مِنْ شَرِّ مَا صَنَعْتُ، أَبُوءُ لَكَ بِنِعْمَتِكَ عَلَيَّ، وَأَبُوءُ بِذَنْبِي فَاغْفِرْ لِي فَإِنَّهُ لَا يَغْفِرُ الذُّنُوبَ إِلَّا أَنْتَ، إِذَا قَالَ ذَلِكَ حِينَ يُمَسِّي فَمَاتَ مِنْ لَيْلَتِهِ دَخَلَ الْجَنَّةَ، أَوْ كَانَ مِنْ أَهْلِ الْجَنَّةِ، وَإِذَا قَالَ ذَلِكَ حِينَ يُصْبِحُ فَمَاتَ مِنْ يَوْمِهِ ... مثله " معنى أبوء: أقرُّ وأُعرف.

جاءت أم سليم إلى النبي صلى الله عليه وسلم، فقالت: يا رسول الله، علمني كلمات أدعو بهن، قال: «تسبحين الله عشراً، وتحمدينه عشراً، وتكبرينه عشراً، ثم سلي حاجتك، فإنه يقول: قد فعلت، قد فعلت».

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Corrections from previous versions:

Versions	Slide # and Place of Error	Before Correction	After Correction
V0 → V1			
V1 → V2			