THE ROYAL COLLEGE OF SURGEONS OF EDINBURGH

Vestibular Physiology

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Learning Objectives

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- Describe the vestibulo-ocular reflex and explain its purpose
- Understand why patients with vestibular disease have a hallucination of movement
- Describe the pathophysiology of vestibular evoked nystagmus

What does the balance system give us?

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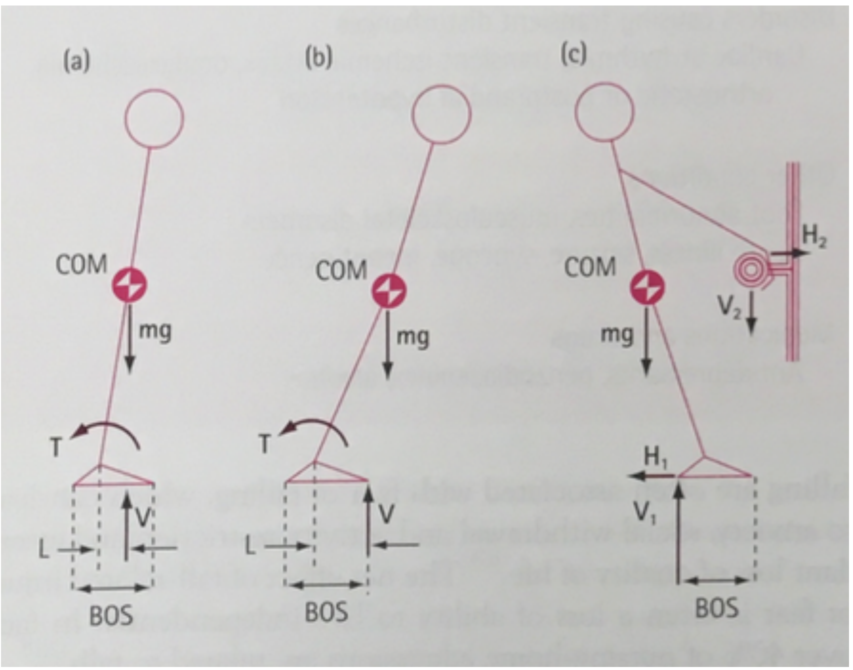
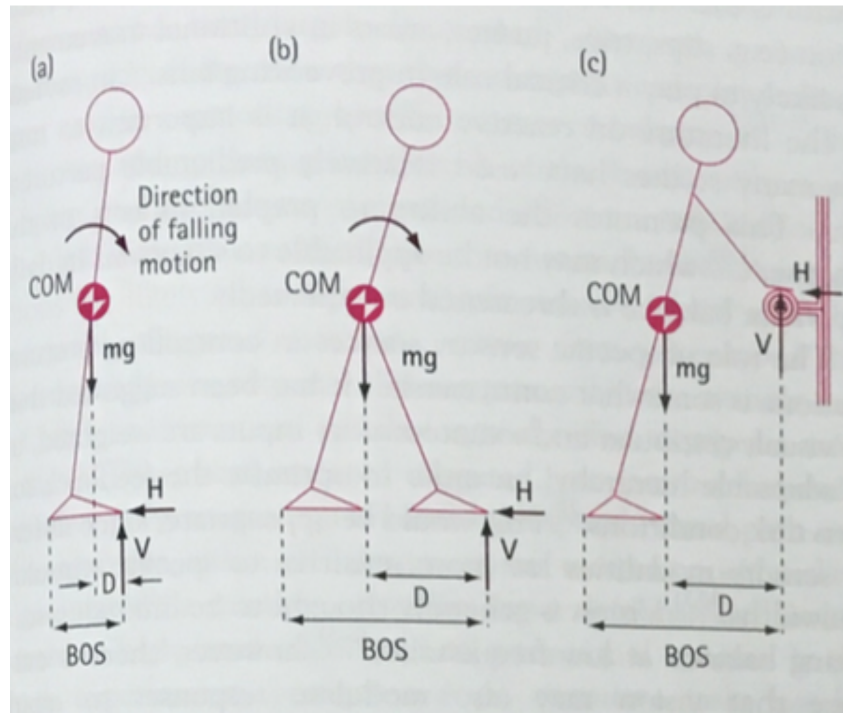
- Posture
  - Vertical, aligned with Gravity
  - Allows upright stance
- Equilibrium
  - Centre of Mass over Base of Support
- Mechanical support for action

Centre of Mass / Base of Support





Causes of Falls

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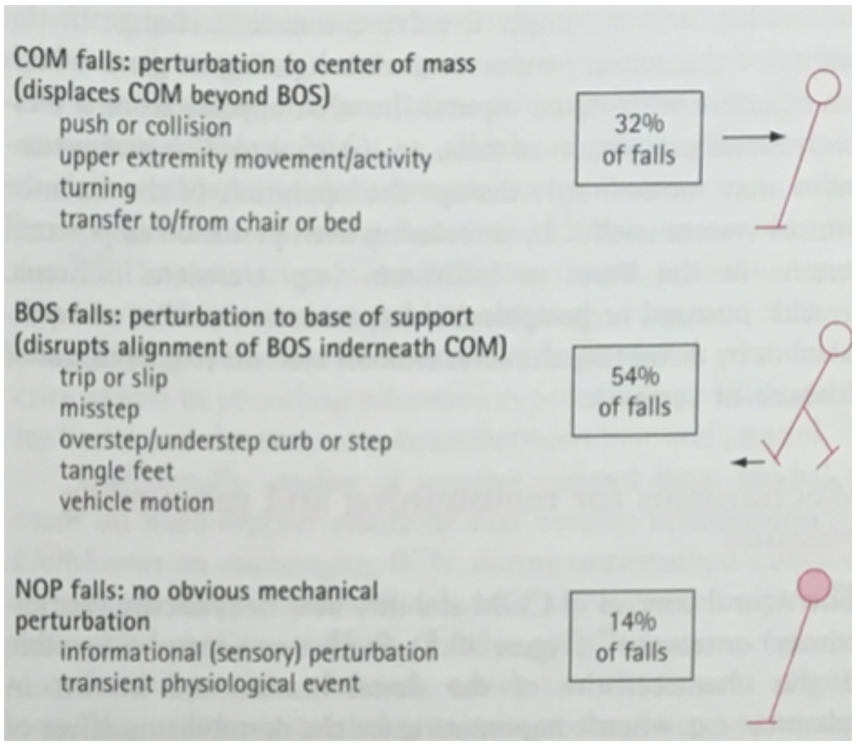
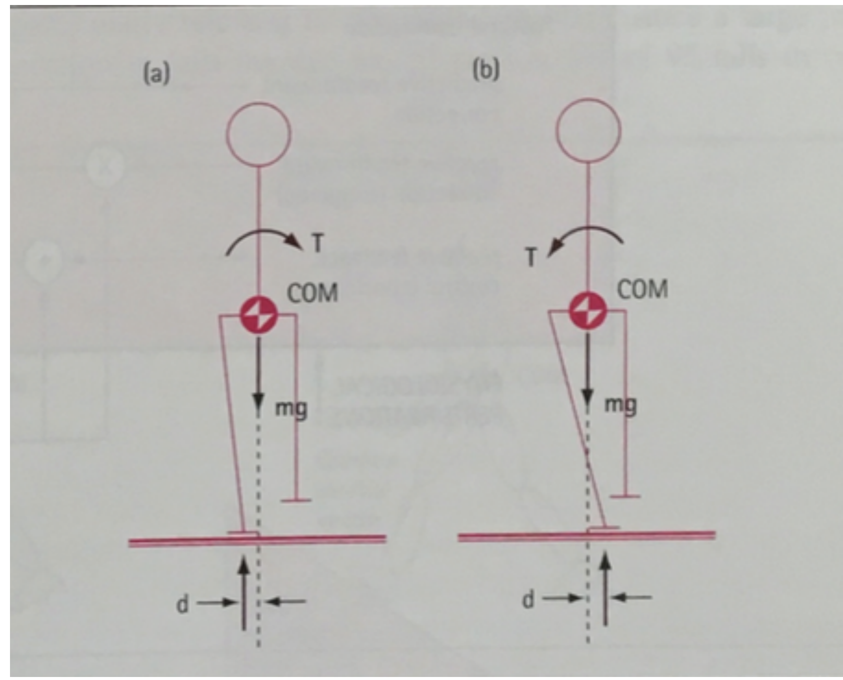
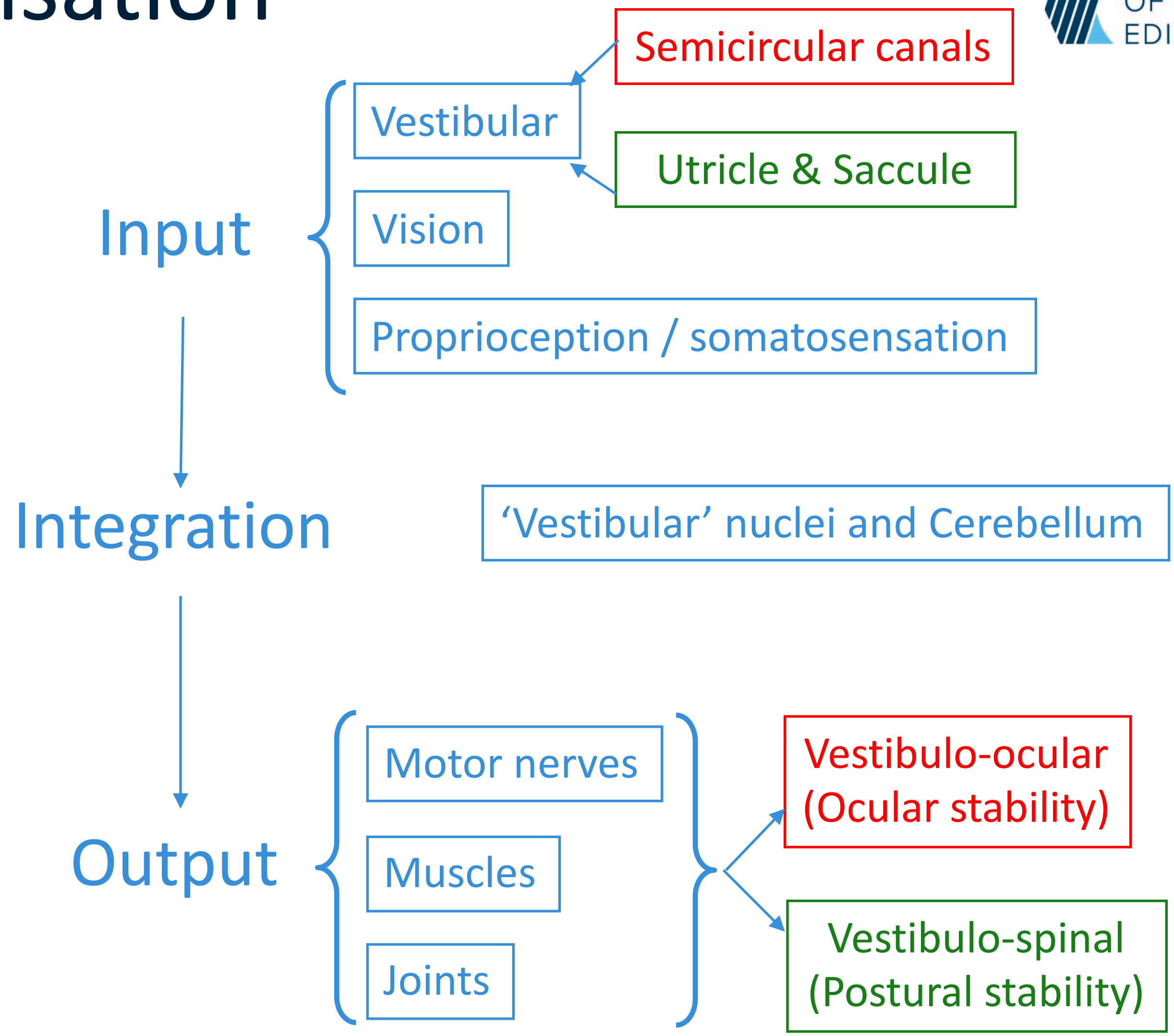




Organisation



Multisensory Convergence

- Sensory redundancy
- Sensory conflict
- Sensory dominance

Input - Vestibular

- The vestibular apparatus is, for the purposes of this tutorial, limited to the semicircular canals, the utricle and saccule.
- The semicircular canals are responsible for detecting rotational movements.
- The utricle and saccule detect linear movements (side-to-side, front-to-back) and gravity (up and down).

Anatomy

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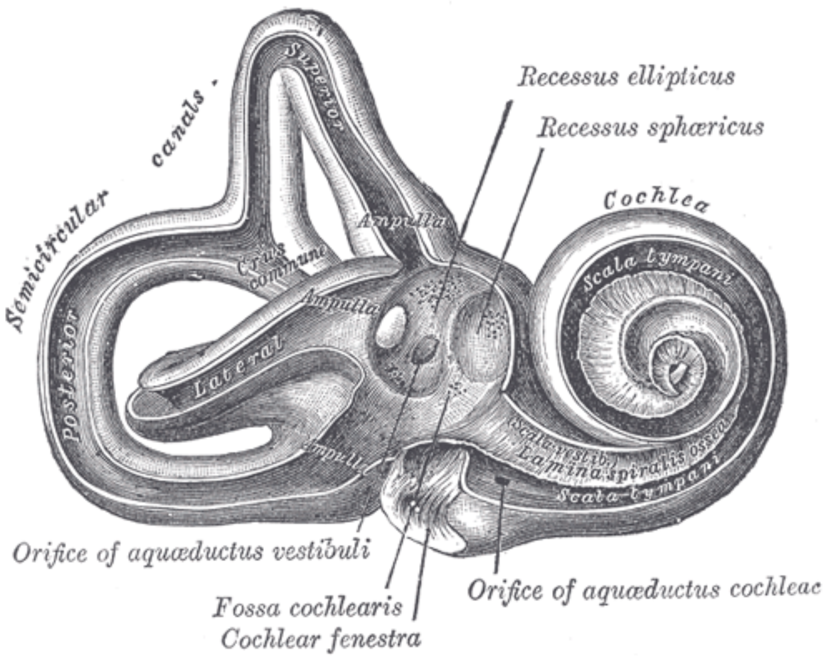
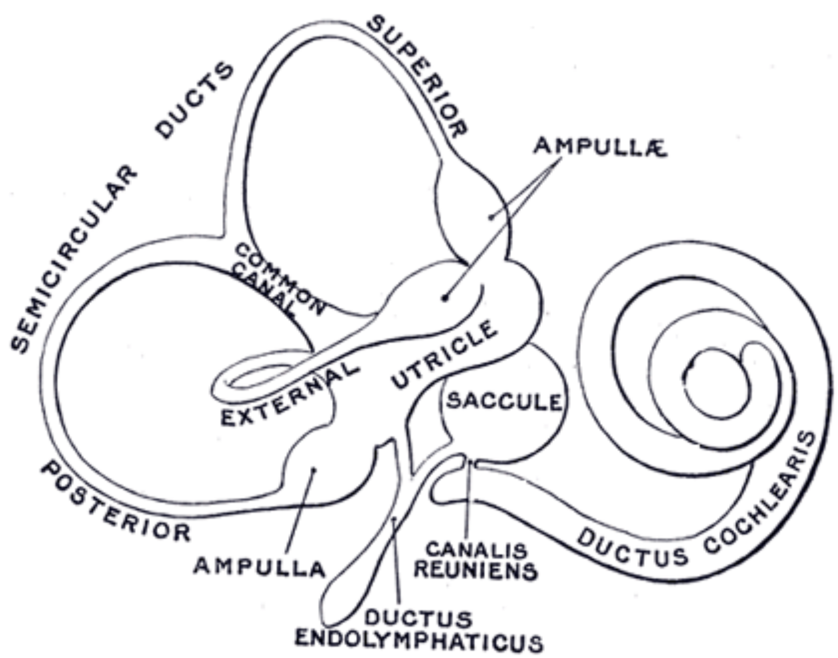
Bony Labyrinth

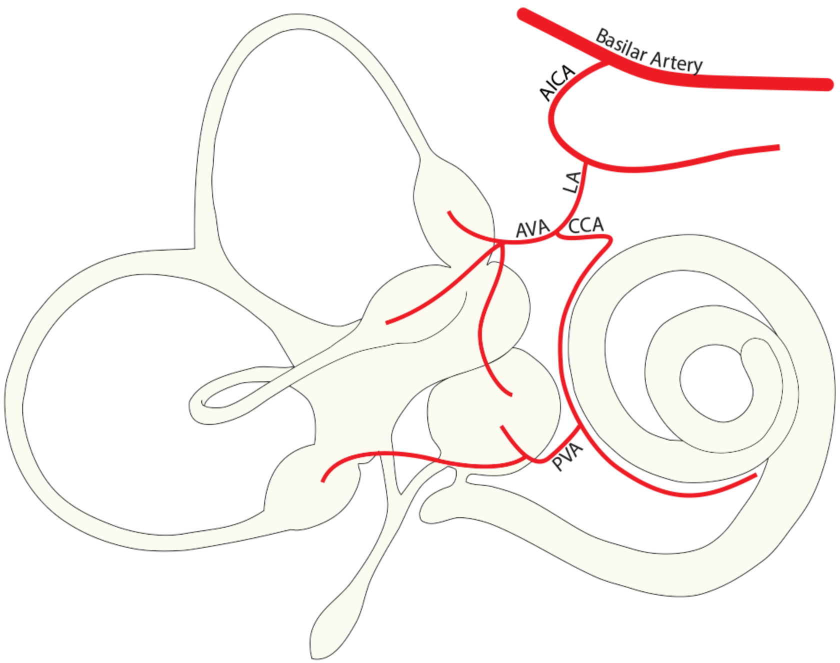


Membranous labyrinth



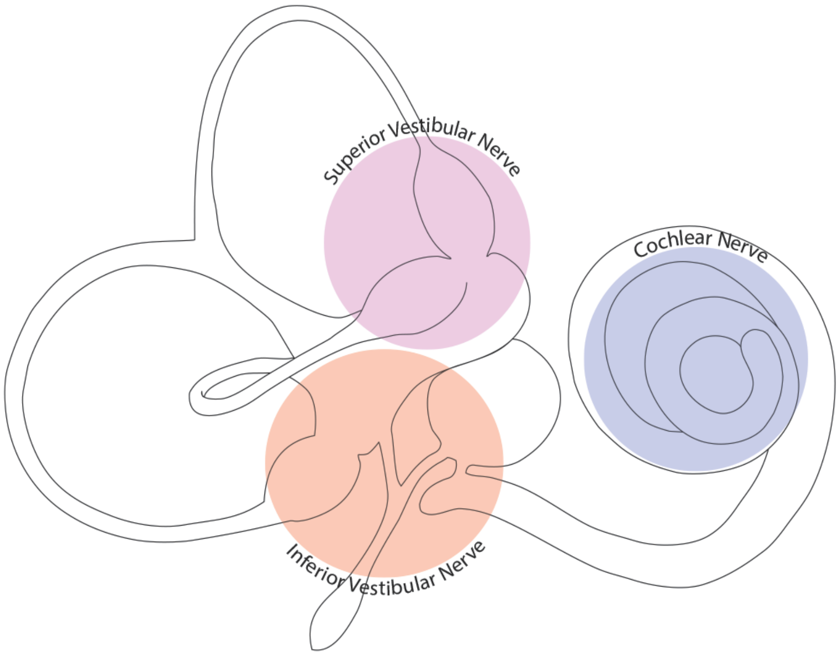
http://www.bartleby.com

Vascular Anatomy



- BA= basilar
- AICA=anterior inferior cerebellar
- CCA= common cochlear
- AVA= anterior vestibular
- PVA= posterior vestibular
- LA = labyrinthine
- End artery system

Nerve Anatomy



- Sup Vest Nerve – SSCC, LSCC, Utricle
  - Longer bony course
- Inf Vest Nerve – PSCC, Saccule
  - Short bony course
- Cochlear Nerve - Cochlea
  - Into modiolus

Inner Ear Fluids

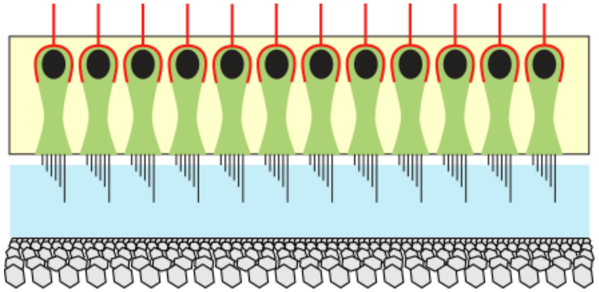
- Endolymph
  - Within membranous labyrinth
  - Bathes neuroepithelia of hearing and balance
  - Like intracellular fluid (Hign K, low Na)
  - Made within membranous labyrinth in ‘Dark’ cells
- Perilymph
  - Separates the membranous labyrinth from the bony labyrinth (c.f. Brain, CSF and skull)
  - Like extracellular fluid
  - Comes from CSF

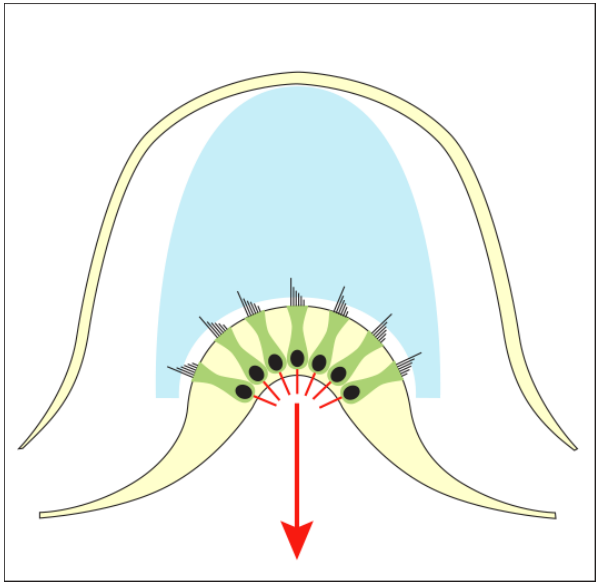
Endolymph - 'a biologic puddle'

- Current thinking is along these lines:
  - No flow of fluids (radial or longitudinal) normally.
  - Some local flow when electrolyte concentrations vary a little or when there is a small change in volume of fluid in one area of the labyrinth (like radial flow theory).
  - Large volume change or electrolyte changes handled by ELS (like longitudinal flow theory).

Salt A N. Regulation of endolymphatic fluid volume. Ann N Y Acad Sci 2001, 942:306-312
Gibson W. Hypothetical mechanism for vertigo in Meniere's disease. Otolaryngol Clin N Am 43 (2010) 1019-1027

Neuroepithelia





- Linear movement is detected by maculae within the utricle and saccule (top).
- Angular movement is detected by semicircular canals (bottom).
- Both neuroepithelia consist of hair cells that work in the same way.

Hair cell Physiology

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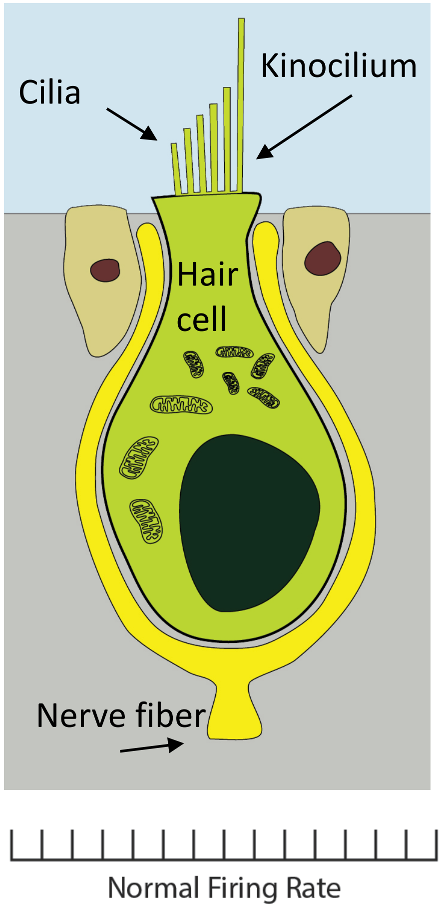

- How does the ear change movement into neural activity?
- This is done in the hair cell. The hair cell has a cell body from which project cilia of varying length and a long kinocilium. The hair cell is closely related to a nerve fiber of the vestibular nerve.
- When the cilia are undistorted the cell undergoes repeated depolarisation and release of neurotransmitter.
- The neuron repeatedly discharges in response to this. This is called a tonic discharge.
- This is a type I hair cell

Hair cell Physiology

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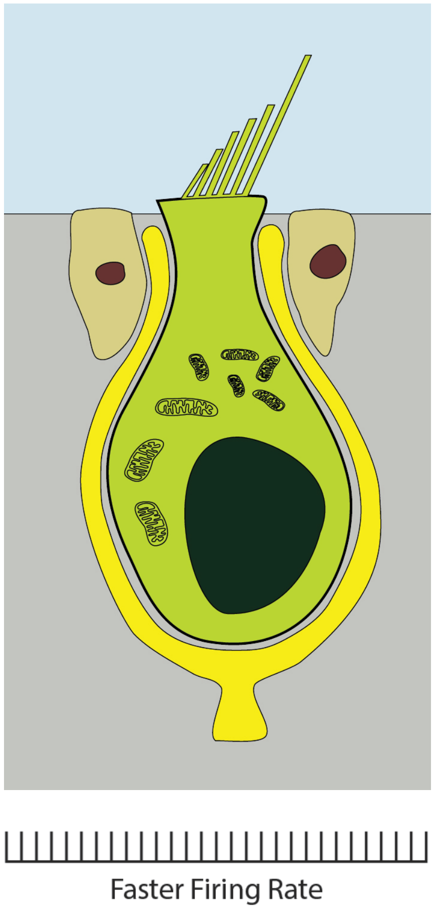
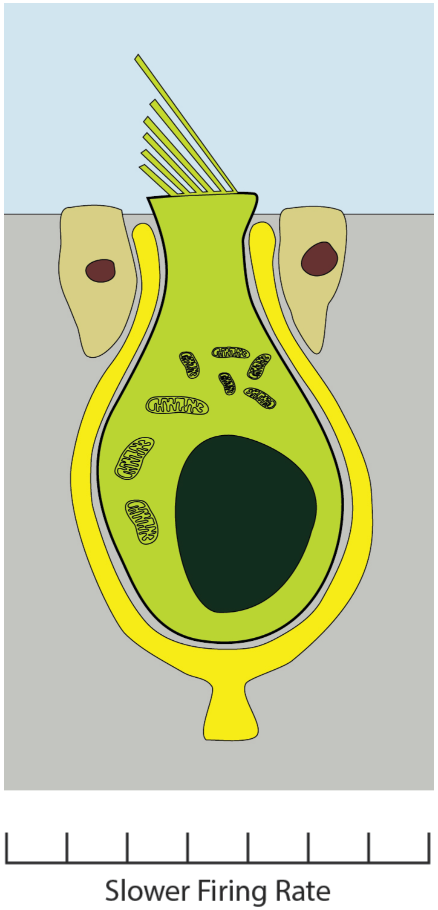


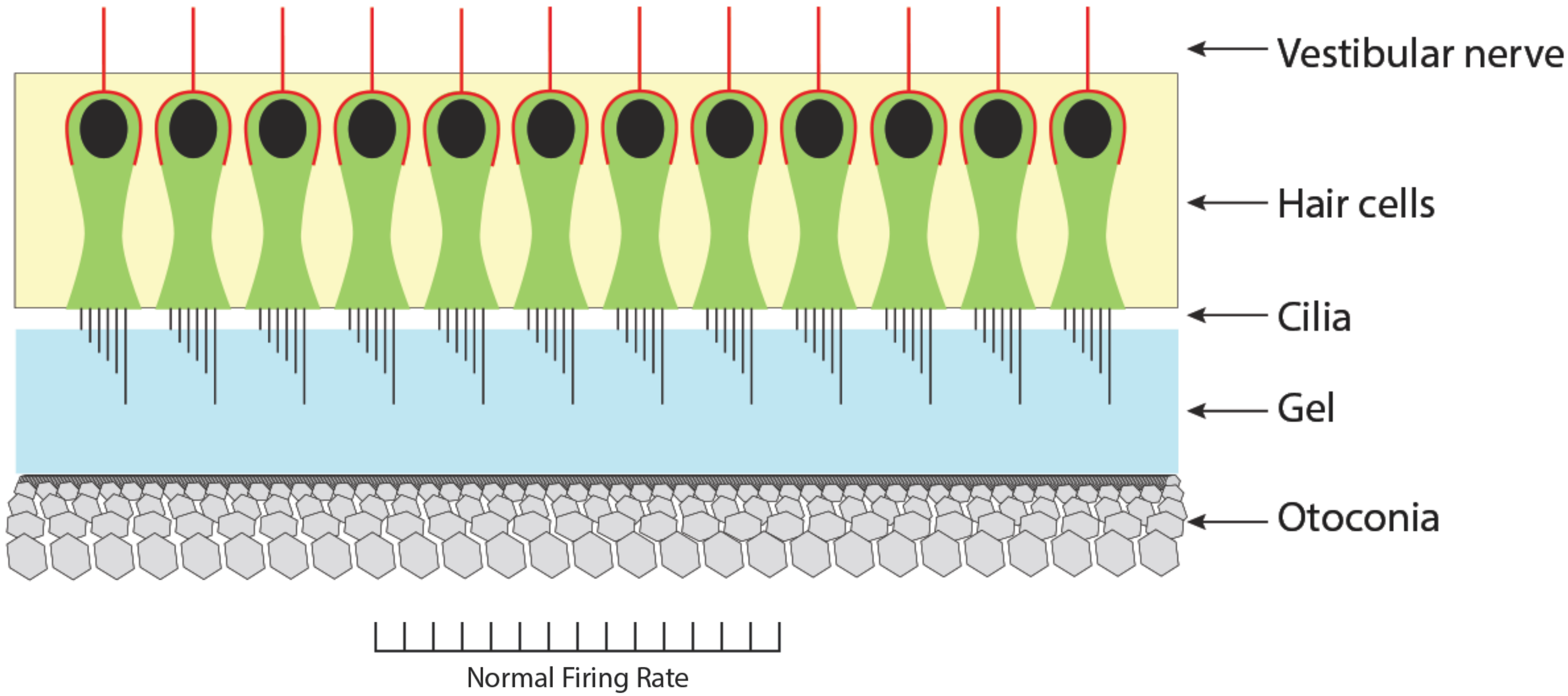
- When the cilia are distorted towards the longest cilium (known as the kinocilium) the firing rate in the nerve fiber increases.
- The molecular physiology of this complex but in brief:
  - Movement opens membrane channels mechanically
  - K^+ moves along its electrical gradient into the cell
  - Ca^{2+} channels open
  - Neurotransmitter is released
  - The nerve fibre depolarises
  - A nerve impulse is set off

Hair cell Physiology

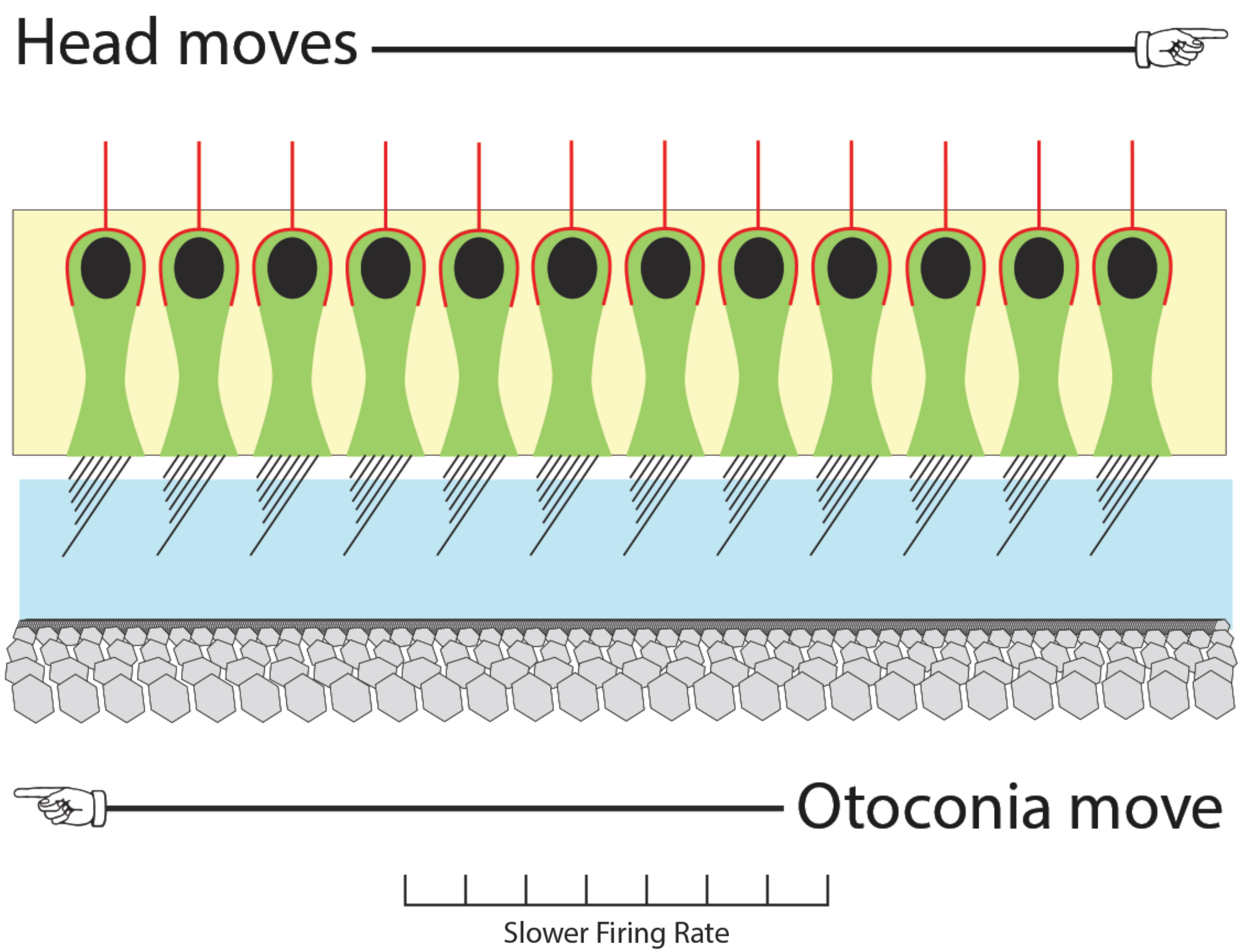


- When the cilia are distorted away from the kinocilium the firing rate drops.
- The cell becomes hyperpolarised and releases less neurotransmitter to the neuron
- Note that the firing rate is modified by movement of the cilia but that there is always some firing (except in pathological circumstances).

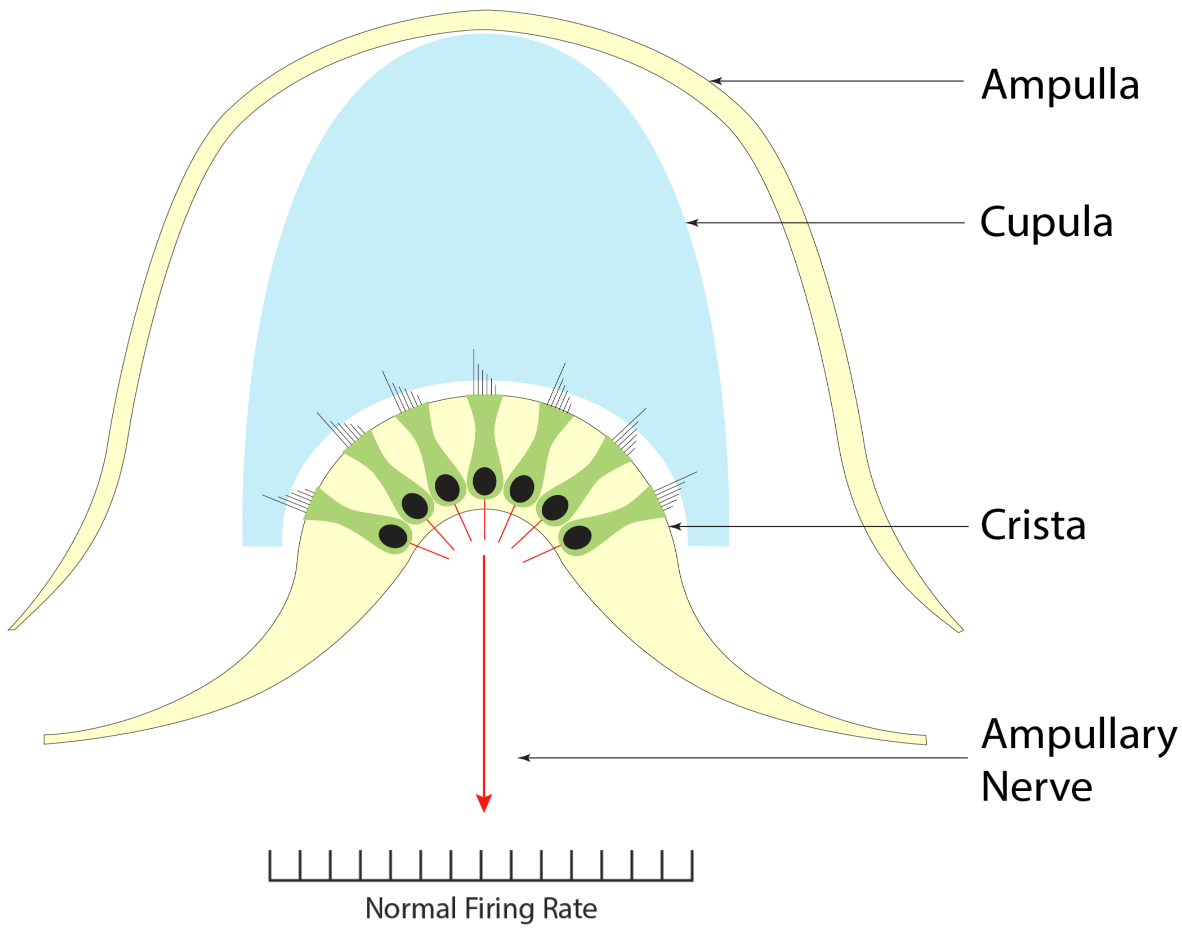
Macular Anatomy



Macular Physiology



Ampullary Anatomy



Ampullary Physiology

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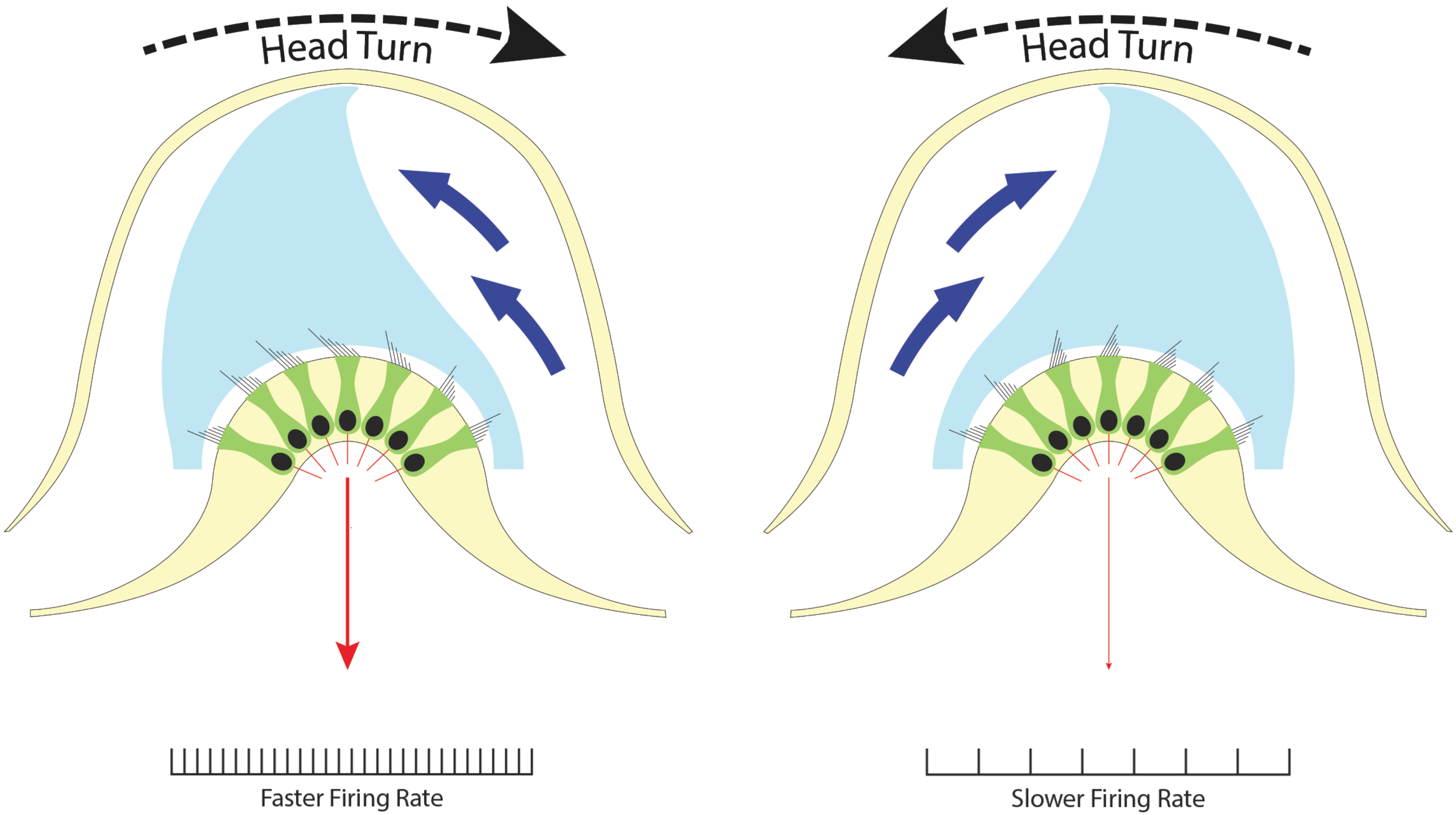

Physiology Round Up

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Crista in the Ampulla

- Hair cell is the basic unit of the neuroepithelium
- Has a tonic discharge
- Crista does not detect gravity in health
- Detects rotational movement

Macula in the Utricle and Saccule

- Hair cell is the basic unit of the neuroepithelium
- Has a tonic discharge
- Otoconia confer intertia on gel
- Detects linear movement

Functional Pairs – Push / Pull

- We have balance organs on both sides of our heads – they are a mirror image of each other.
- Any movement that increases activity in the balance organ on one side will inhibit activity on the other side.
- Lets start by taking a look at what happens in the lateral semicircular canal when we turn our heads to the left.

Functional Pairs

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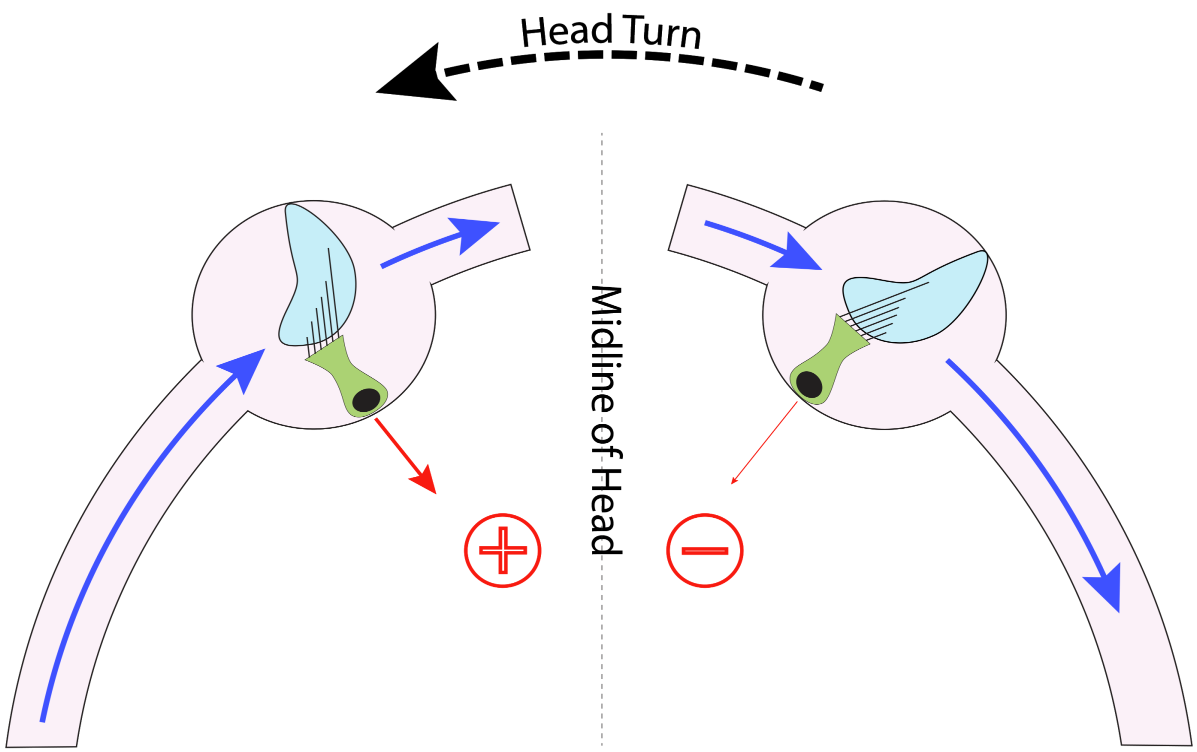
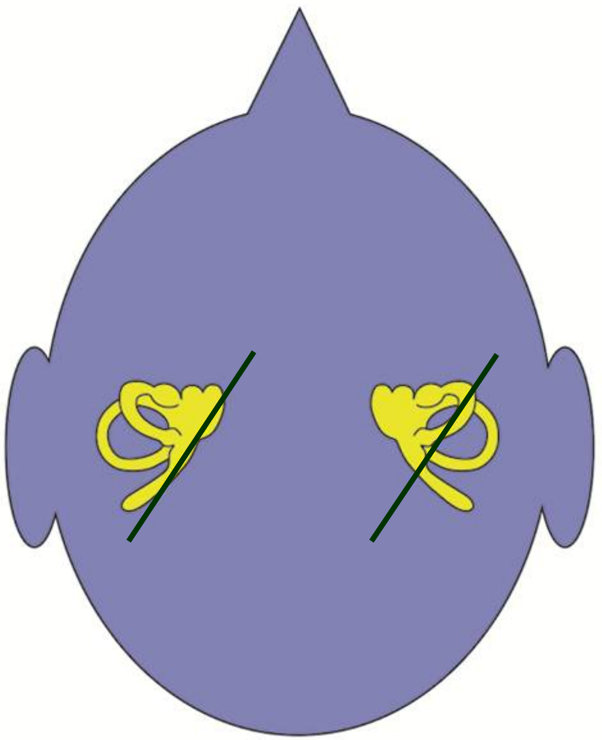
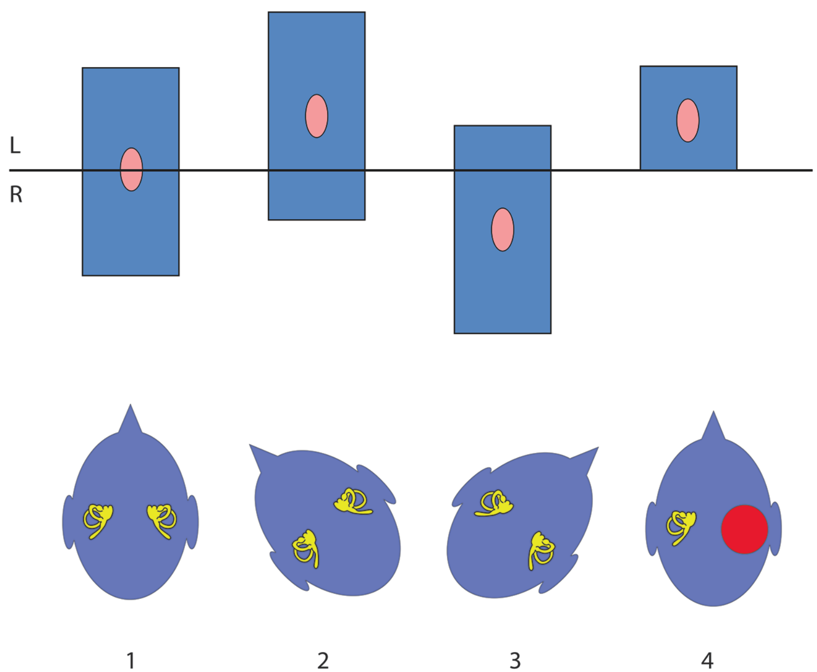


Functional Pairing

- The semicircular canals are paired thus:
  - The left lateral with the right lateral
  - The left superior with the right posterior
  - The left posterior with the right superior
- When the activity in one goes up the activity in its paired canal goes down.



Paired Information & The Brain



- Vestibular nuclei are sensory integration nuclei with multiple inputs.
- Activity from the canals travels to both vestibular nuclei.
- Comparison is made between the activity in one canal and the activity in its paired canal.
- The difference between the two determines the direction of turn.

Where does this information go?

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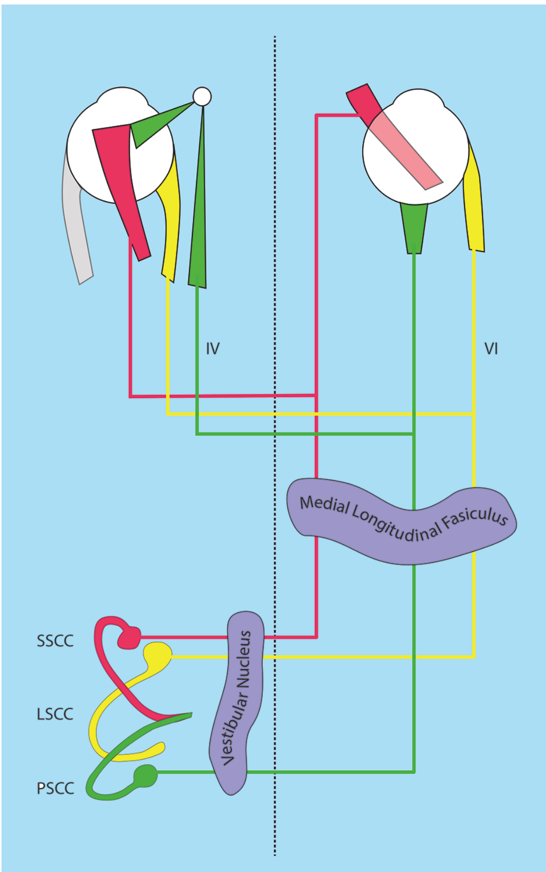
- Generally SCC information travels up the brainstem to the eye motor nuclei.
- Generally macular information travels down the brainstem to the neck and muscles of posture / antigravity muscles.
- Remember that this is a simplification.

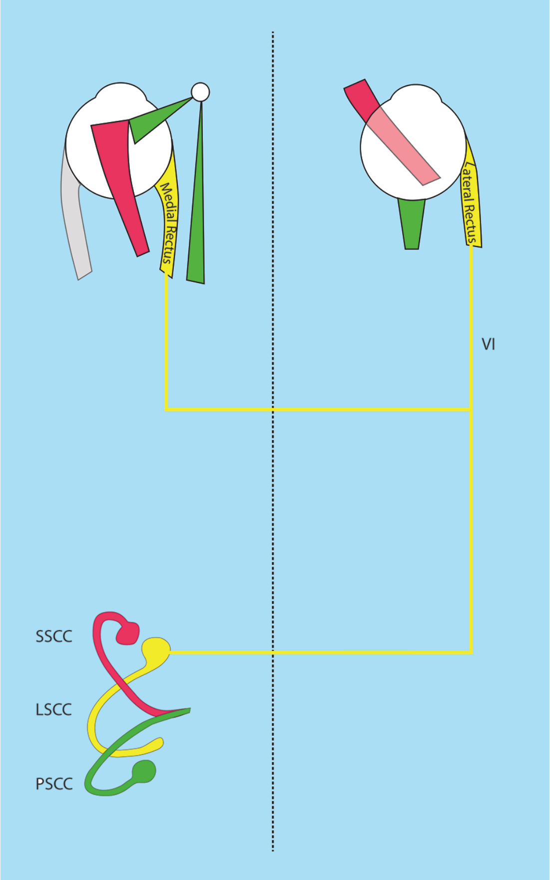
SCCs and Eye Muscles



- Look at the simplified 'wiring' diagram opposite.
- See how each canal is connected to a pair of extra-ocular muscles.
- This system is complex especially when you realize that the right ear connections are not included and neither are the contralateral inputs.
- Let us consider the lateral canal and it's connections.

After Baloh and Honrubia 1990. Clinical Neurophysiology of the Vestibular System

The lateral canals



- The lateral canal on the left side will increase it's firing when the head turns to the left (see previous slides).
- Increased firing will lead to an increase in activity within the nerves that innervate the lateral rectus muscle of the right eye and the medial rectus of the left eye.
- The effect will be to turn the eyes to the right.

The lateral canals

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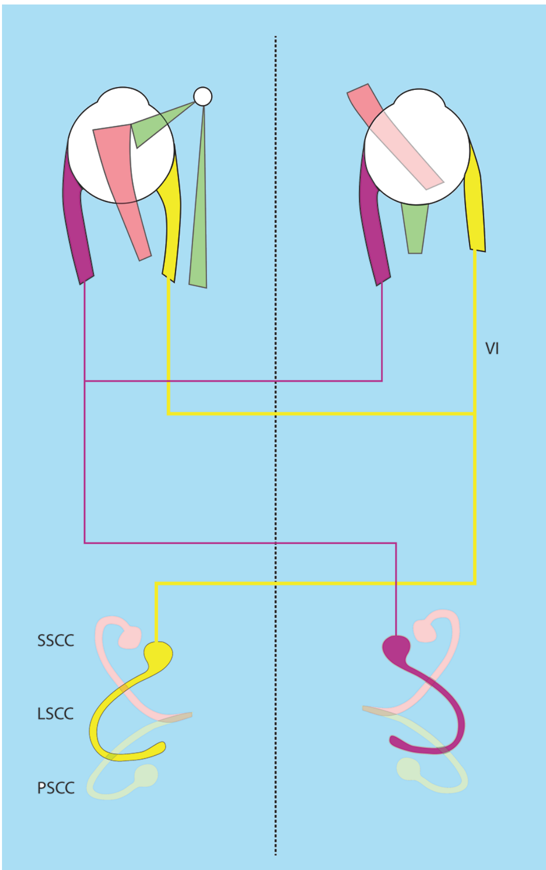
X

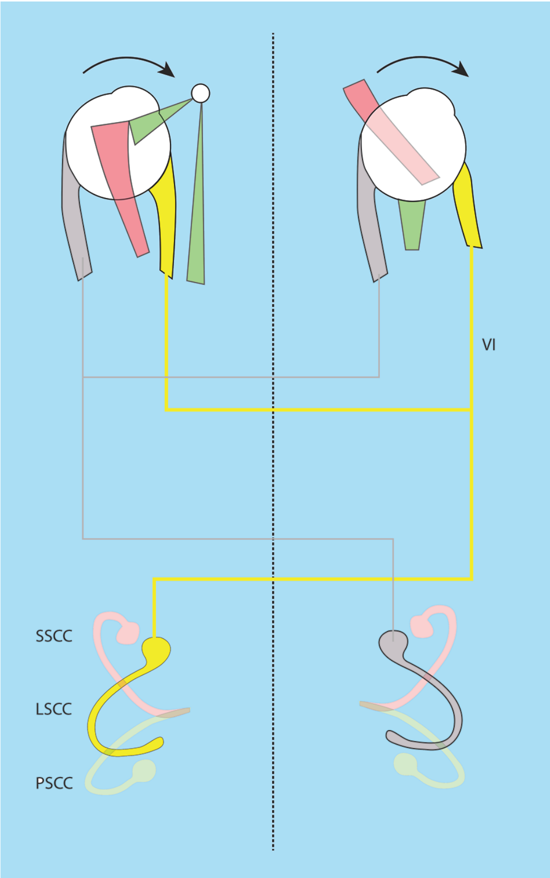
- Try this: look at the 'X' and quickly turn your head to the left. Your eyes move to the right to keep fixated on the 'X'.
- This is you lateral canal in action.

LSCC & Nystagmus



- In this diagram both lateral canals and their connections are shown.
- When the head is not moving the neural firing in both canals is the same and thus the activity is the same in all muscles. The eyes remain looking forwards.
- If the activity in the left (yellow) canal increases because of a left head turn then the activity in the yellow muscles increases.
- At the same time the activity in the right lateral canal (purple) decreases and the muscular tension in the purple muscles decreases.
- Thus the eyes turn to the right.

LSCC & Nystagmus



- But what would happen if one of the ears was damaged and sent no information to the brain and the eye muscles?
- In this diagram the right lateral canal is weak and sending little information to the brain and eye muscles.
- The effect is that the eyes drift towards the right because of the unopposed action of the muscles innervated by the left canal (yellow).
- This is the pathological phase of nystagmus. Soon central correction will occur and the eyes will snap back into place. Thus there is a slow phase and a fast phase with nystagmus.

Alexander’s Law

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- States that the nystagmus is greater when looking in the direction of the fast phase.

Alexander's Classification

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- 3rd degree – nystagmus seen in when looking in all directions
- 2nd degree – nystagmus seen when looking forwards and in direction of fast phase
- 1st degree – nystagmus seen when looking in direction of the fast phase only

- This progression marks the initial phase of central vestibular compensation for a peripheral lesion

Summary

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- You have seen the basics of the anatomy of the inner ear.
- You should understand the physiology of the hair cell.
- The tutorial explains how the hair cell is stimulated and how the type of stimulation varies (linear v. angular).
- You have learned some neuroanatomy.
- Functional pairing is relevant because it helps you understand why the patient feels as if they are spinning in inner ear disease. It also explains why nystagmus occurs.
- Alexander's law and classification.