Master in Bionics Engineering

University of Pisa and Scuola Superiore Sant'Anna

Human and Animal Models for BioRobotics

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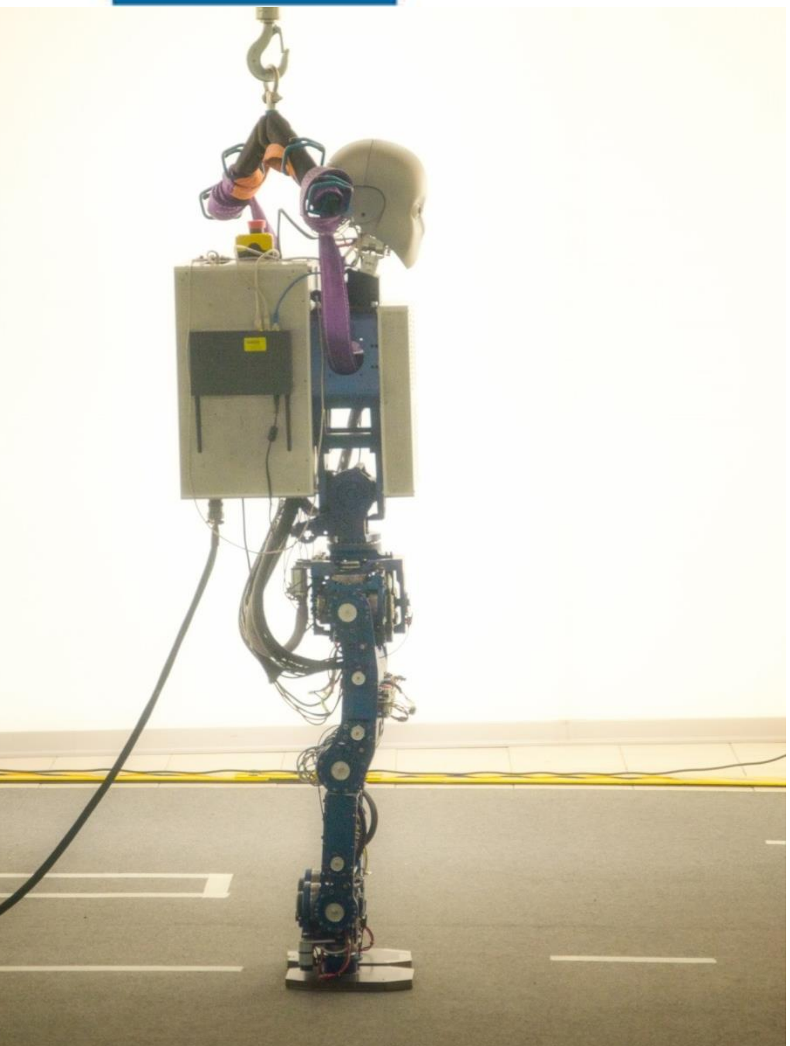

Vestibular system

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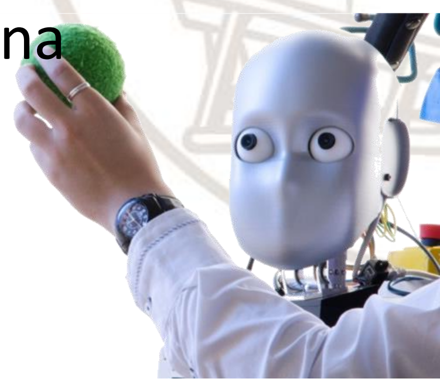
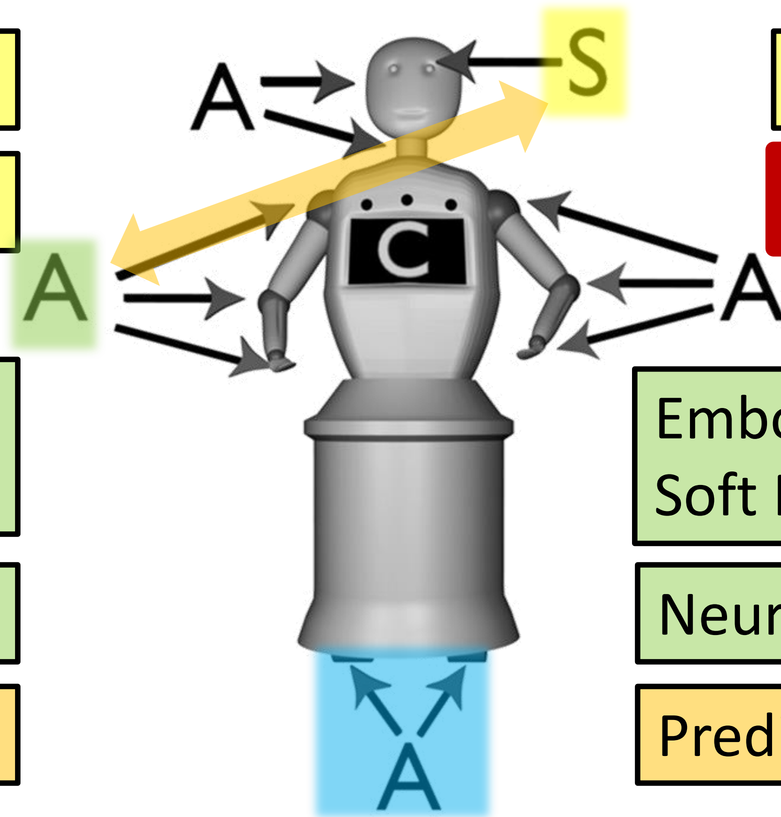


Summary of bioinspired approaches to robotics (in this course…)

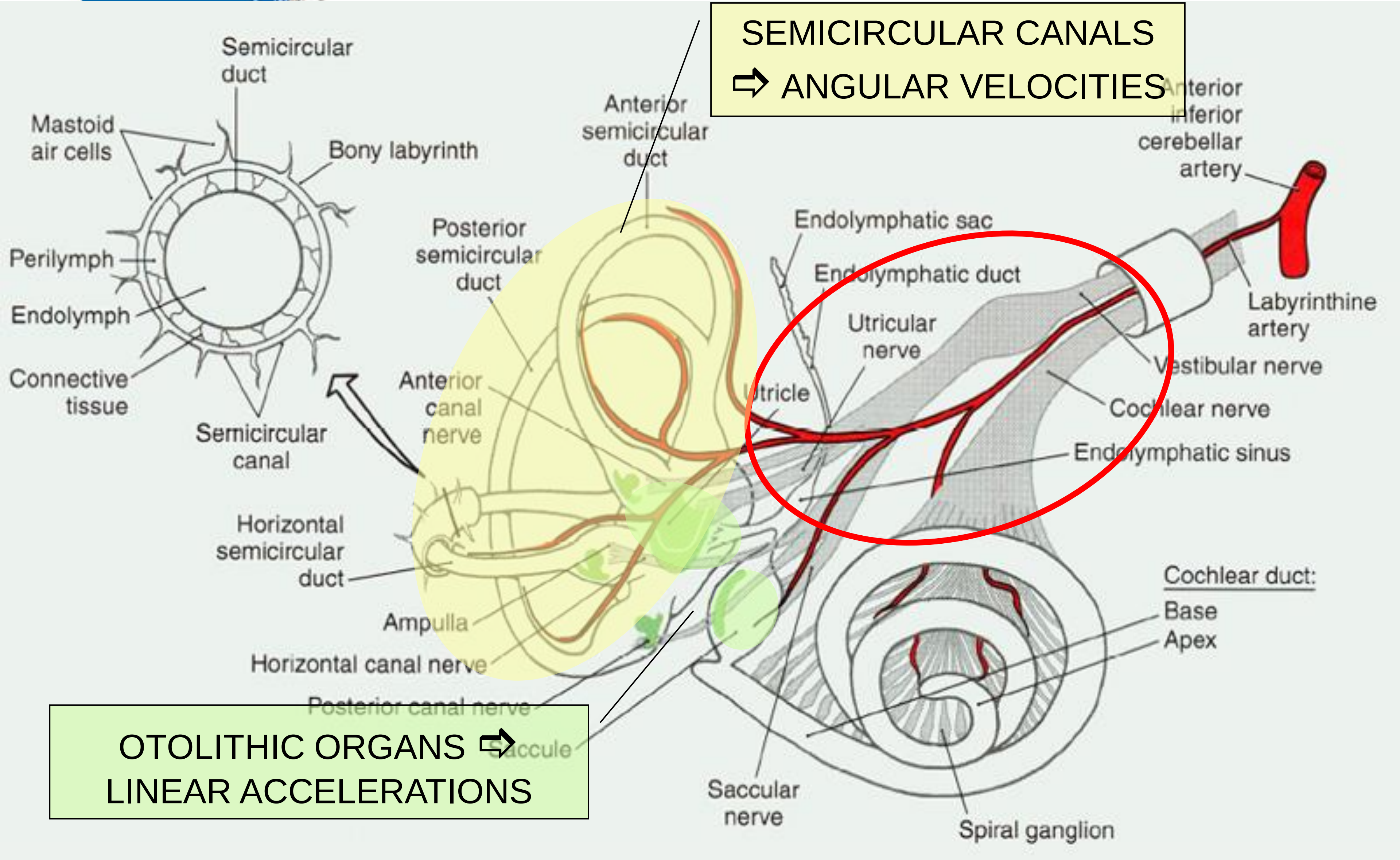
Robot approach	Bioinspired approach
Robot vision	Bioinspired vision
Robot sensors	Vestibular system
Robot mechanics and kinematics	Embodied Intelligence, Soft Robotics
Robot control	Neurocontrollers
Robot behaviour	Predictive behaviour
Robot navigation	Bioinspired navigation, Soft locomotion



The human vestibular system

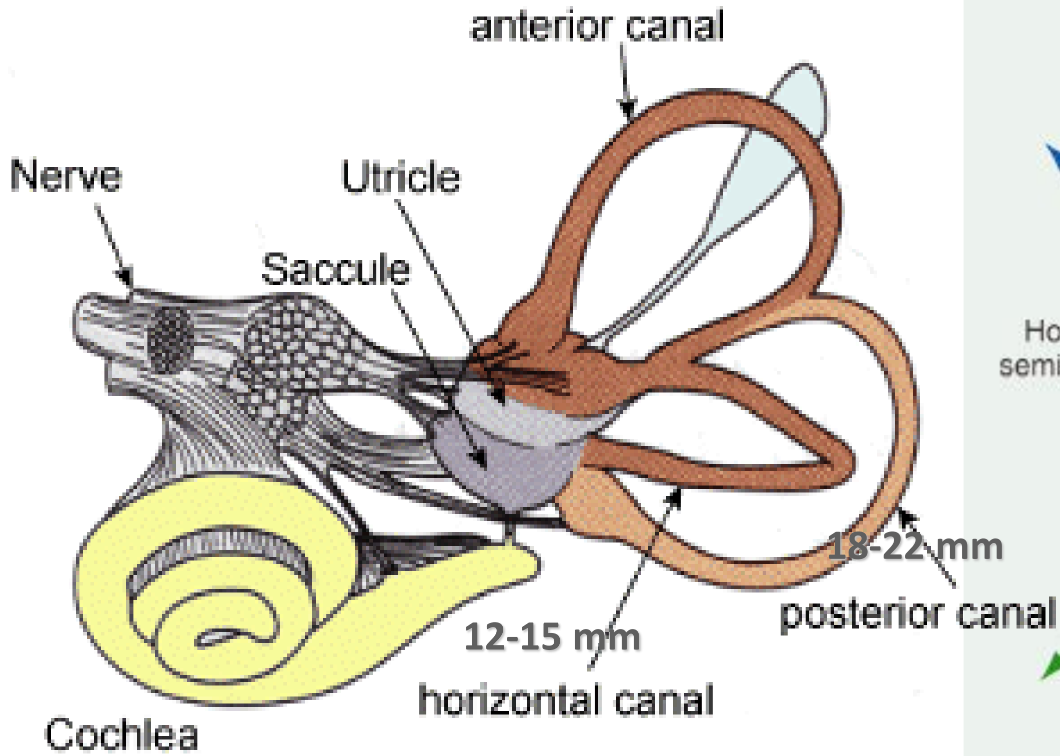
- "Organ of balance"
- Sensitive to:
  - head movements
  - head position in space
- Measures:
  - Angular velocities
  - Linear accelerations
- Fundamental role in several motor functions:
  - control of posture
  - coordination of movements
  - control of eye movements

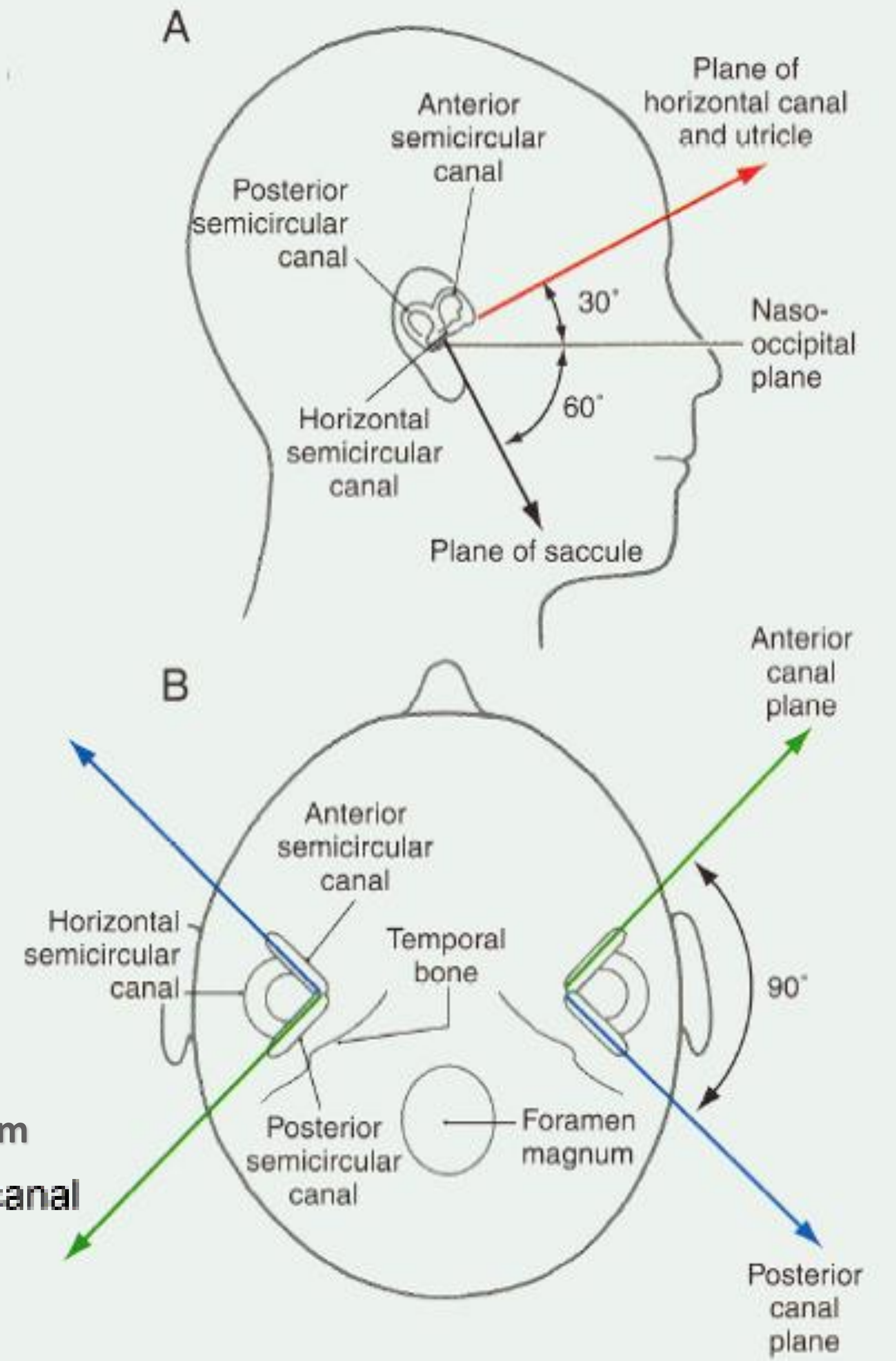
The human vestibular system



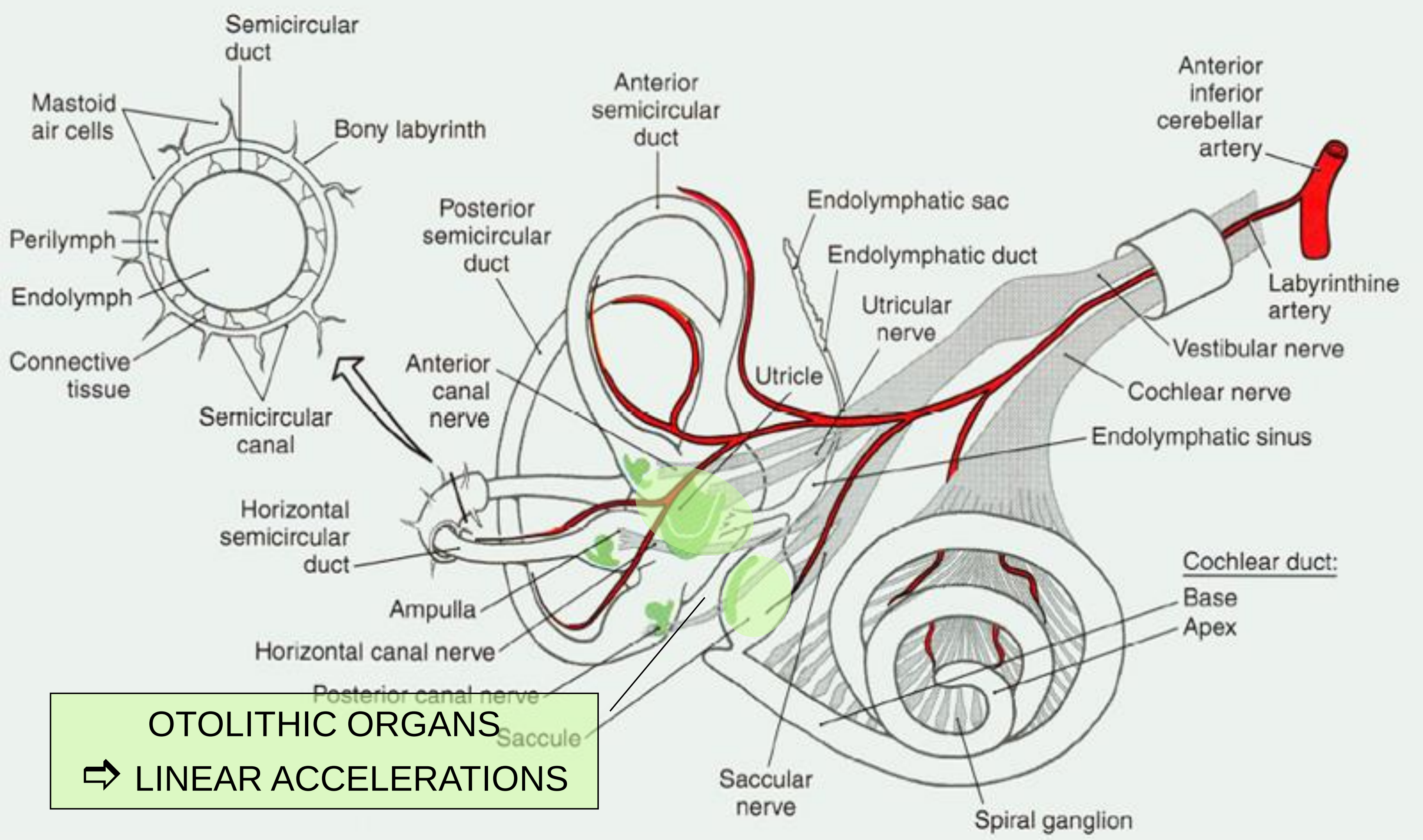
Semicircular canals

2/3 of a circle with 6.5-mm diameter
Inner diameter: 0.4 mm



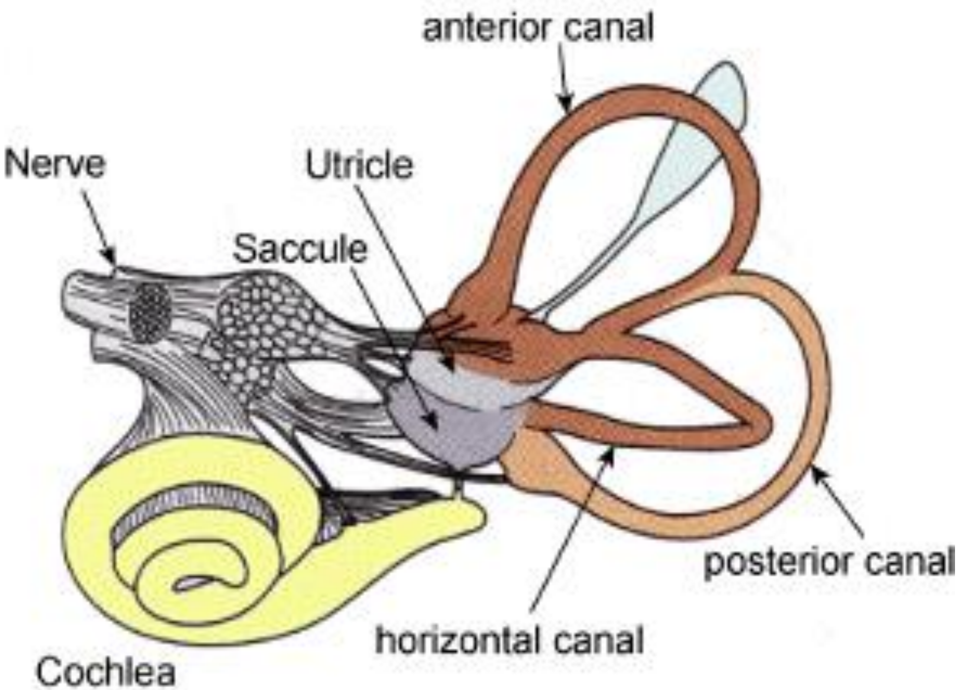


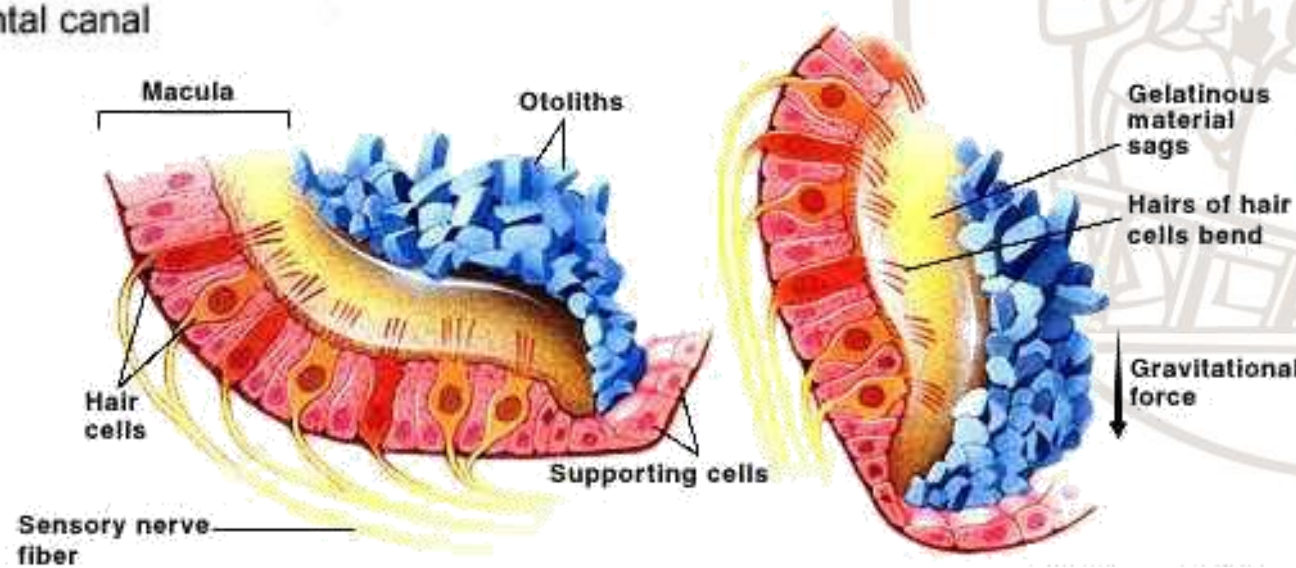
Otolithic organs



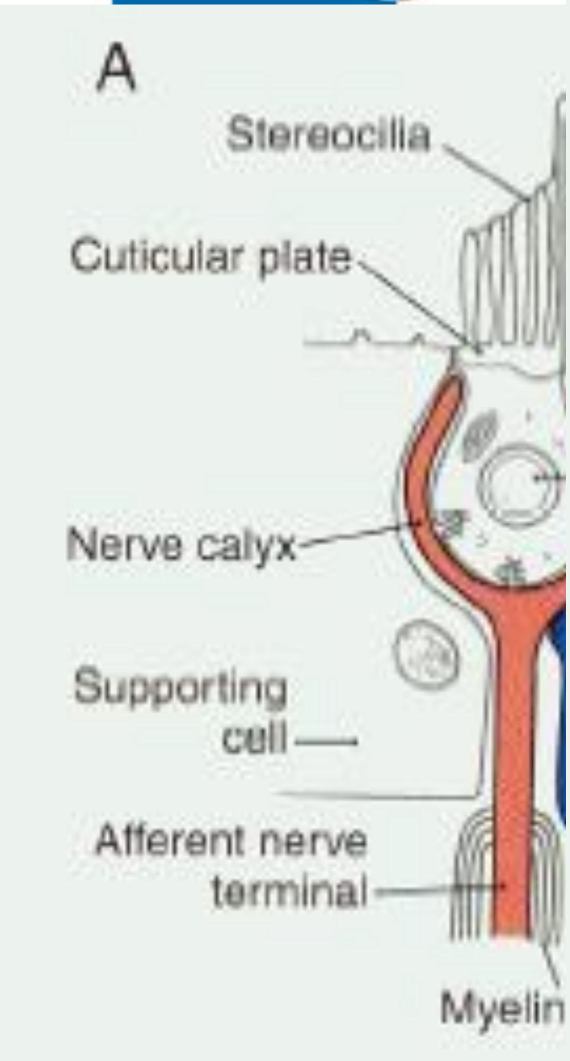
OTOLITHIC ORGANS
⇨ LINEAR ACCELERATIONS

Otolithic organs

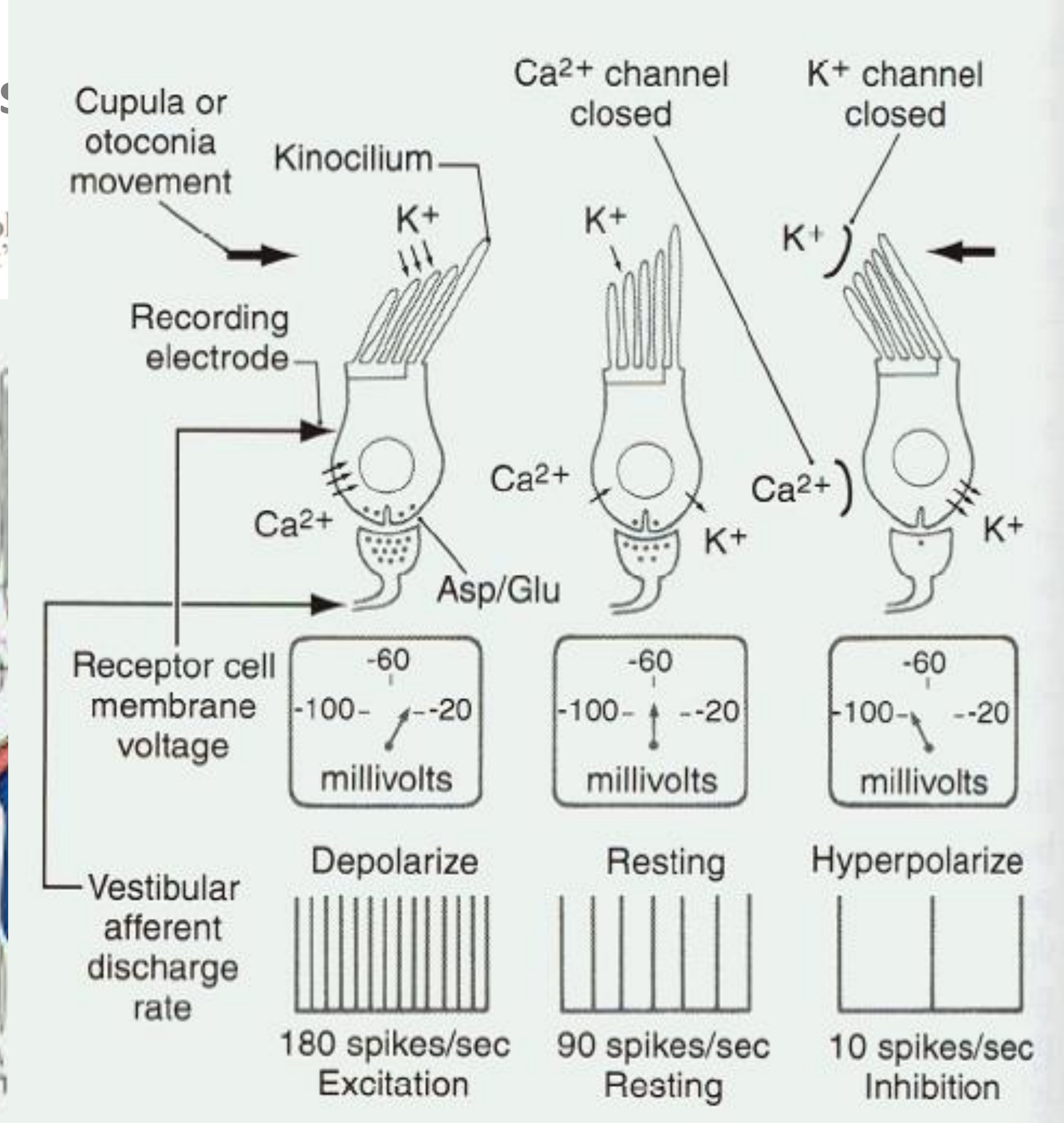




Ves



A
Stereocilia
Cuticular plate
Nerve calyx
Supporting cell
Afferent nerve terminal
Myelin



Cupula or otoconia movement
Kinocilium
Ca2+ channel closed
K+ channel closed
K+
K+
K+
Recording electrode
Ca2+
Ca2+
Ca2+
K+
K+
Asp/Glu
Receptor cell membrane voltage
-60
-100
-20
millivolts
-60
-100
-20
millivolts
-60
-100
-20
millivolts
Vestibular afferent discharge rate
Depolarize
Resting
Hyperpolarize
180 spikes/sec Excitation
90 spikes/sec Resting
10 spikes/sec Inhibition

Vestibular receptors

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How is motion transduced into neural firing?

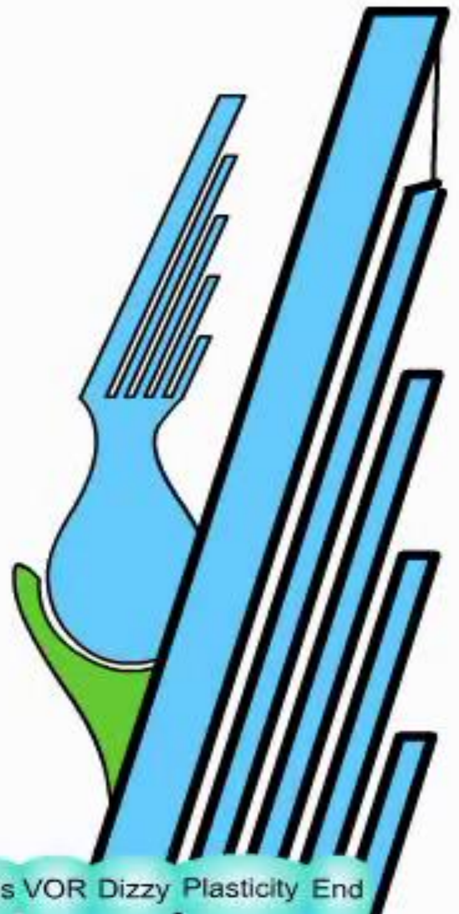
The steps are.

1) As in auditory hair cells, motion bends the hairs.

2) The filament between adjacent hairs opens ion channels allowing K+ to enter the hair cell.

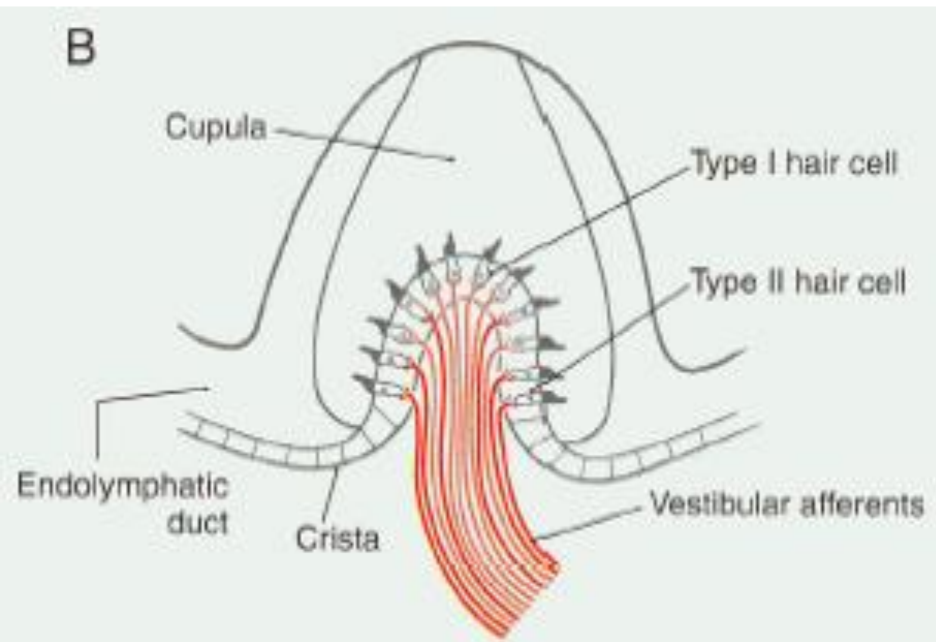
3) The hair cell depolarizes, releasing neurotransmitter.

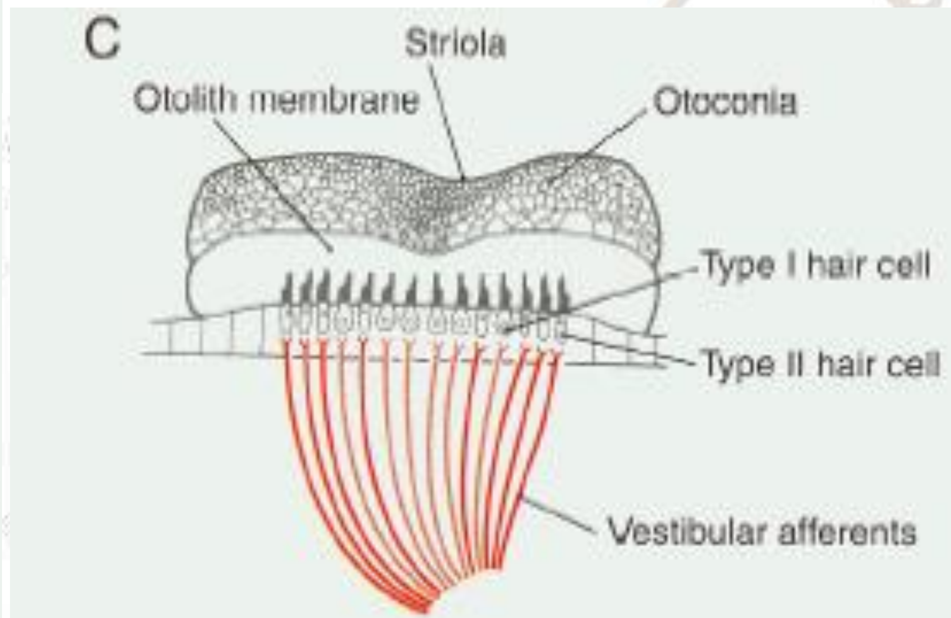
4) There is an increase in the frequency of AP's in the bipolar 8th nerve afferent.

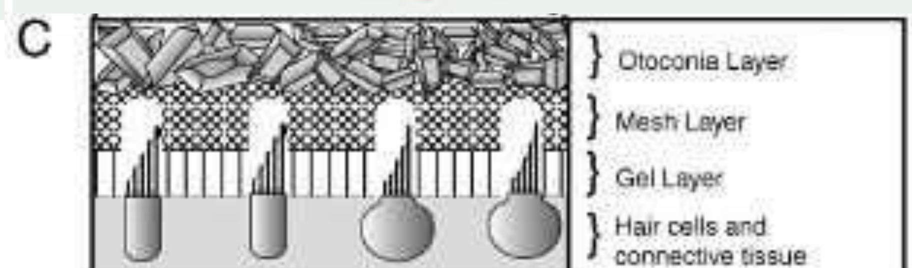


Vestibular receptors in the semicircular canals and in the otolithic organs

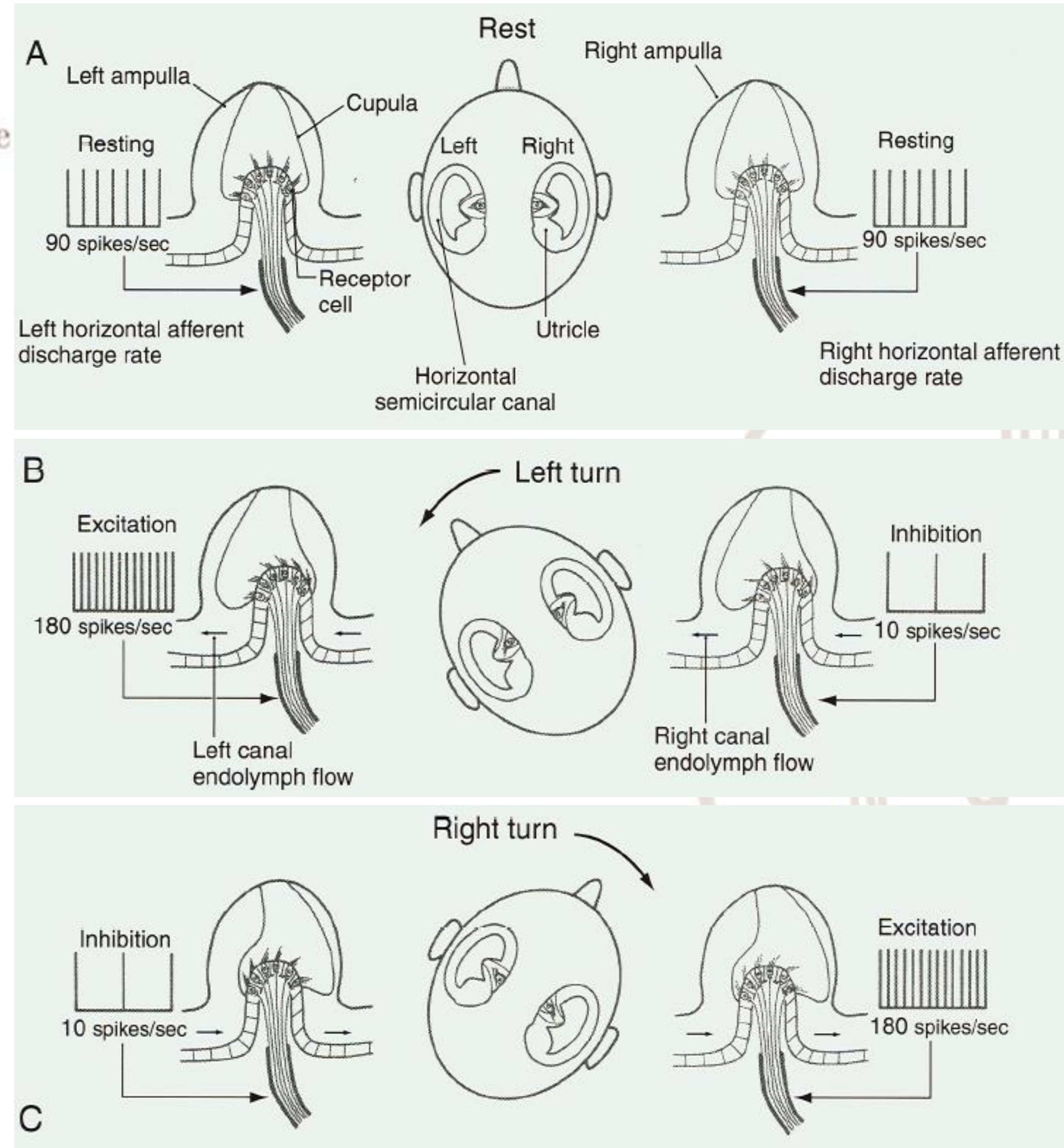
- Semicircular canals
- Otolithic organs







Response mechanism of semicircular canals to head rotations



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Human Vestibular System

What is the functional anatomy of the semicircular canals?

There are three canals in each side.
One is approximately horizontal (h), and the other two, the anterior (a) and posterior (p), are aligned vertically and are about perpendicular to each other.

Within the canals are endolymph-filled semicircular ducts which open at both ends onto the utricle.

Human Vestibular System

What is the functional anatomy of the semicircular canals?

Each duct has a swelling called the ampulla.

The crista, a crest covered with sensory hair cells, projects into the cavity of the ampulla.

The cilia of the hair cells are embedded in a pliable membrane called the cupula which spans the inner diameter of the ampulla.

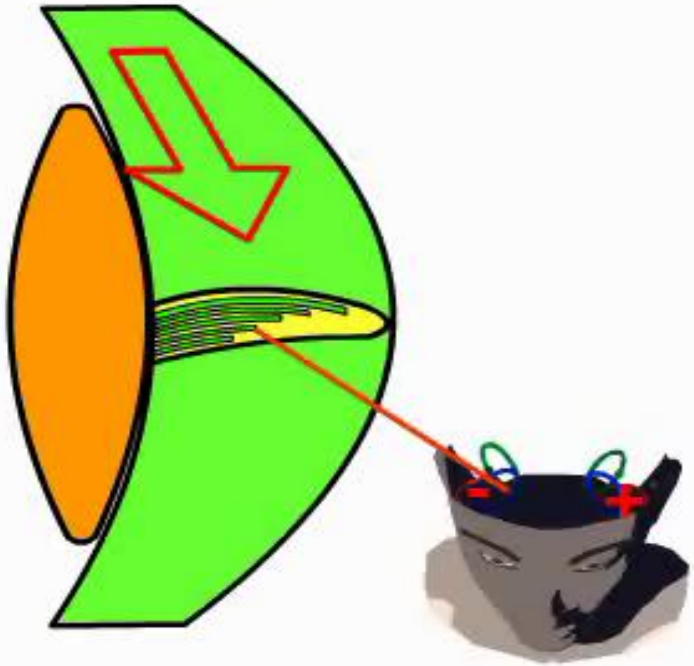
Human Vestibular System

How does this structure detect angular acceleration of the head?

When there is a change in speed of head rotation, the endolymph fluid lags behind because of inertia, pushing on and distorting the cupula.

Bending of the stereocilia **towards** the kinocilium causes **increased** excitation of the hair cell.

Bending occuring **away** from the kinocilium causes **less** excitation of the hair cell.



Response mechanism of otolithic organs to head tilts

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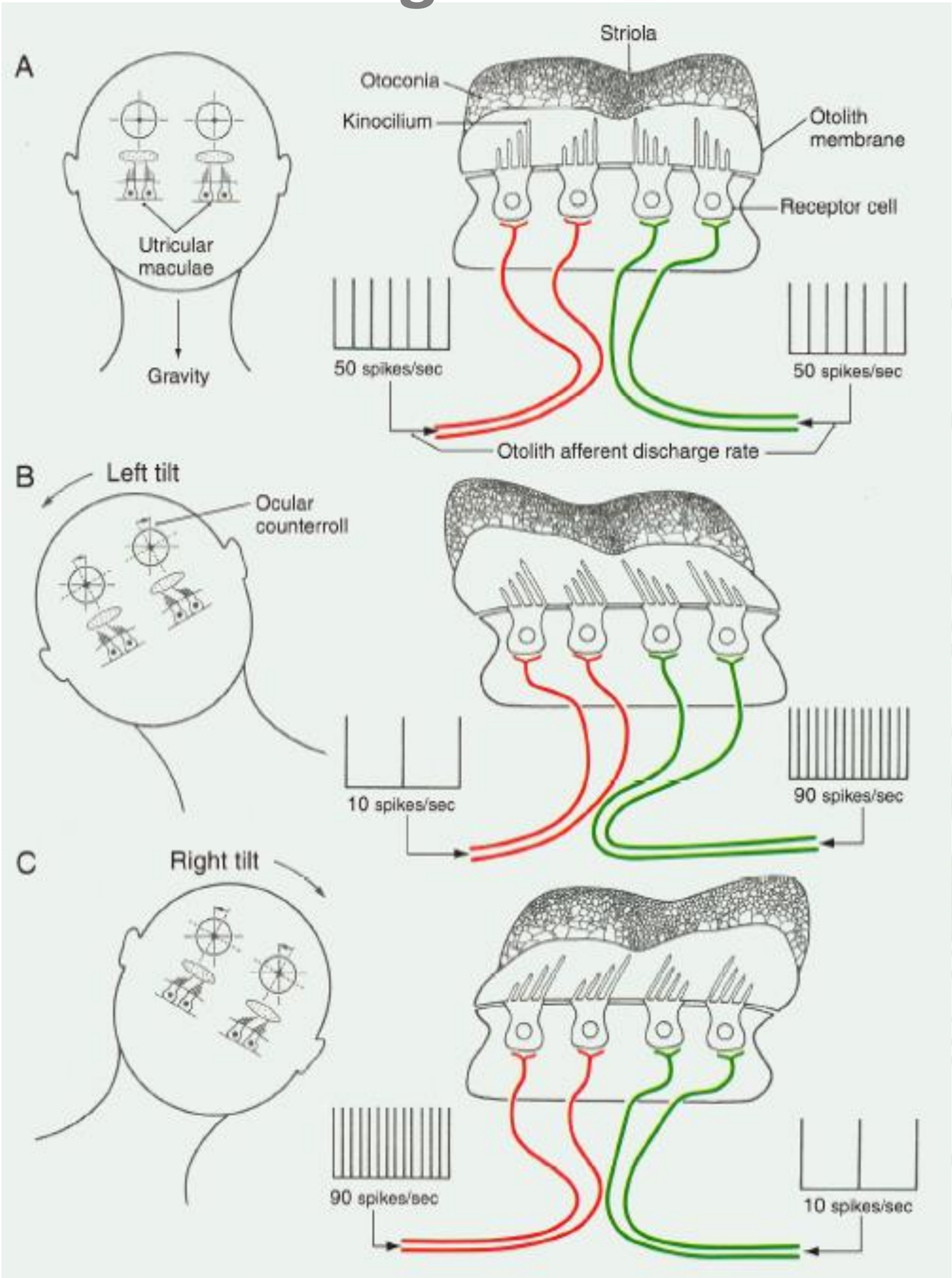

VOR (Vestibulo-Ocular Reflex)

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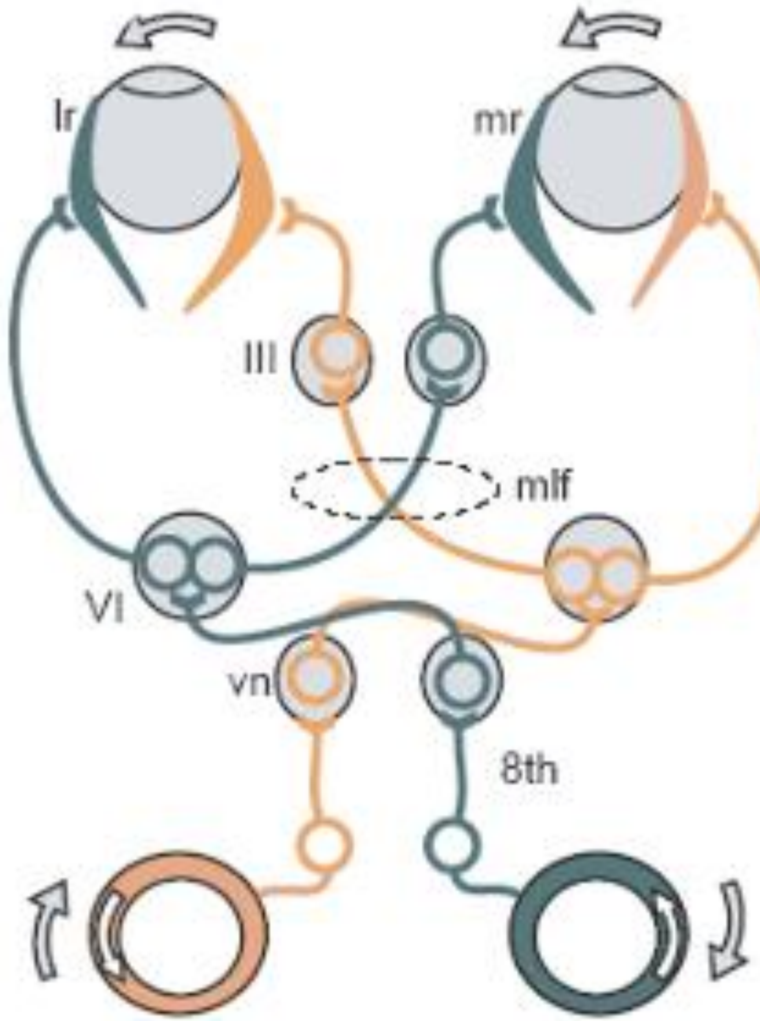
- Reflex eye movement that stabilizes images on the retina during head movement by producing an eye movement in the direction opposite to head movement, thus preserving the image on the center of the visual field.
- Since slight head movements are present all the time, the VOR is very important for stabilizing vision: patients whose VOR is impaired cannot read, because they cannot stabilize the eyes during small head tremors
- The VOR reflex does not depend on visual input and works even in total darkness or when the eyes are closed
- Latency of 14 ms (time between the head and the eye movement)

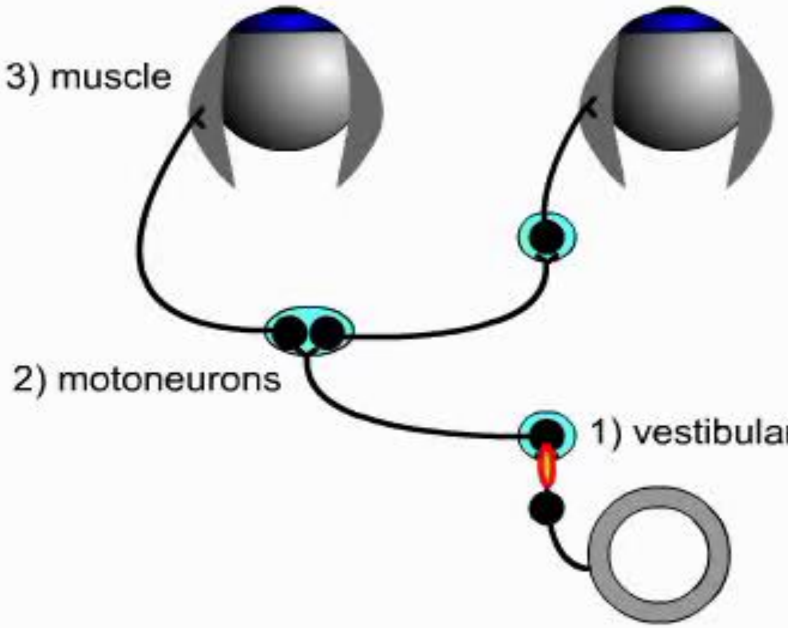
The Vestibulo-Ocular Reflex (VOR)



Vestibulo-ocular Reflex (VOR)

Explain the neural mechanism for a horizontal VOR.

The direct path is a short reflex with 3 synapses.



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Vestibulo-ocular Reflex (VOR)

Explain the neural mechanism for a horizontal VOR.

When the **head rotates rightward** the following occurs.

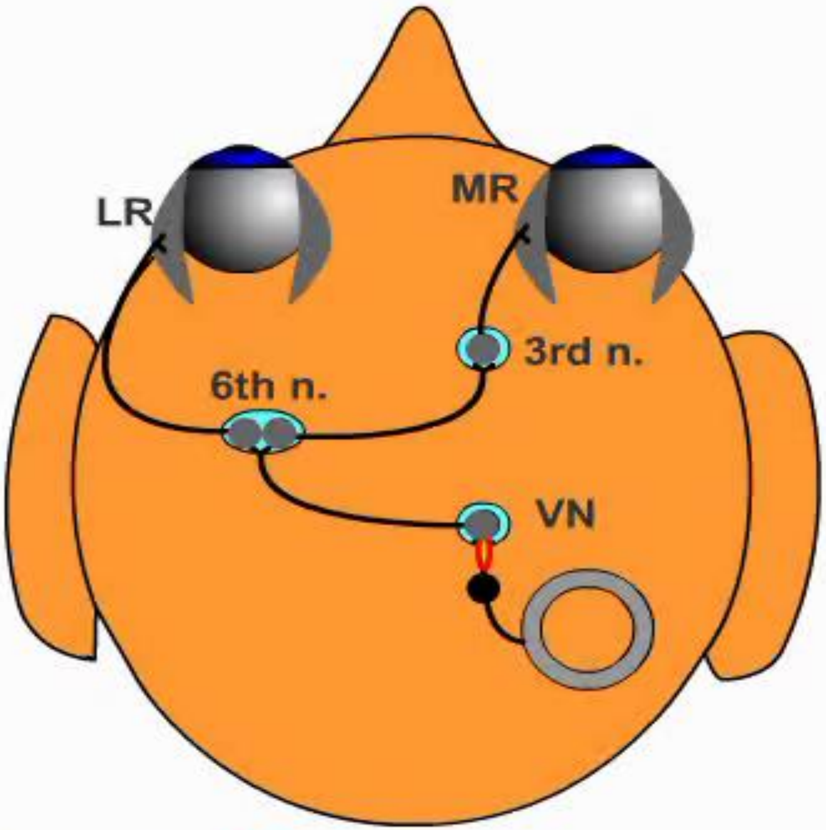
The right horizontal canal hair cells depolarize.

The right vestibular nucleus (VN) firing rate increases.

The motoneurons (in the right 3rd and left 6th nuclei) fire at a higher frequency.

The left lateral rectus (LR) extraocular muscle and the right medial rectus (MR) contract.

Both **eyes rotate leftward**.



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Vestibulo-ocular Reflex (VOR)

Explain the neural mechanism for a horizontal VOR.

The VOR is a push-pull reflex.
Neurons on other side do the opposite.

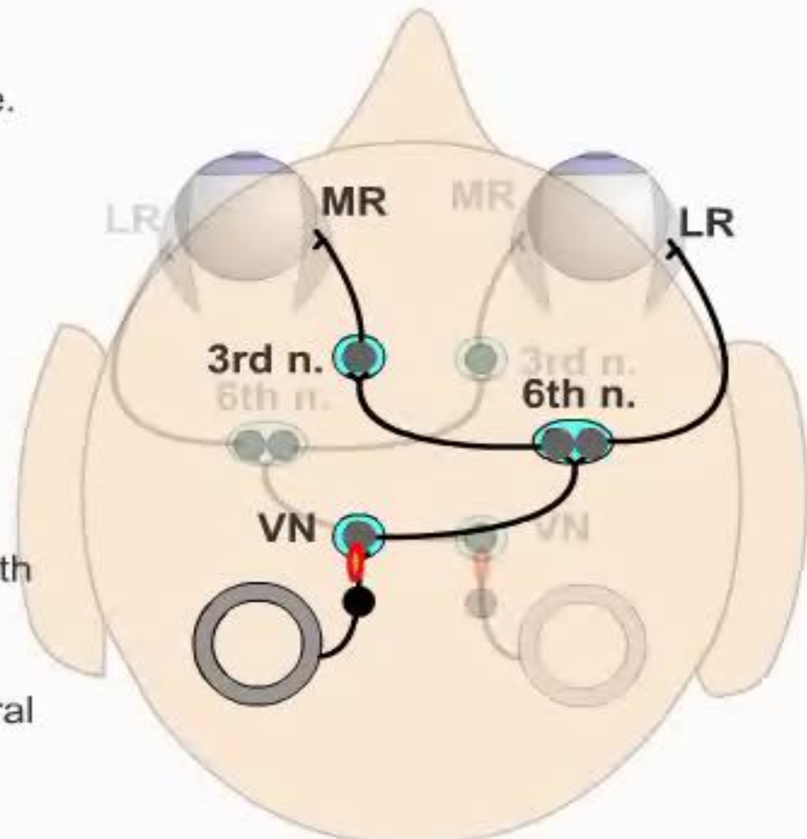
When the **head rotates rightward** the following occurs.
The left horizontal canal hair cells hyperpolarize.

The left vestibular nucleus firing rate decreases.

Motor neurons in the left 3rd and right 6th nuclei fire at a lower frequency.

The left medial rectus and the right lateral rectus relax.

This helps the **eyes rotate leftward.**



Start Labyrinth Otoliths Canals VOR Dizzy Plasticity End