The vestibular system

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Please sit where you can examine a partner

(or you may be my subject like the guy in the purple sweater was last week)

First you tell them what your gonna tell them

- The vestibular organs sense head motion: canals sense rotation; otoliths sense linear acceleration (including gravity).
- The central vestibular system distributes this signal to oculomotor, head movement, and postural systems for gaze, head, and limb stabilization..
- The visual system complements the vestibular system.
- Visuo-vestibular conflict causes acute discomfort.
- Peripheral and brainstem vestibular dysfunction causes pathological sense of self-motion and visuo-vestibular conflict.

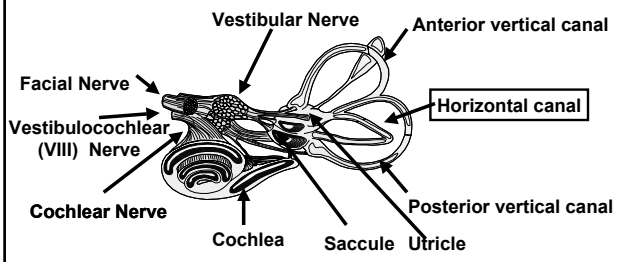
The vestibular labyrinth answers two questions basic to the human condition

- Where am I going?
- Which way is up?

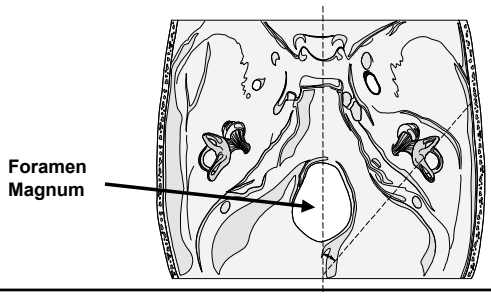
The vestibular labyrinth answers the two questions basic to the human condition by sensing

- Head angular acceleration (semicircular canals)
  - Head rotation.
- Head linear acceleration (saccule and utricle)
  - Translational motion.
  - Gravity (and by extension head tilt).

The vestibular organ



The vestibular organ lies in the temporal bone

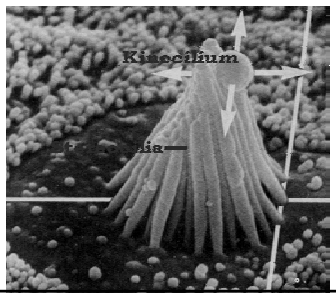


Each vestibular organ has a sensor for head acceleration, driven by hair cells similar to those in the cochlea

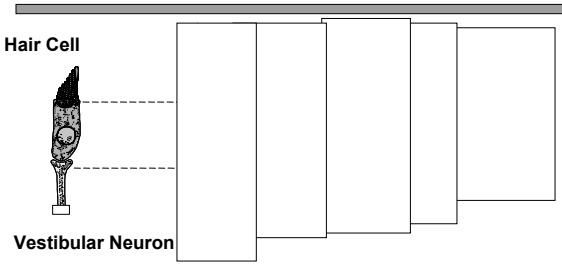
- In the cochlea vibration induced by sound deforms the hair cells.
- In the labyrinth acceleration deforms the hair cells.
- In the semicircular canals the sensing organ is the ampulla

Deformation of the stereocilia towards the kinocilium causes hyperpolarization

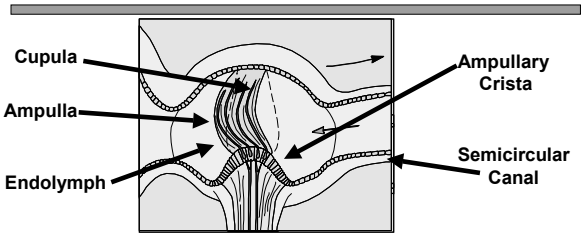
⇒ depolarization
⇐ hyperpolarization



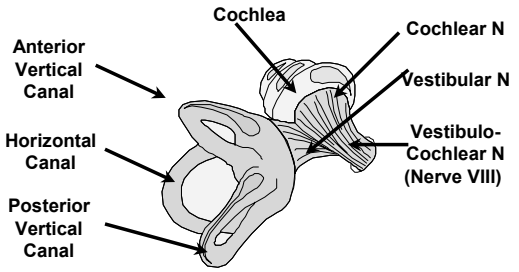
Hair cells respond to deformation



How the semicircular canals sense rotation



The three semicircular canals lie in 3 orthogonal planes



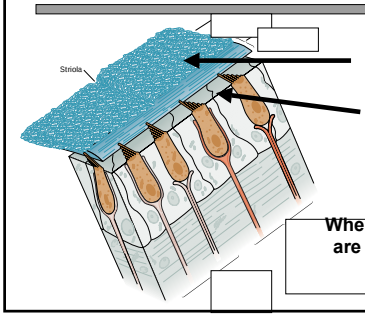
The semicircular canals are functionally paired and sense rotation

- Horizontal canals: rotation in the horizontal plane
- Left anterior and right posterior canals (LARP): rotation in the vertical plane skewed 45° anteriorly to the left.
- Right anterior and left posterior canals (RALP): rotation in the vertical plane skewed 45° anteriorly to the right.

The semicircular canals are functionally paired

- The canals lie in roughly the same planes as the extraocular muscles:
  - Horizontal canals: lateral and medial recti.
  - LARP: left vertical recti, right obliques.
  - RALP: right vertical recti, left obliques.
- Each canal excites a pair of muscles and inhibits a pair of muscles in its plane. Its partner excites the muscles it inibits, and vice-versa.

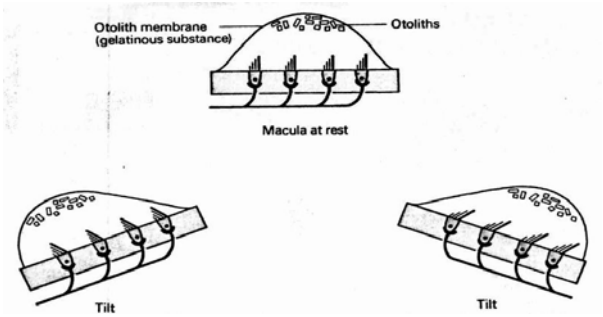
The otolith organs sense linear acceleration. Hair cells lie in the macula.



Otoconia (ear dust)

Otolithic Membraine

When the head tilts the hair cells are distorted by the shift of the otolithic membrane



The otolith organs sense linear acceleration

- The saccule senses acceleration in the sagittal vertical plane: up and down (so it senses gravity) and forward and backward. Mnemonic: Saccule - Sagittal
- The utricle senses acceleration in the horizontal plane:

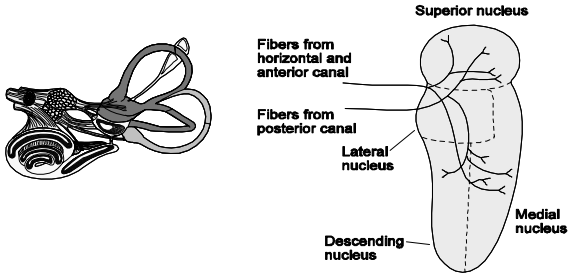
The signals in the vestibular nerve

- Although the cupula senses acceleration, the canal signal in the vestibular nerve is a tonic signal, deviations from which are proportional to head velocity.
- The macular afferents have a tonic signal, deviations from which are sensitive to acceleration.

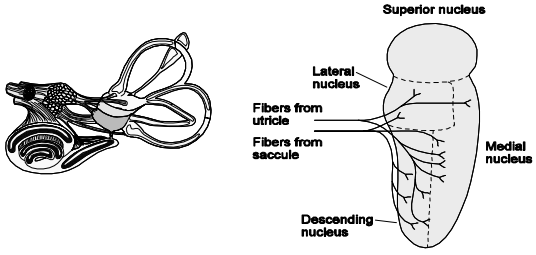
There are 3 major vestibular reflexes

- Vestibulo-ocular reflex – keep the eyes still in space when the head moves.
- Vestibulo-colic reflex – keeps the head still in space – or on a level plane when you walk.
- Vestibular-spinal reflex – adjusts posture for rapid changes in position.

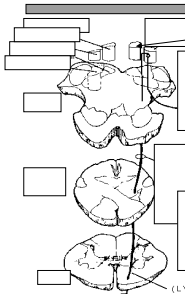
Connections to the vestibular nucleus from the canals



Nuclear Connections of the Otolith Organs

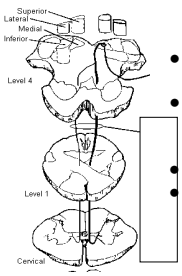


The lateral vestobulospinal tract



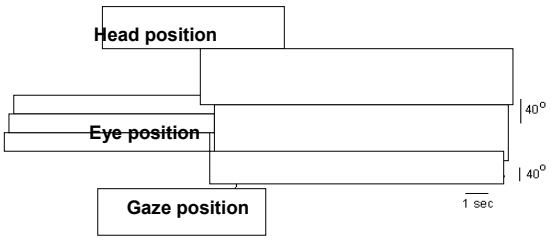
- Originates in the lateral vestibular nucleus, predominantly an otolith signal.
- Projects to cervical, thoracic, and lumbar segmen via the ventral funiculus.
- Entirely ipsilateral.
- Allows the legs to adjust for head movements.
- Provides excitatory tone to extensor muscles.
- Decerebrate rigidity is the loss of inhibition from cerebral cortex and cerebellum on the LVST, and exagerates the effect of the tonic signal in the LVST.

The Medial Vestibulospinal Tract (MVST)



- Originates in the medial vestibular nucleus, predominantly a canal signal.
- Predominantly projects to cervical segments via the medial longitudinal fasciculus.
- Predominantly ipsilateral.
- Keeps the head still in space – mediating the vestibulo-colic reflex.

The Horizontal Rotational Vestibulo-ocular Reflex



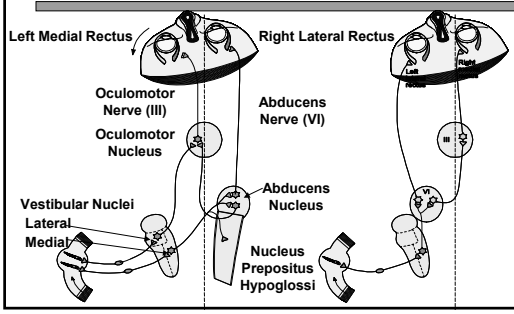
The Horizontal Translational VOR

- Keeps the eyes still when the head moves laterally (for example when you are looking out of the window of the A train and trying to read the name of the station past which you are traveling).
- Gain is dependent on viewing distance: during translation a far object moves less on the retina than a near object.
- The rotational VOR is not dependent upon viewing distance.
- Most head movement evokes a combination of the rotational (canal) and translation (otolith) VOR's.

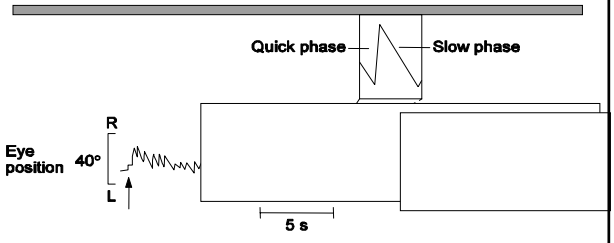
The VOR is plastic

- It can be suppressed when you don't want it.
- Its gain can change.
  - How do you know if the VOR is doing a good job?
  - There is no motion on the retina when the head moves.
  - If a muscle is weakened, a given central signal will be inadequate, and the world will move on the retina.
  - This can be mimicked by spectacles that increase retinal slip.
  - In either case, the brain adjusts the VOR signal so the retinal slip is eliminated.
- The cerebellum is necessary for both suppression of the VOR and for slip-induced gain change.

The horizontal vestibulo-ocular reflex (VOR)



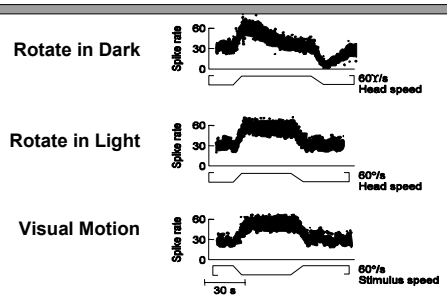
Vestibular Nystagmus



The optokinetic signal

- The vestibular system is imperfect
  - The cupula habituates in 5 seconds.
  - The brainstem and cerebellum extend this time to roughly 25 seconds, after which there is no further response to head acceleration.
  - The vestibular system is a poor transducer of very slow (<0.1Hz) rotation.
- The visual system compensates for the inadequacies of the vestibular signal by providing a description of the retinal motion evoked by the head movement.
- The optokinetic response is mediated by neurons in the accessory optic system in the pretectum, and the motion-sensitive areas in the cortex (MT and MST).

The vestibular nucleus combines visual and vestibular signals



Visual-vestibular conflict

- Full-field stimulation is an effective stimulus for the vestibular nucleus. The neurons can't tell the difference, nor can you!
- Ordinarily the head movement implied by the visual and visual signals are equal.
- Motion sickness – nausea and vomiting – occurs when the visual and vestibular signals are unequal.

Vertigo and nystagmus

- The vestibular system has a tonic signal, changes of which are interpreted as head motion.
- Anything that deranges that signal causes ***vertigo***, a perception of head motion when the head is still.
- This may be associated with visuovestibular conflict, nausea, and vomiting.

Other sequelae of peripheral vestibular dysfunction

- Head tilt.
- Difficulty compensating for perturbations of head positon – functional imbalance.
- Difficulty with path integration.

Peripheral causes of vestibular dysfunction

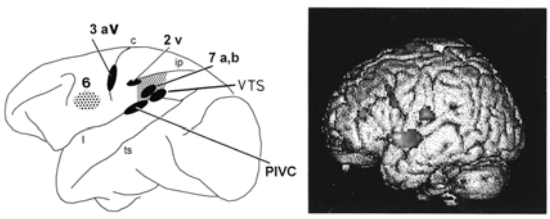
- Benign positional vertigo: debris from the otoconia in the utricle float into the posterior canal, causing interference with cupula function, brought out by motion in the plane of the affected posterior canal. This can be treated by the Epley maneuver, that rotates the head to float the debris away.
- Acute viral labyrinthitis.
- Alcohol – alcohol is lighter than blood, so the hair cells float in the endolymph.
- Meniere's disease – increased endolymphatic pressure.
- Toxins – especially guanidino-sugar antibiotics like streptomycin and gentamycin.

Central causes of vertigo and nystagmus.

- Vestibular nuclei.
- Cerebellum.
- Peripherally caused nystagmus is worse with the eyes closed, because the normal cerebellum can use vision to suppress the nystagmus.

Cortical vestibular areas

Monkey **Human**



Perceptual aspects of vestibular function

- Self-motion.
- Vertical orientation.
- The vestibular nuclei project to the ventral thalamus (VP/VL) and thence to area 2v. A number of cortical areas have vestibular responses, but cortical vestibular processing is poorly understood.
- Patients with lesions of parietoinsular cortex have difficulty perceiving the vertical: they think vertical lines tilt towards the side of the lesion.