Anatomy and Physiology of Systems involved in dizziness

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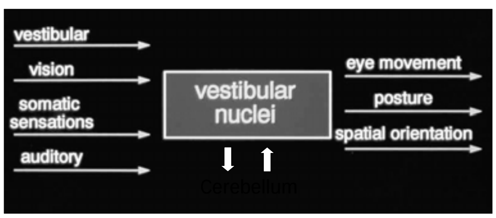
Lecture Plan

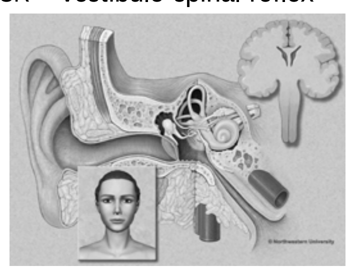
1. Overview of neurophysiology of the vestibular and auditory systems
2. Anatomy/Clinical
   - External ear
   - Middle ear
   - Inner ear
   - Nerve
   - Central structures

Vestibular Overview

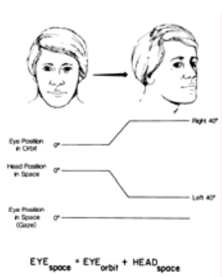


Two main reflexes

- VOR – vestibulo-ocular reflex
- VSR – vestibulo-spinal reflex

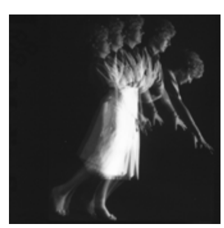


Vestibulo-ocular reflex V.O.R.



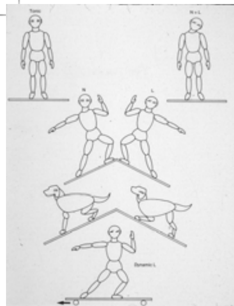
- Stabilizes eye in space
- Necessary to see

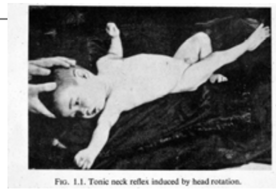
Vestibulo-spinal reflex V.S.R.



- Stabilizes body
- Helps maintain desired orientation to environment

VSR





Tonic neck – and tonic labyrinthine reflexes add together to allow head to tilt without arm extension.

Sailors Sea Chanty

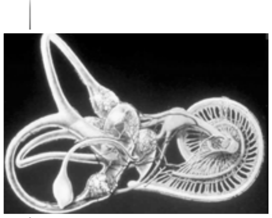
Roll, roll roll you son of a bitch !

The more you roll

The less you pitch

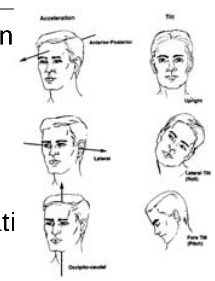
(anon)

Inertial navigation



6 degrees of freedom problem

- Three axes of rotation
  - Roll, pitch and yaw



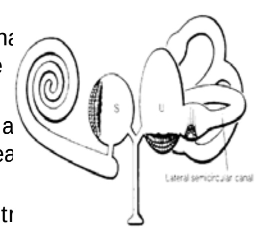
- Three axes of translati
  - AP, Lateral, Vertical

<u>The Navigation Problem.</u>

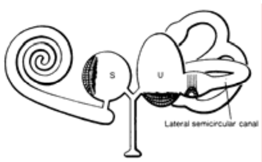
- Motion sensing is a "mission critical" task -- for example, vestibular system is needed to walk reasonably safely in the dark.
- The vestibular system incorporates considerable redundancy.

The vestibular inner ear is an inertial navigation device

- Semicircular Cana are angular rate sensors.
- Otoliths (utricle a saccule) are linea accelerometers
- Bilateral symmetr means redundant design.

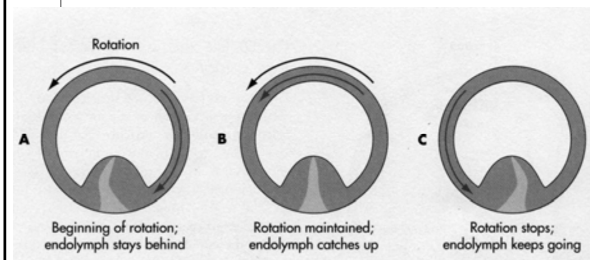


5 sensors, 2 tests



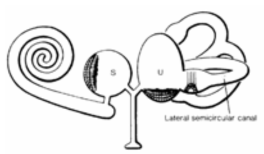
- Clinical Correlate: can only measure 2/5 -- lateral canal and saccule with available vestibular tests.

STARTING AND STOPPING = ACCLERATION



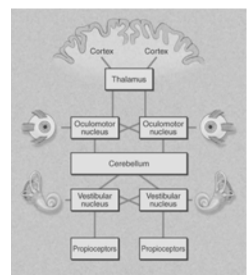
Imperfections in Vestibular Sensors

- Imbalance
- Timing
- Gain
- Noise



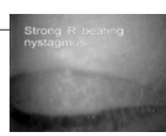
Imbalance

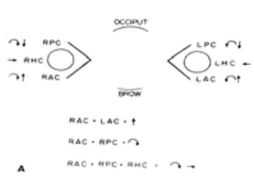
- Push-pull arrangement
- Common mode rejection
- Illusion of motion when one side goes bad



Vestibular Nystagmus

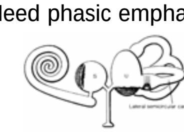
1. Both sides – no nystagmus
2. One side – lateral/rotatory
3. One horizontal canal lateral nystagmus.
4. One vertical – mixed vertical/rotatory
5. Vertical or horizontal usually central



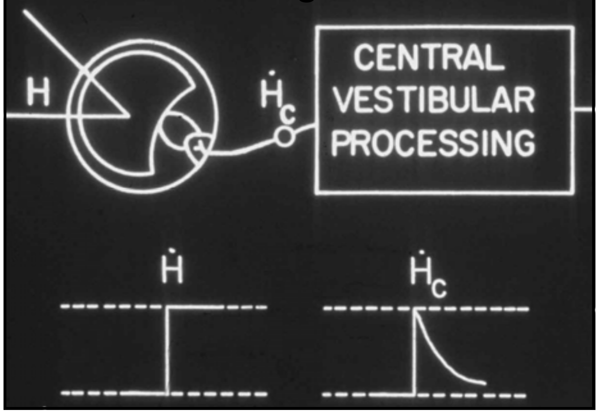


Imperfections in Vestibular Sensors

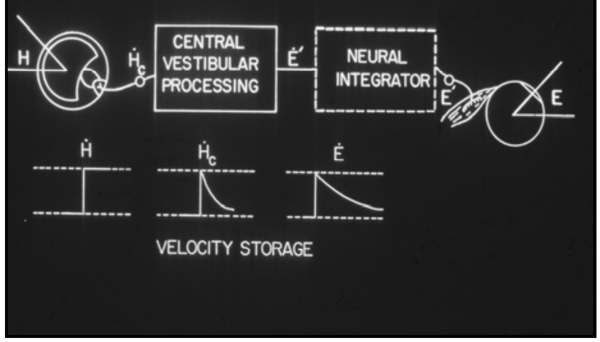
- Timing of canals isn't good for eyes or body
  – Need to extend timing for eyes
  – Need phasic emphasis for neck



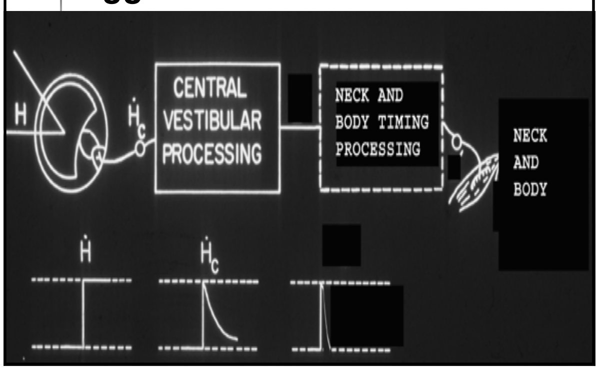
Built in Timing Problems



Velocity Storage for VOR Adjust to agile eye



Different timing needed for sluggish neck



In vestibular lesions

- Velocity storage goes away for eyes (VOR). Time constant drops from 21 to 7 sec.
- Not clear what happens to timing in the neck/body – may be unchanged.

Hain TC, Zee D. S. : Velocity storage in labyrinthine disorders. New York Academy of Sciences, 656, 1992, 297-304

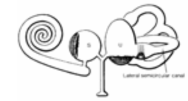
Ewald’s 3 Laws (1892)

Observations made upon the exposed membranous labyrinth of Pigeons (Ewald’s pneumatic hammer)

- Eye and head movements occur in the plane of the canal being stimulated and in the direction of endolymph flow
- In the lateral canal, ampullopetal flow causes a greater response than ampullofugal flow
- In the vertical canal the reverse is true

Imperfections in Vestibular Sensors

- Gain
  - Ewald’s 2nd law – built in problem
  - Growth and development
  - Disease – bilateral vestibular loss



Ewald's 2nd Law

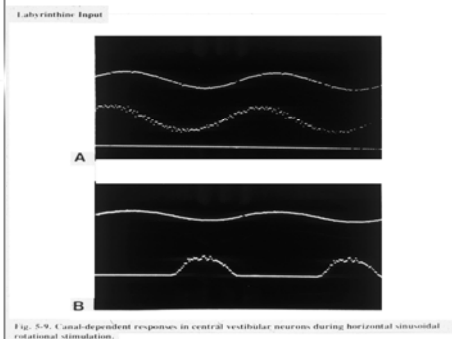


Fig. 5-9. Canal-dependent responses in central vestibular neurons during horizontal sinusoidal rotational stimulation.

Ewald JR. 1882. Physiologische Untersuchungen uber das Endorgan des Nervus Octavus. Bergman, Wiesbaden.

Ewald's Compensation need for both eyes and neck

Saturation → Anti-Saturation → Linear behavior

In unilateral vestibular loss, Ewald's 2nd law probably causes head-shaking nystagmus, positive rapid-dolls head reflex. We are not sure what happens to VCR/VSR.

Hain TC, Fetter M and Zee DS: Head-shaking nystagmus in unilateral peripheral vestibular lesions. American J. Otolaryngology., 8:36-47, 1987.

Imperfections in Vestibular Sensors

- Noise – a common problem
  - Positional vertigo (BPPV mainly)
  - Fluctuations in vestibular function
    - Ménière's, Fistula
- Noise makes vestibular input unreliable
  - Logical consequence is to decrease weighting

Clinical correlations

- Grocery Store Syndrome (AKA visual dependence)
  - Unable to tolerate busy visual environments
  - Normally people switch between most salient sensory mode – visual/vestibular/somatosensory
  - Can't switch -> bothered by Target

Higher Level Vestibular Problems

- Coordinate rotation is needed to communicate with VCR and VSR
- Integration is needed of vision and somatosensation with vestibular input
- Estimation is needed to process multiple unreliable sensors

Coordinate Rotation is needed between head and body

- Ears are in head which can turn on body
- Must rotate vestibular signals into body coordinates (Nashner, 1974)
- This is probably computationally intensive and slow.
- Is there a clinical correlation ? Must be, but we haven't figured it out yet.

Sensory Integration

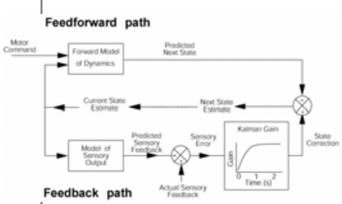
- Visual, vestibular, somatosensory senses must be integrated to form best estimate.
- If incorrect estimate
  - Motion sickness
  - Visual dependence
    - Grocery store syndrome
    - Simulator sickness

Internal Model Theory (how the brain works ?)

- Outgrowth of Space program
- Space Shuttle – 100's of inputs and outputs
  - Some intermittent
  - Some more reliable than other
  - Some sluggish, some rapid
  - Some are noisy
- Needed a method of formally computing best estimate of Space Shuttle State

Kalman Filter (internal model)

- Grew out of work by Kalman at MIT



Wolpert, 1997

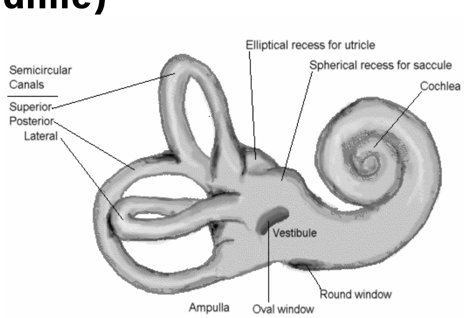
Formal method of forming "optimal estimate".

Integrates efference with afference

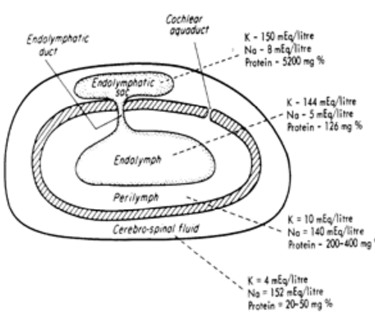
Accounts for noise, sensor differences.

Anatomy

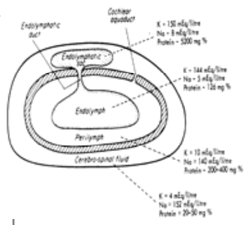
Bony labyrinth (size of dime)



The Labyrinth is filled with Endolymph and Perilymph



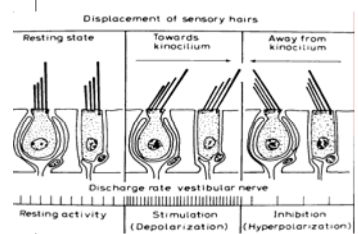
Clinical Correlations



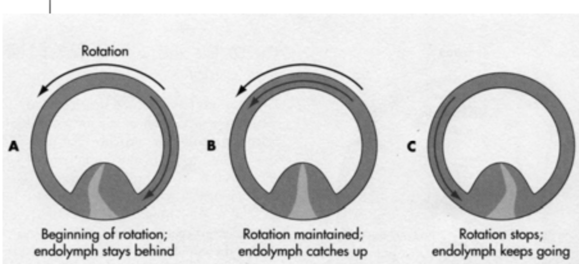
- Meniere's disease (?)
- Meningitis in children
- Perilymphatic fistula

Vestibular Hair cells – measure force

- Relative movement of hair cells to head causes change in electrical potential
- Same general design for hearing

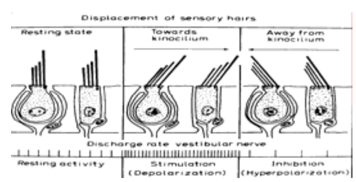


STARTING AND STOPPING = ACCLERATION



Clinical Correlation – Hair Cells

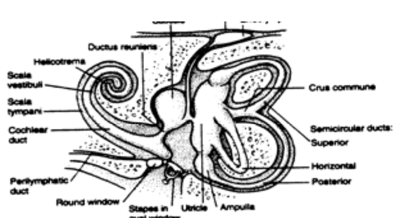
- Aminoglycosides kill hair cells
- Loop diuretics and NSAIDS are hair cell toxins



Membranous Labyrinth

Narrow lumen increases effect of viscosity

Allows mechanical integration to take place



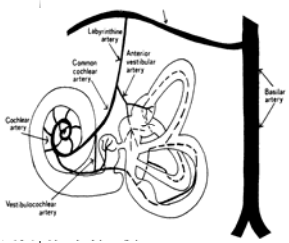
Clinical correlates

Vestibular Atelectasis

Collapse of membranous labyrinth

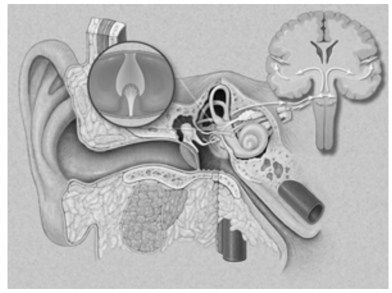
May correlated with dysequilibrium in elderly population.

Peripheral circulation to inner ear



- AICA
  - Labyrinthine
  - Vestibulocochlear
    - PC, Saccule
  - Anterior vestibular
    - AC, LC, Utricle

Cupula to Brain



Cupula

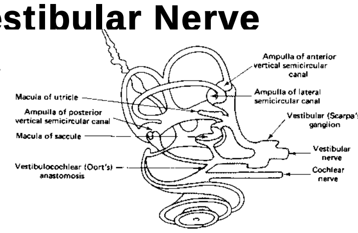
Scarpa’s ganglion

Vestibular Nerve

Vestibular Nucleus

Cortex

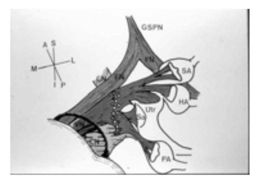
Vestibular Nerve



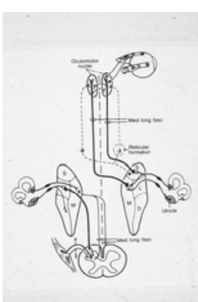
- Superior vestibular nerve: AC, LC, Utricle
- Inferior vestibular nerve: PC, Saccule
- Scarpa’s ganglion

Clinical Correlations

- Vestibular neuronitis – infection of Scarpa’s ganglion ?
- Acoustic Neurinoma
- Microvascular compression syndrome



Vestibular Nucleus



Major Nuclei (4)

1. Superior, ‘S’, Bechterew, vertical canals, VOR
2. Lateral (‘L’, Deiters), VSR
3. Medial (‘M”, Schwalbe), lateral canals, VOR
4. Descending (‘D’), cerebellar connections

Vascular supply – almost everything affects the vestibular nucleus

- Big nucleus
- Vertebral/PICA
- AICA
- Basilar branches

Vestibular References

- Baloh and Honrubia. Clinical neurophysiology of the vestibular system, (F.A.Davis) 1979
- Baloh. The essentials of Neurotology (F.A.Davis).
- Brodal A. Neurological anatomy in relation to clinical medicine. Oxford, 3rd Edition.
- Dichgans J, Mauritz K. Patterns and mechanisms of postural instability in patients with cerebellar lesions. In: Motor Control Mechanisms in Health and Disease (Ed. J. E. Desmedt), Raven, New York, 1983, 633-
- Fukuda T. Statokinetic reflexes in equilibrium and movement. U Tokyo Press, 1981 (This is a neat book !)
- Leigh and Zee. The neurology of eye movements (F.A.Davis), 1991
- Pender DJ. Practical Otology. Lippincott. 1992
- Schwartz's chapter in Volume IV of Otolaryngology - Head and Neck Surgery, 1986. Good for VSR.
- Wilson and Melville Jones, Mammalian Vestibular Physiology, 1979.

References

- Baloh, RW. The Essentials of Neurotology. F.A.Davis, 1984, there is a newer edition also.
- Katz J. Handbook of clinical audiology, III edn. Williams and Wilkins, 1985. (There is a newer edition also)
- Kelly JP. Hearing in Principles of Neural Science, 3rd edn (Ed. Kandel ER, Schwartz JH, Jessel TM), 1993. Appleton and Lange, Norwalk Conn. Basic stuff.
- Pender DJ. Practical Otology, Lippincott, 1994 (available and useful)
- Webster DB, Popper AN, Fay RF (Editors). The mammalian auditory pathway: neuroanatomy. Springer-Verlag, New York, 1992 (excellent in-depth coverage of auditory neuroanatomy).