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
Inertial navigation

6 degrees of freedom problem

- Three axes of rotation
  - Roll, pitch and yaw
  - Roll, pitch, yaw
- Three axes of translation
  - AP, Lateral, Vertical

The Navigation Problem.

- 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 Canals are angular rate sensors.
- Otoliths (utricle and saccule) are linear accelerometers
- Bilateral symmetry 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 = ACCELERATION

Imperfections in Vestibular Sensors

- Imbalance
- Timing
- Gain
- Noise

Imbalance

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

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

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
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.

Ewald’s 3 Laws (1892)

- 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


Ewald’s Compensation
need for both eyes and neck

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.


Imperfections in Vestibular Sensors

- Noise - a common problem
  - Positional vertigo (BPPV mainly)
  - Fluctuations in vestibular function
    - Ménière’s, Fatula
- 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/somatose
  - 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 others
  - 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

Formal method of forming “optimal estimate”.
Integrates efference with afference
Accounts for noise, sensor differences.

Anatomy

Bony labyrinth (size of dime)

- Semicircular Canal
- Superior, Posterior, Lateral

The Labyrinth is filled with Endolymph and Perilymph

- Endolymph
  - Na+: 150-160 mmol/L
  - K+: 10-14 mmol/L
  - Mg2+: 10 mmol/L
- Perilymph
  - Na+: 140 mmol/L
  - K+: 20-40 mmol/L
  - Ca2+: 0.1 mmol/L
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 = ACCELERATION

Membranous Labyrinth
- Narrow lumen increases effect of viscosity
- Allows mechanical integration to take place

Clinical Correlation - Hair Cells
- Aminoglycosides kill hair cells
- Loop diuretics and NSAIDS are hair cell toxins

Clinical correlates
- Vestibular Atelectasis
- Collapse of membranous labyrinth
- May correlated with dysequilibrium in elderly population.
Peripheral circulation to inner ear
- AI CA
  - Labyrinthine
  - Vestibulocochlear
    - PC, Saccule
  - Anterior vestibular
    - AC, LC, Utricle

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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
- AI CA
- Basilar branches
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