I have no financial interests to declare.
Questions to ponder

- Speaker's assumptions
- What keeps eyes aligned at birth?
- How important is the vestibular system to child development?
  - To brain injuries?

Questions to ponder

- Is there a vestibular, motor, auditory, and visual space world?
  - How do they work together?
    - (Hint - Actions of EOM parallel the SC canals!)
- What is underlying etiology of strabismus, paresis, palsy?
  - Could there be a vestibular component?

Neuro Terms and Abbreviations

- VOR: Vestibulo-ocular reflex
- rVOR: Rotational or angular movement of the head evokes the reflex which stabilizes visual images on the retina. Stimulated by semicircular canals.
  - It can be overridden by cervical ocular reflex (COR), which develops before voluntary eye movements.
- tVOR: Translational or linear VOR-The reflex that is similar to the rVOR, but is from the otoliths rather than the semicircular canals. It detects linear movements versus angular movement.
VOR

- VOR latency of 16 msec
  - Initially sub-cortical at birth (gain = 1.0)
  - Adult like (sub-cortical with cortical control) at 8-9 months (gain = 0.6-0.7)
- Testing
  - DVA 2 hertz
  - Head thrust
  - ENG
- Patient complaints – dizziness, lack of coordination, vertigo, reading delays, hx of ear infection, and blur with motion

VOR

- Almost always effected with ABI
- Sometimes causative in oculomotor deficiencies
- Primarily reflexive early on, cortical develops control later
- Can be adapted/changed
  - Changed by LENSES®
  - Plus lens increases gain
  - Minus lens decreases gain
  - Prism changes (+ or -) in one plane...
  - Changed with therapy

VOR stabilizes the retinal image during BRIEF and SHORT head or body movements.

How about SUSTAINED and LONGER Durations?
Motion Processing

- OKR (okn) - Latency of 140 msec
  - Registers sustained stimulus through subcortical with cortical integration (along with development)
  - Stimulated by visual motion input
  - Involves smooth pursuit, saccade, and optokinetic systems
  - Deficiencies found in strabismus (commonly infantile)

Motion Processing

- OKR
  - We are born (if neurologically intact) with monocular pursuit tracking asymmetries (sub-cortical system in one direction)
  - Born with the ability to track T→N ≠ N→T
  - Exophoria at birth – drives us to converge/orthophoria/trophia

Motion Asymmetry

- Infants
  - N→T is functional at about 4-6 months old (with binocularity) and should be symmetrical by 9+- months
- Brain injury patients
  - Motion processing affected?
- Questions on whether a strabismus is from early infancy or not
- Patient complaints – Strabismus, depth perception, divergence difficulties, sports difficulties, hx of ear infections, & more
Motion Asymmetry – pursuit, saccades, OKN
How do we prevent blur with head movement?

- VOR motion sensing 16 msec
- OKN motion sensing 140 msec
- Fixation (inhibition of movement)
- Mismatching with the two systems = blur, nausea, motion hypersensitivity, etc
  - Mismatch = Neural integrator “leaky”
    - Horizontal - Medial vestibular nucleus and the NPH (nucleus prepositus hypoglossi)
    - Vertical – interstitial nucleus of Cajal

Peripheral Vestibular System

- Bony Labyrinth
  - SCC, vestibule, cochlea (hearing)

Peripheral Vestibular System

- 3 Inner ear semicircular canals (lateral/superior/posterior) in each ear sense angular acceleration via cupula deflection
  - Rotational movement like turning around a corner, getting out of bed, etc.
Peripheral Vestibular System

- Inner ear otolith organs sense **linear acceleration** via macula (saccule/utricle)
  - Sense gravity changes (static tilt), linear acceleration
  - Horizontal movement, vertical jumping, walking up stairs, lateral movement, etc.
  - Muscle tonus\(^ {11,12} \)
- Multi-factorial functions
  - Similarly is anything purely accommodation or purely convergence?
"The semicircular canals respond to angular acceleration and the otoliths respond to linear acceleration. Together they provide inputs for the VOR."

r-VOR and t-VOR respectively

*The Neurology of Eye Movements* - Leigh and Zee
Peripheral Vestibular System

- Semi-Circular Canals (SCC) (r-VOR)
  - Lateral isolation – 30° down to be horizontal
  - Superior/posterior isolation:
    - 30° down from horizontal and 45° head tilt right isolates right posterior and left superior to horizontal plane
    - 30° down from horizontal and 45° head tilt left isolates left posterior and right superior to horizontal plane
    - Side tilted makes posterior on same/superior on opposite side as if horizontal

Peripheral Vestibular System

- Otoliths (t-VOR) 2 ways to register movement
  - Saccule
    - Register vertical linear acceleration/deceleration movement with head upright
  - Utricles
    - Register horizontal linear acceleration/deceleration movement with head upright
  - All vestibular registration in head movement is based on acceleration/deceleration only. Sustained movement does not stimulate the VOR
Peripheral Vestibular System

Peripheral vestibular effects on EOMs

- Position of SC canals is nearly the same as that of the EOM
- 6 EOMS direct plane of action with SCC
  - L-lateral SCC to RLR and LMR
  - L-anterior SCC to RIO and LSR
  - L-posterior SCC to RIR and LSO
  - R-lateral SCC to LLR and RMR
  - R-anterior SCC to LIO and RSR
  - R-posterior SCC to LIR and RSO

- Excitation and inhibition is always a two way street
  - L-lateral SCC to RLR and LMR excitatory in one direction and inhibitory in other direction
  - L-anterior SCC to RIO and LSR excitatory in one direction and inhibitory in other direction
  - L-posterior SCC to RIR and LSO excitatory in one direction and inhibitory in other direction
  - R-lateral SCC to LLR and RMR excitatory in one direction and inhibitory in other direction
  - R-anterior SCC to LIO and RSR excitatory in one direction and inhibitory in other direction
  - R-posterior SCC to LIR and RSO excitatory in one direction and inhibitory in other direction
Is it coincidence that the eye muscles and semicircular canals function in the same plane of action?

Peripheral vestibular effects on EOMs

- Review - what do we get out of this?
  - rotational or angular VOR = SCC
  - translational or linear VOR = Otoliths (saccule & utricle)
- Semi isolation - VOR and PRN
  - Lateral - 30 deg to horizontal
  - Posterior/Superior - 30 forward and 45 deg left/right to horizontal/vertical
- Can you have SCC stimulation without otolithic involvement? Vice versa?
Central Vestibular System

- Neural Integrator in Cerebellum
  - Prolongs/decreases signal from peripheral apparatus
  - Signals from SCC/otoliths
  - Velocity signal aligns eye to speed of rotation
- Horizontal oculomotor – Nucleus Prepositus Hypoglossi
- Vertical and torsional oculomotor – Interstitial Nucleus of Cajal

“Velocity signals from SCC or acceleration signals from otoliths, need a signal encoding eye position” – Vestibular Rehabilitation; Herdman (feldenstruktur fibers role?)

Peripheral vestibular effects on EOMs

- Feldenstruktur fibers
  - New findings with electron microscopy (thanks to Dr. Richard Brunech)
  - 1:1 or 1:2 neuron to motor unit
  - So far only found in the ear (stapes and tensor tympani) and EOMs
    - Stapes allows focus of audition (ciliary body)
    - Tensor tympani contracts when too loud (pupils)
  - 20% of all motor neurons in EOMs
  - Not fully developed till 6-8 years of age
    - Should this be how much and when we do near work?
  - Proprioceptive feedback loop for EOM position
    - Should we cut? Do they grow back?

Take home message

- Peripheral vestibular apparatus
  - SCC, Otoliths
    - Motion detectors - rotational and linear
  - Basis for VOR
- Central vestibular
  - Processes signals from vestibular, ocular, proprioception
  - Neural connections to all sensory motor systems
- Motion processing
  - All the above makes VOR + OKN = stabilized imagery and can be adapted/changed
Vestibular Processing

- Balance and postural control is based upon:
  - Vision
  - Vestibular
  - Somatosensory: Proprioception/Kinesthetic-body plus neck (Cervical reflexes)
  - Integration through the neural integrator
- Example of eyes closed-effects of each upon balance

Functional development

- Relationship to arousal, infant development
- Postural control is integration of vestibular/motor/vision (vestibular more for arousal?)
- Early postural control is based on vision and motor
- Then vestibular motor takes the lead of postural control around age 6-8, freeing vision for cognition, exec function
Specific functions of vestibular processing (Herdman)

- Extensor tone
  - postural input for stability – basis for CI???
- Cocontraction - flexion/extension balance
- Equilibrium responses
  - Ability to move freely in space depends on integration of reflexes/stereopsis development?
  - Falling, rigid movement - spasticity

**Functional development**

“In sensory integrative therapy, vestibular stimulation is used to either quiet or stimulate or organize a child’s activity level.”

Cortical connections to and from:
- Ocular/Auditory/Proprioception/Tactile

"Vestibular sensations are generally accompanied by congruent visual and somatosensory inputs; when conflicts arise, discomfort and motion sickness can result" - Neurology of Eye Movements – Leigh and Zee

add “AND FUNCTIONAL DEFICITS OF VISION AND ADL’s OCCUR” – Jason Clopton

**Saccades** 150-250 msec latency — reflexive and voluntary
- Reflexive saccade
  - Reflex from peripheral movement awareness
    - Retina – LGN – V areas to...
    - Superior Colliculus
    - CN 6 then CN 3 to - Horizontal reflexive saccade
    - CN 3 then CN 4 to - Vertical reflexive saccade

- Voluntary saccade
  - Controlled from attention and inhibited by dorsolateral prefrontal cortex
    - Retina – LGN – V areas to...
    - visual details or visual attention to frontal eye fields to superior colliculus No.
    - Pons-PPRF and Midbrain reticular formation to...
    - CN 6 then CN 3 to –Horizontal voluntary saccade
    - CN 3 then CN 4 to - Vertical voluntary saccade
Vestibular Pathways/Neurology

- Smooth pursuit 90-150 msec latency
  - Visual cortex V area to...
  - Temporal eye fields to...
  - Frontal eye fields to...
  - Dorsolateral pons to...
  - Vestibulocerebellum to...
  - Vestibular Nuclei to...
    - Midbrain reticular formation and MLF to...
    - CN 6 and CN 3 to - Horizontal voluntary pursuit
    - CN 3 and CN 4 to - Vertical voluntary pursuit

SUMMARY – VOR and OKN

- VOR-16 msec latency-
  - Registers brief stimulus through subcortical
- OKN-140 msec latency-
  - Registers sustained stimulus through subcortical with cortical integration (along with development)
- Pursuits – 90-150 msec latency –
  - Subcortical and cortical
- Saccade – 150-250 msec latency –
  - Subcortical and cortical
Summary of Systems

Peripheral vestibular processing (SC canals and otoliths) is NOT simple, intimate to eyes & visual processing.
Central processing outputs from vestibular nuclei to every other sensory system.

Vestibular Pathways/Neurology

Duality of all Sensorimotor Systems

Is there ever a purely sympathetic function or parasympathetic function?

Tactile
- Light touch (sympathetic/ambient/where/excite)
- vs. Deep touch (parasymp/focal/what/calm)

Proprioception
- Pushing-extension (sympathetic/ambient/where)
- vs. Pulling-flexion (parasymp/focal/what)

Vestibular
- Rotational (sympathetic/ambient/where/excite)
- vs. Linear (parasymp/focal/what/calmin)

Auditory
- Peripheral (sympathetic/ambient/where/excite)
- vs. Central (parasymp/focal/what/calmin)

Vision
- Peripheral (sympathetic/ambient/where/excite)
- vs. Central (parasymp/focal/what/where)
Thank You

Comments, criticisms, complaints, confusion, or $$...

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