Vestibular Disorders and Rehabilitation

Week 8: Dr. E

Dizziness is a Health Concern

- From 2001-2004, 35.4% of US adults age 40 y/o and > had vestibular dysfunction.
- People with a measured vestibular dysfunction who are also symptomatic have a nearly 8x increase in odds of falling.
- Dizziness is a common symptom affecting about 30% of people > 65 y/o.
- A majority of individuals > 70 y/o report problems of dizziness and imbalance, and balance-related falls account for more than 1/3 of the accidental deaths in the elderly.

Reflexes

- Vestibulo-ocular Reflex (VOR): compensates for head movement by moving the eyes at a velocity equal to head velocity in the opposite direction 1:1 ratio.
- Vestibulo-spinal Reflex (VSR): visual and somatosensory cues to maintain balance.
- Vestibulo-collic reflex (VCR): acts on the neck to stabilize the head; reflex produced counters the movement sensed by the otolithic or SCC canals.

Reflex (cont.)

- Cervico-ocular Reflex (COR): works with VOR-eye movements driven by neck proprioceptors. Facilitated when the vestibular system is injured.
- Cervicospinal Reflex (CSR): changes in limb position driven by neck afferent activity. Supplements the VSR.
- Cervicocollic Reflex (CCR): cervical reflex that stabilizes the head on the body. The extent that is contributed to head stabilization is uncertain, but appears to be useful in vertical plane and may be facilitated after labyrinthine loss.

Functions of Vestibular System

- Gaze Stability: VOR compensates for head movements by moving the eyes at a velocity equal to the head velocity in the opposite direction to the head.
- Postural Stability: VSR assists with visual and somatosensory cues to maintain balance.
- Sense of Orientation
- Detection of Linear and Angular Acceleration
- Other: integration of arousal and conscious awareness of the body via connections with the vestibular cortex, thalamus, and reticular formation.

Dysfunction

- Oscillopsia (VOR dysfxn)
- Disequilibrium
- Vertigo and Dizziness
- Sense of tilt/lateropulsion
- Imbalance
- Motion Sensitivity
- Gait Difficulties
- Falls

- Problems with vision, muscles, concentrations, and memory/attention span
- Suffer headaches, muscular aches (back/neck)
- Increased sensitivity to noise and bright lights
**Vestibular System Organization**

- Sensory Input (peripheral) = Afferent
  - Hair cells in the otoliths and semi-circular canals
- Central Processing = Central
  - Vestibular nuclei in the midbrain
  - Adaptive processor/cerebellum
- Motor Output (peripheral) = Efferent
  - Eye movements = VOR
  - Postural Movements = VSR

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**Sensory System in Postural Control**

- Vestibular: provides CNS with info about movement, speed, and acceleration of head with respect to gravity.
- Visual: orients us to the environment and provides info about slow movements or static tilt of head with respect to visual field.
- Helps us orient the body in space by using a reference to the objects around us.
- Somatosensory: provides info about the support surface and what position the body is at all times (positional info).

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**Central Processing of the Vestibular System**

- Cerebellum is responsible for the fine-tuning of the motor outputs (VOR and VSR).
- Essential role in neural plasticity and adaptation
- Adjusts for “error signals” coming from malfunctioning or absent vestibular system
- Feedforward and Feedback Loops
  - Combines sensory inputs, weighs them according to their relevance and reliability, and provides a reasonable estimate of orientation in space.

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**Motor Output of the Vestibular System**

- Gaze stabilization while the head and body are in motion is one of the major functions of the vestibular system
- 4 oculomotor control systems that keep the fovea on a given target
  - Saccades: voluntary/central control
  - Smooth pursuits: voluntary/central control
  - Vergence: voluntary/central control
  - VOR: reflexive/peripheral vestibular system
  - To stabilize a given target with head movement

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**Vestibular Portion of Labyrinth**

- Semicircular Canals
  - Anterior/ Superior
  - Posterior/ Inferior
  - Horizontal/ Lateral
- Otoliths
  - Utricle
  - Saccule

Blue is Bony
Orange is Membranous
## Principles of the Vestibular System

- **Tonic Firing Rate**
  - Vestibular nerve and nuclei have a normal resting firing rate of 70-100 cycles/sec
  - Baseline firing rate present without head movement
  - Tonic firing rate is equal in both sides (if not, sense of motion)

- **Velocity Storage System**
  - Normal VOR can deliver high standards of performance for brief head motions (firing rate decays to 32% in 7 sec; time constant)
  - Used as a repository for info about head velocity
  - Keeps vestibular related responses going after vestibular afferent info decays.

- **Push-Pull Relationship**
  - Excitation and inhibition (always together)
  - Actions that stimulate one inhibit the other

- **Inhibitory Cut-off**
  - Beyond a certain velocity, excitatory stimuli causes a greater response than inhibitory stimuli

- **Ewald's 2nd Law**:
  - Depolarization (excitation) of the cupula within the inner ear does not saturate, whereas hyperpolarization (inhibition) does.
  - The system can be excited more than it can be inhibited.

## Semi-Circular Canals

- **Detect Angular Acceleration**
  - Aligned at right angles to each other
  - Horizontal slopes 30 deg down and back
  - Work in pairs/coplanar
  - R anterior/L posterior
  - L anterior/R posterior
  - R/L Horizontal

- **Both ends attach to the utricle**
  - One end widens into a bulb-like area called the ampulla/crista ampullaris
  - The non-ampulla ends of the anterior and posterior canal fuse to form the common crus

## Otoliths

- **Detect Linear Acceleration**
  - Including gravity (static tilt of head)
  - Utricle: horizontal
  - Saccule: vertical
  - Functional unit is Macula
  - Also work in pairs

## Cupula

- Impermeable diaphragm like structure connecting sensory hair cells at the crest of the ampulla to the roof of the ampulla.
- Same specific gravity as the surrounding endolymph, so its presence does not make the SCC's sensitive to the static pull of gravity.
- Inertia causes the endolymph fluid to be pushed against the cupula causing an angular displacement of the hair cells.
- Membranous labyrinth moves with head motion, the endolymph does not, causing a relative endolymph motion opposite of the head motion.

## Sensory End Organ Hair Cells

- Embedded inside each of the 3 cupula and in the macula of the otolith organs
- Composed of ciliary bundles
- When they are deflected toward the largest hair, the hair cell is depolarized which increases the firing rate/excitation of the vestibular nerve fibers to the brainstem
- When the hairs are deflected away from the largest hair, they are hyperpolarized which causes a decrease in firing rate/inhibition of the corresponding vestibular nerve.
**Otolithic Membrane**

- Saccule and Utricle
- Hair cells within the macula project up into membrane
- Gelatinous membrane embedded with otoconia
- Increases the specific gravity of the membrane compared to the fluid surrounding it, causing the otoliths to be responsive to the static pull of gravity.
- Central region is called striola.

**Peripheral Vestibular Causes**

- Benign Paroxysmal Positional Vertigo (BPPV)
- Vestibular Neuritis
- Acoustic Neuroma
- Bilateral Vestibular Loss
- Meniere's Disease
- Fistulas
- Temporal Bone Fracture
- Post-traumatic vertigo
- Labyrinthine Concussion

**BPPV**

- Caused by mechanical displacement of otoconia from the otolithic membrane of the utricle into one of the SCC’s
- Idiopathic or Traumatic
- Most Common Cause of Vertigo
  - Signs/Symptoms
    - Sudden onset
    - True vertigo/Spinning Sensations
    - Latency of 1-5 seconds
    - Lasts only seconds
    - Induced by changes in head position
    - Visible nystagmus
    - Reversal of nystagmus direction on returning to upright
    - Response diminishes with repetition of maneuver (fatigability)
- Test: Dix-Hallpike or Roll Test

**Vestibular Neuritis**

- Sudden Onset with vertigo and nausea lasting ~ 2 days
- 2nd most common cause of vertigo
- Residual head motion provoked dizziness and imbalance
- Acute Phase: spontaneous horizontal nystagmus beating toward non-involved ear (always beats toward the most active side)
- Primary cause: viral
- Unilateral loss (UVL)
- PT is very effective
- Tests: + head thrust, DVA, head shaking nystagmus, vestibular function testing

**Meniere’s Disease**

- Endolymphatic hydrops: malabsorption of the endolymph in the endolymphatic duct and sac.
- Symptoms persists from minutes to 24 hours.
- Meniere’s Triad
  - Fluctuating unilateral hearing loss
  - Episodic vertigo
  - Tinnitus
- Requires medical diagnosis/testing to confirm
- Not appropriate for PT in active state
- Control with diet, medication, and external devices.

**Acoustic Neuroma**

- Tumor originates in the Schwann cells lining the axons of the VIII cranial nerve.
- Typically benign (MRI/CT to confirm)
- Surgical Management
- PT following surgery to promote compensation for vestibular loss
- Signs/Symptoms
  - Gradual Hearing Loss
  - Tinnitus
  - Imbalance
  - Positive Hyperventilation Testing
### Bilateral Vestibular Loss

- **Acute Onset:** ototoxicity typically from Gentamycin or Chemotherapy (Cisplatin).
- **Gradual Onset:** common in elderly with degeneration of hair cells or subsequent UVL’s.

**Signs and Symptoms**
- Severe Imbalance
- Will have NO dizziness/vertigo with complete loss
- Unable to walk or balance in the dark
- Head Thrust Bilaterally

### Fistulas

- Perilymph Fistula is an abnormal connection between the air-filled middle ear and the fluid-filled inner ear usually at the round or oval window.
- Superior Canal Dehiscence: caused by thinning or complete absence of the part of the temporal bone overlying the superior semicircular canal.
- Cholesteatoma: abnormal growth that invades the mastoid air spaces and can erode into the horizontal SCC causing body fistula damage.

In all cases, vestibular and auditory signs/symptoms provoked by external stimuli such as sound (Tulio’s Phenomenon), change of pressure or vibration.
- Fluctuates with pressure changes
- Medical: avoid strain, sneeze, cough, or head-hanging positions; surgery

### Other Vestibular Disorders

- **Temporal Bone Skull Fracture**
  - Essentially the patient ends up with a complete loss of equilibrium sense on one side as well as hearing
  - Often associated with TBI
- **Post-traumatic Vertigo**
  - Tends to follow head trauma with similar symptoms to BPPV & UVL
  - Hemorrhage into the labyrinth
  - Prognosis is good with symptoms gradually resolving within weeks to months
- **Hemorrhage into the Labyrinth**
  - Vast majority of patients respond to vestibular rehabilitation
- **Labyrinthine Concussion:** manifests with ataxia, hearing loss, and imbalance; Bilateral BPPV
  - Most common vestibular injury due to TBI

### Concussion

- Dizziness is a frequent symptom of concussion and has been reported to occur in 23-81% of cases in the first days after injury.
- Poor balance, postural instability
- Oculomotor signs, impaired smooth pursuit, vertigo, and perception of tilt
- VRT had a significant treatment effect for all self-report and performance measures.

### Central Vestibular Disorder

- **Vascular:** Wallenberg’s Syndrome, Head injury, cerebellar infarct, Vestibular Nuclei of midbrain.
- **Demyelinating Disease/MS**
- **Post-Concussive Syndrome**
- **Congenital:** Arnold-Chiari
- **Degenerative Cerebellar Disease:** abnormal ocular pursuit, irregular saccades, gaze and end point nystagmus, ataxia.
- **Gradual Decline.**

### Vestibular Dysfunction

- **Acoustic Neuroma**
- **BPPV**
- **Labyrinthitis/Neuritis**
- **Meniere’s Disease**
- **Temporal Bone Fracture**
- **Central Vestibular Region**
- **Ototoxicity/BVL**
- **Perilymph Fistula**
- **Superior Canal Dehiscence**
- **Labyrinthine Concussion**
- **Hemorrhage within vestibular system**
Other Causes

- Multi-factorial
- Hyperventilation
- Peripheral Neuropathies
- Stress/tension/fatigue/depression
- Medications
- Blood sugars
- Cardiac
- Systemic

Non-Otogenic causes of Dizziness

- Aneurysm
- Arrhythmia
- Atherosclerosis
- Defective heart valve
- Dehydration
- Degenerative arthritis
- Embolism
- Heart Attack
- Hyperventilation
- Medications
- Orthostatic Hypotension
- Osteoarthritis
- Peripheral Neuropathies
- Stress/tension/fatigue
- Tumor in brain stem
- Visual disturbances
- Mal de Debarquement
- Vertebro Basilar Insufficiency
- Cervicogenic
- Anxiety Disorder
- Chronic Subjective Dizziness/Visual Vertigo

Vestibular Rehabilitation

- Designed to provide small, controlled, and repeated movements that provoke dizziness and/or unsteadiness in order to:
  - Desensitize the balance system to the movement
  - Enhance the fine-tuning involved in long-term compensation
- Three compensation techniques:
  - Adaptation: ability to make long term changes in the neuronal response to head movement with the goal of decreasing retinal slip and increasing the gain of the remaining vestibular system
  - Substitution: BVL, alternative strategies to overcome loss
  - Habituation: long-term reduction of a response to a noxious stimulus - more you move, the better you feel.