Differential Diagnosis and Treatment of Balance Disorders:
The interaction of visual, vestibular and somatosensory systems

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Objectives
• Describe normal interaction of vision, vestibular and somatosensory systems
• Describe differential diagnosis process for vestibular dysfunction
• Appraise status of vision and balance research

Content Overview
• Postural Control and Balance
• Differential diagnosis of vestibular dysfunction
• Vision loss and consequences

Functional Definition of Balance:
Ability to:
stand still or quietly in place (slight 12.5º sway is normal)
move voluntarily – there is a limit of stability within our specific base of support
respond automatically to external challenges and regain quiet stance – called perturbations
perform these tasks under various environmental conditions

Role of Vestibular System in Normal Function
Postural control:
1. Sensory input about head position in space (related to gravity) and acceleration.
2. Input for appropriate motor response to conflicting visual/somatosensory input.
Visual control:
1. Gaze stabilization with head motion
2. Head stabilization with respect to vertical

(Nasher 1990)
Impact of Vision on Development of Normal Postural Control

- Head control at 3 months visually driven
- Tonic Labyrinthine reflex supported by interaction of eyes/head.
- Visual mapping of hands/feet for interacting with environment essential for normal function.
- Vision and interaction to horizon/environment essential for developing trunk proprioception and kinesthesia.

Motor strategies with perturbed stance

<table>
<thead>
<tr>
<th>Motor</th>
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</thead>
<tbody>
<tr>
<td><strong>Ankle</strong></td>
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</table>
| Best strategy:  
| Smallest adjustment in center of mass (COM)  
| Efficient muscle recruitment:  
| distal to proximal  
| Energy efficient  
| Loss of ankle strategy documented in elderly |  
| **Stepping** |  
| Largest adjustment in COM  
| Slowest strategy  
| Realign BOS through limb motion  
| Normal response to very large perturbations  
| More likely to result in fall |  
| **Hip** |  
| Larger adjustment in COM  
| Less efficient muscle recruitment:  
| Slower reaction time as more muscles recruited  
| Proximal muscle recruited first  
| Full body response  
| Normal response to larger faster perturbations |

Common Diagnoses involving Vestibular System:

**Central:**
- CVA, seizure, TBI, central tumor

**Peripheral:**
- BPPV, vestibular hypofunction, fistula, Meniere’s disease, peripheral tumor, migraines, labyrinthitis,

Differential Diagnosis: Vertigo/dizziness

- Must be differentiated from non-vertiginous vertigo
  - Hypoxia
  - Myocardial ischemia/cardiac arrhythmias
  - Medication side effects
  - Infection/dehydration with electrolyte imbalance
  - Toxins
  - Hypoglycemia
  - Migraines
  - Cerebellar ataxia, basal ganglia disorders
  - Psychogenic

Causes of Dizziness

- Percentages
  - BPPV 48%
  - Meniere 19%
  - Middle Ear 6%
  - UVH 14%
  - BVH 8%
  - Fistula 5%

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Vestibular Anatomy Review

- Labyrinth
- Vestibular afferents
- Efferent pathways
Vestibular labyrinth

- Bony labyrinth
  Contains SSC, utricle, saccule
  Filled with perilymphatic fluid (like CSF)

- Membranous labyrinth
  Structure suspended within body labyrinth
  Supported by CT
  Filled with endolymph

Vestibular Labyrinth

- 3 semicircular canals:
  90° from each other
  Horizontal
  Anterior
  Posterior
- 2 otolith organs
  Saccule
  Utricle

Vestibular Afferents:
Hair cells that generate action potentials

- SSC - stimulated by rotatory fluid flow that moves cupula
  Function in matched pairs
  PUSH-PULL mechanism

- Otoliths – stimulated by acceleration (NOT velocity) motions of otoconia
  - Saccule=up/down
  - Utricle=forward/back
  - both=head tilt

Vestibular Afferent Nerves

- Regular afferents
  - Have resting firing rate of 70-100 spikes/second
  - Increases firing when stimulated on same side, decreases rate on opposite side
  - Function primarily in VOR

- Irregular afferents
  - Typically have no resting firing rate
  - Function primarily in VSR
  - Can have highly fluctuating spikes when stimulated for variable responses

- Both types function as matched pair in normal vestibular system to give directional information.
  Called the push-pull mechanism

Main Efferent pathways

- Vestibulospinal pathway – slower velocities
  - Medial – to trunk/neck
  - Lateral – to Lower extremities
  - Also has connections to limbic system

- Vestibulo-Ocular pathway- faster velocities
  (via Paramedian Pontine Reticular formation)

- Vestibulococcolic pathway-
  Delivers vestibular information to cervical muscles

Vestibular Disorder Categories

- Peripheral loss
  - Unilateral and bilateral hypofunction

- Peripheral hypersensitivity
  - BPPV(benign paroxysmal positional vertigo)
  - Motion sensitivity
  - Migraines
  - Meniere’s disease

- Central Pathology
  - Pathway disorders
  - Degenerative disorders
Vestibular Disorder Categories

Peripheral loss: Unilateral hypofunction:
- Remaining vestibular apparatus has resting firing rate
- Body interprets this as turning, since one side is firing faster than the other (push/pull mechanism)
- Over time patients can adapt to the inaccurate sensory information
- Many remain symptomatic for long periods
- VOR remains permanently lost/damaged on one side

Peripheral loss: Bilateral hypofunction
- Neither vestibular apparatus is functioning ideally
- Patient must depend on vision and somatosensory systems
- Some evidence of neuroplastic changes are possible, depending upon the etiology
- All vestibular reflexes affected.

Vestibular Disorder Categories

Peripheral hypersensitivity: BPPV
(benign paroxysmal positional vertigo)
- Otoconia in utricle become dislodged
- Move into SCC
- Stimulate hair cells where they lie:
  • Free floating in SCC=canalithiasis
  • Attached to cupula=cupulolithiasis
- Each time head is moved, the otoconia re-stimulate the SCC
- Cause profound sensation of vertigo in certain positions
- Etiology: head trauma, labyrinthitis, anterior vestibular artery ischemia, also spontaneous unknown etiology
- KEY finding is LATENCY of symptoms
- Vestibular Reflexes will be normal

Vestibular Disorder Categories

Peripheral hypersensitivity: Motion sensitivity
• General hypersensitivity to vestibular and/or visual input.
• Symptoms IMMEDIATELY after mild stimulation
• Often people report limiting activity to avoid symptoms
• Can present as a vicious cycle
• Responds to habituation training
• Strong link to visual system as symptoms often triggered by visual stimulus (e.g., Looking down from heights)
• Vestibular reflexes will be normal

Vestibular Disorder Categories

Peripheral hypersensitivity: Migraines
- Common cause of episodic vertigo and dysequilibrium – very similar symptoms to Meniere’s disease – difficult to differentiate
• Associated with:
  – BPPV
  – Torticollis
  – Benign recurrent vertigo
  – Motion sickness/visual stimulation of vertigo including fear of heights
  – Meniere’s disease

Migraine vs. Meniere’s Disease

<table>
<thead>
<tr>
<th>Migraine</th>
<th>Meniere’s Disease</th>
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<tbody>
<tr>
<td>Tinnitus: high pitched</td>
<td>Tinnitus: low-pitched, roar</td>
</tr>
<tr>
<td>May have ear fullness, phonophobia</td>
<td>Usually ear fullness or hearing loss</td>
</tr>
<tr>
<td>Photophobia</td>
<td></td>
</tr>
<tr>
<td>True spontaneous vertigo is rare; can occur for minutes</td>
<td>True spontaneous vertigo is common, can occur for hours</td>
</tr>
<tr>
<td>Short nap usually helps</td>
<td>Short naps usually do not help</td>
</tr>
<tr>
<td>Visual auras are common</td>
<td>Visual auras NOT common</td>
</tr>
<tr>
<td>Motion sickness common</td>
<td>Motion sickness NOT common</td>
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</table>
Vestibular Disorder Categories

Central Pathology
– Pathway disorders
– Degenerative disorders

• More complex to diagnose and treat.
• Pathology can occur in a single area of the pathway or impact multiple areas
• Impaired vestibular reflex findings may be peripheral AND central in origin.
• Degenerative disorders have poorer prognosis

Vestibular Center Examination

• Eye motions in response to direct stimulus:
  (Particularly look for nystagmus)
• Bithermal Caloric Test
  ◆ Warm water: nystagmus with the fast component moving toward the canal that was stimulated
  ◆ Cold water: nystagmus in the opposite direction of the canal that was stimulated
• Rotational Chair Testing
  ◆ A motorized rotational chair tests the horizontal semicircular canal
  ◆ Angular acceleration can be controlled and responses to angular acceleration measured
  ◆ Rotational stimuli are ideally suited for testing those with bilateral peripheral vestibular lesions because both labyrinths are stimulated simultaneously

Examination via Computerized Posturography

• Sensory orientation test is gold standard for vestibular exam (AMA 2000)
• Computerized dynamic testing definitive test for nonorganic sway
  – (otolaryngeal head neck surg 117: 293-3021997)
• MRI low yield for diagnosis of dizziness (Gizzi 1996)

Sensory Organization Test

<table>
<thead>
<tr>
<th>Cond</th>
<th>Vision</th>
<th>Surface</th>
<th>Disadvantaged system</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Eyes open</td>
<td>Fixed</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>Eyes closed</td>
<td>Fixed</td>
<td>Vision - absent</td>
</tr>
<tr>
<td>3</td>
<td>Sway referenced</td>
<td>Fixed</td>
<td>Vision - incorrect</td>
</tr>
<tr>
<td>4</td>
<td>Eyes open</td>
<td>Sway referenced</td>
<td>Somatosensory - absent</td>
</tr>
<tr>
<td>5</td>
<td>Eyes closed</td>
<td>Sway referenced</td>
<td>Somatosensory and vision - both absent</td>
</tr>
<tr>
<td>6</td>
<td>Sway referenced</td>
<td>Sway referenced</td>
<td>Somatosensory absent, vision incorrect</td>
</tr>
</tbody>
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Clinician Clinical Examination

Subjective Measures

• Dizziness Handicap Inventory
  – Measure of self perceived disability from vestibular disorder
  – 100 = maximum perceived disability
  – Useful measure perceived treatment efficacy
• Disability Scale
  – Self perceived disability measure
  – Score of 4 or higher is correlated with poor outcome
  – High test-retest validity (r=0.97)
• Activity Specific Balance Scale (ABC)
  – Confidence in balance
  – 100% is no fear of falling
  – Correlates negatively with the DHI

Subjective Assessment

<table>
<thead>
<tr>
<th>Subjective Assessment</th>
<th>Motion Testing</th>
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<tr>
<td>Onset</td>
<td>Motion sensitivity testing</td>
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<tr>
<td>Quality and intensity</td>
<td>Examination of the vestibulo-ocular system</td>
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<tr>
<td>Provoking</td>
<td>Functional tests</td>
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<tr>
<td>Alleviating factors</td>
<td></td>
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<tr>
<td>Temporal factors</td>
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<td>Contributing factors</td>
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<tr>
<td>Medication side effects</td>
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<td>Movement induced</td>
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Oculomotor Function Tests
• Gaze stability at rest
• Smooth pursuits
• Saccades / Optokinetic test
• Visual fields

Vestibulo-ocular tests
• VOR/ Head thrust
• Dynamic Visual Acuity
• VOR cancellation (Smooth pursuits with head motion)
• BPPV tests

Key Clinical Finding: Nystagmus
1. Slower drift of eye triggered by stimulus
2. Fast component:
   Parapontine RF (in brainstem) repositions fovea in midline. Named by direction of fast component
   Suppression by visual fixation when CNS intact (use Frenzel Lenses to inhibit visual fixation)

Nystagmus in BPPV
Nystagmus will beat in 2 directions:
• Up or down (opposite direction of canal)
• Torsion towards impaired side.

Motion Sensitivity Quotient Test
• Tests each semicircular canal with motions
Rate intensity and duration of symptoms
Observe for nystagmus:
  – Direction
  – Duration
• Incorporates the Hallpike maneuver for BPPV
• Immediate onset of symptoms indicates peripheral hypersensitivity
• Latency of symptoms - BPPV

Functional tests for Vestibular Loss
• Fukuda Step Test
• SOT- Sensory Organization Test
• mCTSIB- modified Clinical Test of Sensory Organization in Balance
• TUG – Timed up and Go
• DGI – Dynamic Gait Index
• FSST- Four Square Step Test

Treatment of Vestibular Dysfunction
• Adaptation
  – Use stimulus to induce CNS adaptation – modifies the gain of the vestibular system.
• Habituation
  – Positional movements to provoke symptoms, nervous system habituates to the position and symptoms are reduced
• Substitution of other strategies
  – Somatosensory/Vision/ or environmental modification
• Canalith repositioning or liberation
  – Use sequence of positioning to move dislodged otoconia from SSC back into otolith.

Vision and Mobility – Current Understanding
• Vision essential for normal postural control development
• Adults with visual deficits have higher incidence of:
  Osteoporosis Stroke
  Depression HTN
  Heart disease Arthritis
  Diabetes
• Falls are common in aging population often the first step towards immobility and death.
• Falls are significantly more prevalent in visually impaired elderly
Opportunities for Collaborative Research

Simulating a visual impairment is not adequate.

Research on mobility in visually impaired often without proper diagnosis of visual impairment

Research done by optometrists/ophthalmologists on mobility in visually impaired population relies heavily on survey, NOT direct measure of function.

Comments/Recommendations

- Interaction of vision, vestibular and somatosensory systems is essential for normal function
- Identifying motion impairments in all populations is critical to reducing risk of co-morbidities including falls.
- Vision is driving factor in typical development of postural control, and those with impaired vision of ALL ages and reasons are at increased risk for mobility concerns.
- The interaction of vision and balance is an emerging area of research, rich with interdisciplinary possibilities
- Include subjective screening for falls, mobility concerns and vestibular dysfunction in primary care settings

References


