

Dizziness and Balance Dysfunction in Traumatic Brain Injury

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Objectives

- At the end of the lecture the participant will be able to:
 - Describe the anatomy and physiology of the vestibular system
 - Describe the differential diagnosis for dizziness and balance dysfunction following TBI
 - Describe the evaluation for dizziness and balance dysfunction following TBI
 - Describe treatment for common disorders following TBI

Incidence of Dizziness in TBI

- 24-80% initial symptoms
- 20-47% at 5 years
 - Minor TBI: 20 - 32%
 - Moderate TBI: 37 - 47%
 - Severe TBI: 26%
- 23% of a brigade combat team returning from Iraq had TBI
 - 88% due to blast injuries
 - Dizziness and Balance Disorders among the top 3 complaints of service members following blast injuries
 - Dizziness 59%
 - Balance dysfunction 26%

Prevalence of Vestibular Dysfunction in TBI

- Of 100 patients with dizziness post-TBI
 - 71% Peripheral Vestibular Dysfunction
 - 61% BPPV
 - 8% Central Vestibular Dysfunction
- Of 58 patients with dizziness post-TBI (military)
 - 28% BPPV
 - 41% Migraine-related Dizziness
 - 19% Spatial Disorientation

Association of Dizziness and TBI

- Dizziness may be due to TBI pathology (CNS)
- Dizziness may be due to vestibular pathology due to TBI
- Dizziness may be underlying cause for TBI (falls)
- Dizziness may complicate rehabilitation for sequelae of TBI
- Dizziness may mimic cognitive impairments seen with TBI
- Cognitive impairments due to TBI may complicate vestibular rehabilitation

Vestibular role in Postural Control

- Provides input on head movement and position
- Provides gaze stabilization
- Provides postural adjustments
 - Vestibular spinal reflexes

Differential Diagnosis for Dizziness Associated with TBI

- Benign Paroxysmal Positional Vertigo
- Labyrinthine Concussion
- Brainstem Concussion
- Central Vestibular Dysfunction
- Cervicogenic Dizziness
- Post-traumatic Meniere's Disease
- Post-traumatic Migraine-related Vestibulopathy
- Perilymphatic Fistula
- Anxiety-related Dizziness
- Non-vestibular causes

Benign Paroxysmal Positional Vertigo

- Most common form of dizziness
- Presentation
 - Short duration episodic vertigo during head movements
 - May also complain of imbalance, disorientation
 - Worse in am
- Pathophysiology
 - Otoconia become dislodged from utricle and either float in endolymph of semicircular canal or attach to cupula
 - This causes the semicircular canals to respond to gravity
 - Patients demonstrate characteristic nystagmus in response to head movements that has a latency of 2-15 seconds and a duration of <1 minute

Post-traumatic BPPV

- Onset with mild TBI within a few days *Katsarkas, 1999*
- Higher incidence of bilateral involvement *Katsarkas, 1999*
- Consider checking all 3 canals on both sides before treating
- Recurrence rate of 26-30% *Nunez et al 2000; Epley 1992*
- Results in quicker relapses than non-traumatic *Gordon et al 2004*
- Requires repeated repositioning compared to those with non-traumatic BPPV *Gordon et al 2004; Del Rio et al 2004*

Labyrinthine Concussion

- Damage to the labyrinth, with or without bony fracture
 - Membranous labyrinth very fragile and easily damaged
- Laboratory findings
 - Unilateral peripheral loss with caloric testing
 - Asymmetric sensorineural hearing loss due to damage to the cochlea
 - Rotational chair testing abnormal if compensation is not complete

Brainstem Concussion

- Shearing on the root entry zone of the 8th cranial nerve may lead to hemorrhage or cell death in the area of the vestibular nuclei
- Signs and Symptoms
 - Dizziness/vertigo
 - Postural instability
 - May be associated with other cranial nerve damage or CNS signs
 - VOR and saccadic eye movement abnormalities
 - Implicated if compensation does not occur with labyrinthine concussion

Central Vestibular Dysfunction

- Dysfunction of the vestibular nuclei, cerebellum and other vestibular pathways
 - Presentation
 - Depends on where lesion occurs
 - Less likely to have true vertigo
 - More likely to have constant symptoms
 - More likely to have balance dysfunction
 - More likely to have central nervous system signs

Cervicogenic Dizziness

- A specific form of central vestibular dysfunction
- Responsible for < 1% of all cases of vestibular dizziness
- Diagnostic Criteria
 - History of neck trauma or pathology
 - Symptoms of dizziness and imbalance temporally related to neck pain or headache
 - All other causes of dizziness eliminated
- Current theory of Pathophysiology
 - Aberrant afferent information from C1- C3 causes altered perception of orientation in space

Meniere's Disease

- Presentation
 - Episodic, usually unilateral (lasts hours to days)
 - Vertigo
 - Hearing Loss
 - Tinnitus
 - Nausea
 - Aural fullness
 - Symptoms are totally reversible early in disease, gradually progress to permanent vestibular and hearing loss
- Current theory of pathophysiology
 - Swelling, or distension, of the endolymphatic compartment of the inner ear leading to rupture of membranous labyrinth resulting in transient potassium palsy of the vestibular nerve fibers

Migraine-related Vestibulopathy

- A specific form of central vestibular dysfunction
- Current theory of pathophysiology
 - Increased activity in the brainstem
 - Abnormalities in neurotransmitter levels
- Presentation
 - Dizziness may occur before, during, or after a migraine
 - Episodic vertigo, nausea, disorientation, space and motion intolerance associated with headache
 - Symptoms are often exacerbated by specific visual environments
 - Some patients can have migraine without headache, migraine equivalents, with dizziness instead of headaches

Migraine-related Vestibulopathy

- Diagnostic Criteria
 - Absence of documented vestibular pathology
 - Migraine diagnosis according to the International Headache Society (IHS) Criteria
 - Intermittent vertigo or disequilibrium – at least 2 episodes
 - Accompanied by photo or phonophobia or visual aura, not necessarily headache

Post-traumatic Migraine-Related Vestibulopathy

- Patients with post-traumatic migraine had significantly impaired neurocognitive function compared to non-migrainous headache or no headache *Mihalik et al 2005*
 - Caution should be exercised when returning to work or play

Perilymphatic Fistula

- Abnormal communication of the inner-ear and middle-ear spaces via labyrinthine windows or a microfissure of the bony labyrinth
- Episodic vertigo
- Sensorineural hearing loss/tinnitus – may be fluctuating
- Precipitated by increased intrathoracic or intracranial pressure
- Diagnosis difficult
 - Nystagmus or dizziness with Valsalva maneuver
 - Surgical exploration

Anxiety-related Dizziness

- 41% mild TBI report anxiety 5 years post injury
- Diagnostic Criteria
 - Dizziness is a defining or associated symptom of a psychiatric disorder
 - Dizziness is not correlated with vestibular pathology
- Vestibular abnormalities common in panic disorder and are associated with space and motion discomfort
- Common pathways between anxiety, space and motion discomfort, and perception of dizziness/vertigo

Non-Vestibular Causes

- Orthostatic Hypotension
- Medications
- Physical deconditioning
- Musculoskeletal injuries

Evaluation of the Patient with TBI and Dizziness



Subjective Assessment of Dizziness

- Dizziness Handicap Inventory *Jacobson and Newman, 1990*
 - 25 item test that assess the self perceived handicap due to dizziness
 - 3 subcategories: functional, emotional, and physical
 - Scored No: 0; Sometimes: 2; Yes: 4
 - Maximum: 100
 - High test-retest reliability *Jacobson and Newman, 1990*
 - Useful in directing patient interview
 - Questions 1, 5, 11, 13, and 25 are predictive of BPPV *Whitney et al*
 - Correlates with Physical Function Measures *Whitney, Wisley et al 2004*
 - 0-30 minimal impairment
 - 31-60 moderate impairment
 - 61-100 severe impairment

Subjective Assessment of Dizziness

- Activities-specific Balance Confidence Scale
 - 16 functional items with varying degrees of difficulty
 - Rated on scale of 0 (not confidence) to 100% (Completely confident)
 - Developed to quantify fear of falling in older adults
 - Lower scores indicate greater fear of falling *Myers et al 1998*
 - Scores < 50 indicate home bound older adult
 - Scores 50-79 indicate older adult with chronic health problems or in retirement centers
 - Scores > 80 indicate highly functioning community dwelling older adult
 - Correlates with DHI in persons with vestibular disorders *Whitney et al 1999*
 - High test-retest reliability *Myers et al 1998*

Subjective Assessment of Dizziness

- Vestibular Disorders Activities of Daily Living Scale (VADL) *Cohen et al 2000; Cohen and Kimball 2000*
 - Developed to assess self-perceived disability in patients with vestibular impairments
 - Items include 27 activities of daily living
 - Scale rated from 1 (independent) to 10 (ceasing to participate in the activity)
 - Scored as a median so patients can skip an item and the test still has validity
 - Internal consistency high (Cronbach's $\alpha > .90$)
 - Excellent test-retest reliability ($r > .87$)

Evaluation of the Patient with TBI and Dizziness

• Thorough History

- Relevant medical history
 - Acute or chronic medical problems
 - Family history
 - Description of symptoms: dizziness, vertigo, headache, falls
 - Include frequency and duration
- Medications
- Social history
- Environmental Assessment
- Cognition

Evaluation of the Patient with TBI and Dizziness

• Physical Examination

- Cardiovascular Status
 - Heart rate and rhythm
 - Postural pulse and blood pressure – supine, sitting, and standing
 - Pulse oximetry
- Musculoskeletal System
 - Joint range of motion
 - Muscle strength

Examination of the Patient with TBI and Dizziness

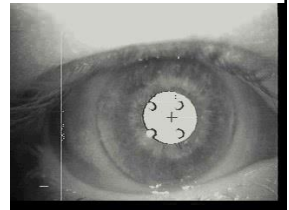
• Neurological Function

- Sensation
- Reflexes
- Cranial Nerves
 - Ocular motor function
 - Vestibular function
- Visual acuity, visual contrast sensitivity, convergence
- Gait, balance, and mobility levels

Ocular Motor Function

• Ocular Motor Function

- Purpose: To determine if CNS problem and to ensure that eye movements are normal so VOR can be tested
- Smooth pursuit
 - Smooth eye movement tracking a slowly moving discrete target
 - Mediated by brainstem eye fields, medial longitudinal fasciculus, and cranial nerves III, IV, and VI
 - Abnormalities are seen with cerebellar or brain stem lesions

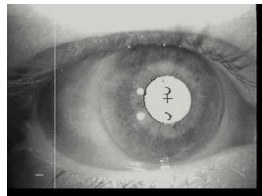


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Ocular Motor Function

• Saccades

- A quick eye movement or refixation
- Mediated by frontal eye fields (voluntary saccades), brainstem reticular formation (voluntary and involuntary saccades) and cranial nerves III, IV, and VI
- Abnormalities are seen with cortical, brainstem and cerebellar lesions



http://library.med.utah.edu/neurologicexam/movies/cranialnerve_n_10_x2.mov

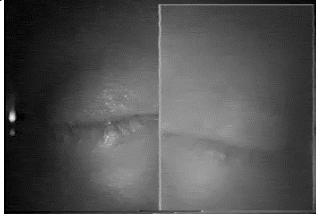
Abnormal smooth pursuit and saccades
http://library.med.utah.edu/neurologicexam/movies/cranialnerve_ab_11_x2.mov

Saccadic Disorder



Convergence Insufficiency

- Convergence Insufficiency observed in 23 -46% of people with TBI
Alvarez et al 2012



Convergence Spasm



Clinical Measures of Vestibular Function

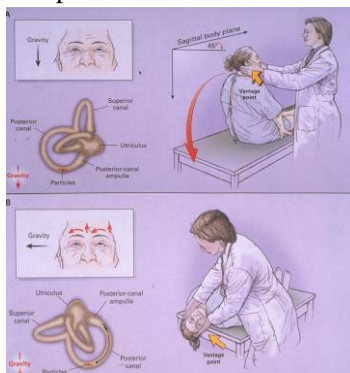
- Eye Head Coordination Testing
 - Active and Passive VOR
 - Mediated by labyrinth, VIII cranial nerve, and vestibular nucleus
 - Active VOR
 - While the patient looks at a target have them move their head horizontally and then vertically at about 2 cycles/second. Look for refixation saccades, note reports of dizziness or nausea
 - Passive VOR
 - Hold the patient's head tipped down approximately 30 degrees, move the patient's head horizontally and vertically at about 2 cycles/second while asking them to focus on your face. Look for refixation saccades, note reports of dizziness or nausea
- Abnormalities are indicative of vestibular dysfunction

Clinical Measures of Vestibular Function

- Eye Head Coordination Testing
 - Head Thrust (Head Impulse Test) Schubert et al 2004; Halmagyi and Curthoys 1988
 - 95% specificity, 35% sensitivity for detecting vestibular lesion
 - 82% specificity, 71% sensitivity UVL, 84% sensitivity BVL Schubert et al 2004
 - The patient is asked to fixate on a target while the examiner moves the patients head rapidly to each side
 - The examiner looks for any movement of the pupil during the head thrust and a refixation saccade
- http://library.med.utah.edu/neurologiceexam/movies/cranialnerve_n_13_x2.mov

Dix-Hallpike Maneuver

The Dix-Hallpike maneuver-45 degrees rotation and 30 degrees extension over the edge of the bed.



Furman and Cass. New England Journal of Medicine. 1999;340:1590-1596

Auditory Testing

- Audiogram and Word Recognition Test (hearing test)
- Tympanometry and Acoustic Reflex Testing
- Brainstem Auditory Evoked Potential Testing
- Electrocochleography

Objective Tests of Vestibular Function

- Electronystagmography/ Videonystagmography
 - Ocular Motor Testing
 - Caloric Testing
 - Positional Testing
- Earth Vertical Axis Rotation (EVAR or rotational chair testing)
- Computerized Dynamic Posturography

Vestibular Function Testing

• Electronystagmography/Videonystagmography

- Ocular motor testing
- Positional testing



• Caloric testing

- Warm or cool air or water is placed in the external auditory canal
- Slow phase velocity of nystagmus is measured and compared between sides
- Gives indication of side of lesion
 - % asymmetry
 - Directional preponderance



Vestibular Function Tests

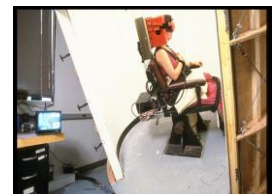
• Earth Vertical Axis Rotation (Rotational Chair Testing)

- Ocular Motor Testing
- Optokinetic Nystagmus
- Sinusoidal Stimulation
 - Gain
 - Phase
 - Directional Preponderance
- Step Stimulation
 - Time constant



Vestibular Function Testing

- Otolith Testing
 - Off Vertical Axis Rotation
 - Vestibular Evoked Myogenic Potentials (VEMP)
 - Linear sled



Vestibular Function Testing

- Computerized Dynamic Posturography
 - Sensory Organization Test
 - Somatosensory and Visual cues are manipulated to determine how a person uses sensory information for balance
 - Motor Control Test
 - Assesses the motor response to platform translations at various velocities
 - Adaptation Test
 - Assesses how a person adapts to repetitive rotational platform translations

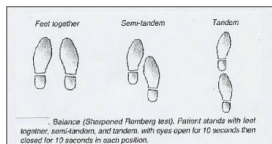
Sensory Organization Test (SOT)

SENSORY EVALUATION -SIX CONDITIONS

Condition	Sensory Systems
1. Normal Vision Head Support	Visual, Vestibular, Somatosensory
2. Absent Vision Head Support	Vestibular, Somatosensory
3. Semi-Referenced Vision Head Support	Visual, Vestibular, Somatosensory
4. Normal Vision Semi-Referenced Support	Visual, Vestibular, Somatosensory
5. Absent Vision Semi-Referenced Support	Vestibular, Somatosensory
6. Semi-Referenced Vision Semi-Referenced Support	Visual, Vestibular, Somatosensory

Evaluation of Gait and Balance

- Single Item Tests
 - Romberg
 - Developed to test posterior column disease
 - Sharpened Romberg (tandem) : holding for < 10 seconds indicate increased risk of falling
 - Single Limb Stance (SLS)
 - Increase risk of injury due to a fall 2 times if cannot perform SLS for 5 seconds *Vellas 1997*



30 Second Chair Stand Test Jones et al 1999

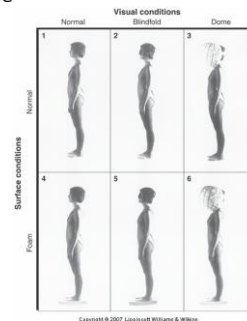
- Administered using a folding chair without arms, placed against a wall
- Measure number of times a person can come to complete standing in 30 seconds without using arms
- Excellent test-retest reliability $r=0.89$
- Criterion fitness standards to maintain physical independence *Rikli and Jones 2013*

Age	60-64	65-69	70-74	75-79	80-84	85-89	90-94
Women	15	15	14	13	12	11	9
Men	17	16	15	14	13	11	9

Evaluation of Gait and Balance

- Clinical Test of Sensory Interaction and Balance Shumway-Cook and Horak 1986
 - Reliable
 - Adults with balance dysfunction Kappa ranged from 0.31 to 0.81 *Loughran et al 2005*
 - Valid
 - Correlates with Sensory Organization Test in people with vestibular dysfunction *Weber and Cass 1993*
 - Inability to maintain stance on foam predicted future multiple falls (OR 4.21)

Clinical Test of Sensory Interaction and Balance



Clinical Test of Sensory Interaction on Balance

Condition	Surface	Vision	Sensory Input Available	Abnormal Scores Indicate
1	Firm	Eyes Open	Accurate Vision Accurate Somatosensory	Possible motor impairment
2	Firm	Eyes Closed	Absent Vision Accurate Somatosensory	Impaired use of somatosensory info
3	Firm	Visual Conflict Dome	Inaccurate Vision Accurate Somatosensory	Impaired use of somatosensory info
4	Compliant	Eyes Open	Accurate Vision Inaccurate Somatosensory	Impaired use of visual info
5	Compliant	Eyes Closed	Absent Vision Inaccurate Somatosensory	Impaired use of vestibular info
6	Compliant	Visual Conflict Dome	Inaccurate Vision Inaccurate Somatosensory	Impaired use of vestibular info

Evaluation of Gait and Balance

• Multiple item balance tests

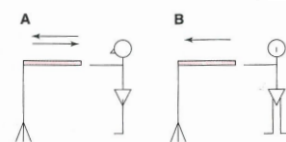
- **Berg Balance Scale (BBS)** *Berg et al 1989*
 - 14 items graded on an ordinal scale 0-4
 - Reliable: ICC $r=0.91$ in older adults
 - Scores below 45 indicate increased risk of falling in community dwelling older adults *Shumway-Cook et al 1997*
 - Scores of < 36 indicate a 100% chance of falling in the next 6 months

Evaluation of Gait and Balance

• Tinetti Performance Oriented Mobility Scale (POMA) *Tinetti et al 1986*

- Balance (10 items, 16 points) and Gait (12 points) Subscales
- Excellent Test-retest reliability in older adults ICC $r=0.96$ *van Iersel et al 2007*
- Fall risk interpretation
 - 24-28 Low risk of falls
 - 19-23 Moderate risk of falls
 - <18 High risk of falls

Functional Reach/Multidirectional Reach



Multidirectional Reach Test Reference Values (mean age 74 years)

Direction	Above average (inches)	Below average (inches)
Forward	>12.2	<5.6
Backward	>7.6	<1.6
Right lateral	>9.4	<3.8
Left lateral	>9.4	<3.8

Evaluation of Gait and Balance

• Gait Tests

- **Timed "Up & Go" (TUG)** *Podsiadlo and Richardson 1991*
 - A person is timed while they stand from a sitting position, walks 3 meters (at self-selected speed), turns, walks back to the chair and sits down
 - Reliable: ICC $r=0.99$ in community dwelling older adults
 - Scores of > 11 seconds correctly classify older adults who will fall *Podsiadlo and Richardson 1991, Trueblood et al 200, Wisley and Kumar 2010*



Evaluation of Gait and Balance

- **Dynamic Gait Index** *Shumway-Cook and Woollacott 2012*
 - 8 gait tasks graded on an ordinal scale (0-3)
 - Reliable: ICC $r=0.82$ community dwelling older adults
 - Scores of $\leq 19/24$ correctly identify older adults at risk for falling *Shumway-Cook et al 1997*
- **Functional Gait Assessment** *Wisley et al 2004*
 - 10 item test graded on an ordinal scale (0-3)
 - Reliability: ICC $r= 0.93$ in healthy adults
 - Scores of $\leq 22/30$ correctly classify older adults who will fall *Wisley and Kumar 2010*
 - LR+: 3.6
 - LR-: 0.00

Table 1.
Functional Gait Assessment Total Scores by Decade

Age (y)	N	Minimum Score	Maximum Score	Mean	SD	95% Confidence Interval
40-49	27	24	30	28.9	1.5	28.3-29.5
50-59	33	25	30	28.4	1.6	27.9-29.0
60-69	63	20	30	27.1	2.3	26.5-27.7
70-79	44	16	30	24.9	3.6	23.9-26.0
80-89	33	10	28	20.8	4.7	19.2-22.6
Total	200	10	30	26.1	4.0	25.5-26.6

Evaluation of Gait and Balance

- **Timed Gait**
 - Low gait velocity (<0.7 m/sec) increases risk of falls *Montero-Odasso et al 2005; Verghese et al 2009*
 - Gait variability (step length, double support phase) increases risk of falls

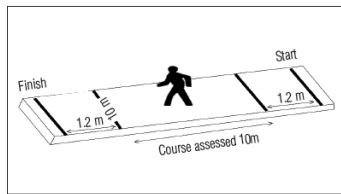
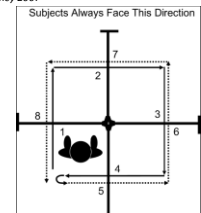


Figure 1. Representative diagram of the 10-meter walk test.

Four Square Step Test *Dite and Temple 2002*

- Measure the amount of time it takes to walk around the squares clockwise then counterclockwise
- Scores of > 12 seconds indicate increased risk of falls in people with vestibular dysfunction *Whitney 2007*
- Excellent test-retest reliability
- Concurrent validity established



Mini-BESTest

- 14 items based on original BESTest
- Scored on ordinal scale of 0-2
- Excellent test-retest reliability
- Excellent correlation with BESTest and Global Rating of Change
- Normative Scores not established
- Scores of $< 20/28$ indicate increased risk of falling in people with Parkinson Disorder
- [http://www.bestest.us/files/7413/6380/7277/MiniBEST_revised_fina l 3 8 13.pdf](http://www.bestest.us/files/7413/6380/7277/MiniBEST_revised_fina%203%208%2013.pdf)

Mini-Balance Evaluation Systems Test (mini-BESTest)

- I. Anticipatory Postural Adjustments
 1. Sit to Stand
 2. Rise to Toes
 3. Stand on One Leg
- II. Reactive Postural Responses
 4. Compensatory Stepping Correction – Forward
 5. Compensatory Stepping Correction – Backward
 6. Compensatory Stepping Correction – Lateral
- III. Sensory Orientation
 7. Stance feet together – eyes open, firm surface
 8. Stance feet together – eyes closed, foam surface
 9. Incline Toes Up – Eyes Closed
- IV. Stability in Gait
 10. Change in Speed
 11. Walk with Head Turns – Horizontal
 12. Walk with Pivot Turns
 13. Step over obstacle
 14. Timed “Get Up & Go” with Dual Task



#5

Differential Diagnosis

- Need to determine
 - Is the dizziness vestibular in origin?
 - If it is vestibular is it peripheral, central or both?
 - Is it a loss of function, irritative or mechanical?



Differential Diagnosis

	Unilateral Peripheral Vestibular Dysfunction	Bilateral Peripheral Vestibular Dysfunction	Central Vestibular Dysfunction	BPPV
Onset	Sudden	Sudden or gradual	Gradual	Sudden
Frequency	Episodic	Constant	Constant	Episodic
Duration	Minutes to hours	Hours to days	Hours to Days	Seconds to minutes
Symptoms	Vertigo, nausea, imbalance	Dizziness, imbalance	Lightheadedness, imbalance	Vertigo

Assessment tool	Expected results if		
	Central vestibular dysfunction	Unilateral vestibular dysfunction	Bilateral vestibular dysfunction
Ocular Motor testing Smooth Pursuit Saccades Spontaneous Nystagmus	Frequently abnormal Frequently abnormal Frequently abnormal: Non-fatiguable Direction changing Gaze evoked Downbeat	Typically normal Typically normal Acute: frequently abnormal or present Chronic: typically normal	Typically normal Typically normal Typically normal
Vestibular Ocular Reflex Testing Active and Passive VOR Head thrust Head Shaking VOR cancellation Dynamic Visual Acuity	May be abnormal Usually normal Usually normal May be abnormal Usually normal	Abnormal if acute Abnormal with head movement in direction of lesion if acute Abnormal if acute Usually normal – may increase symptoms Abnormal if acute	Usually abnormal Usually abnormal bilaterally Usually normal Usually normal Abnormal
Dix-Hallpike Test	May see non-fatiguable nystagmus, downbeat nystagmus	May see non-fatiguable horizontal nystagmus if acute	Usually negative

Acute Management Issues

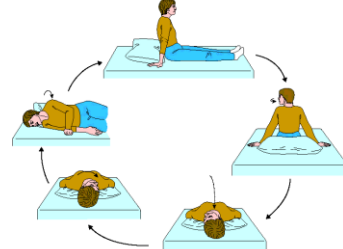
- Musculoskeletal involvement may limit types of exercise a patient can perform
 - Vestibular rehabilitation exercises may need to be modified or postponed
- Due to high prevalence, BPPV should be ruled out on all patients
- Cognitive impairments
 - Memory problems may influence follow through of exercises
 - Family involvement
 - Use of a compliance worksheet
 - Confusion and decreased processing may increase space and motion discomfort

Chronic Management Issues

- Vestibular function testing if dizziness persists or vestibular pathology suspected
- Increase activity level incrementally as long as symptoms are under control
- Migraine management/prevention
- Sleep disorder management if not resolving
- Stress management may be indicated

Treatment Considerations

- BPPV
 - Canalith repositioning maneuver



Treatment Considerations

- Post-traumatic Meniere's Disease
 - Control Fluctuations
 - Vestibular Rehabilitation may decrease frequency and intensity of attacks Dowdal-Osborn 2002; Hahn et al 2001
- Post-traumatic Migraine-related Vestibulopathy
 - Migraine management
 - Control symptoms of space and motion discomfort
 - May need additional emotional support Wisley et al 2004

Questions?

