# VESTIBULAR & BALANCE THERAPY FOR CHILDREN

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## Schedule. April 8, 2017

<table>
<thead>
<tr>
<th>Time</th>
<th>TOPIC</th>
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<tr>
<td>8:00-9:00</td>
<td>Vestibular System Anatomy and Physiology</td>
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<tr>
<td>9:00-9:30</td>
<td>Development of Gaze Stability and Postural Control</td>
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<td>9:30-9:45</td>
<td>Morning Break</td>
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<td>9:45-10:45</td>
<td>Vestibular Related Diagnoses in Pediatrics</td>
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<td>10:45-11:30</td>
<td>Diagnostic and Clinical Testing</td>
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<td>11:30-2:00</td>
<td>LUNCH &amp; BUSINESS MEETING</td>
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<td>2:00-3:30</td>
<td>Interventions to Improve Gaze Stability and Balance</td>
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<td>3:30-3:45</td>
<td>Afternoon Break</td>
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<td>3:45-5:00</td>
<td>Cases</td>
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VESTIBULAR SYSTEM ANATOMY & PHYSIOLOGY

THE VESTIBULAR SYSTEM RESPONDS TO FORCES ACTING ON THE HEAD

Angular head motion:
• Pitch: nodding head as if saying “yes”
• Yaw: shaking head as if saying “no”
• Roll: tipping head side to side

Linear head motion:
• Forward & Back
• Up & Down

Gravity:
• Effect of gravity on head
Peripheral Vestibular System

3 Semicircular Canals:
- Anterior (Superior)
- Posterior
- Horizontal (Lateral)

2 Otoliths:
- Utricle
- Saccule
**Endolymph**: fills membranous labyrinth; like intracellular fluid (high [K] low [Na])

**Perilymph**: fills the bony labyrinth; like CSF (high [Na] low [K])

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**CILIA**: located in AMPULLAE of Canals

Contain the **CRISTA**

* sensory hair cells (cilia) embedded in the **CUPULA** – a gelatinous mass
**Depolarization & Hyperpolarization**

**Semicircular Canals**

- **KINOCILIA** – longest hair cell
  - If stereocilia bend toward the kinocilia
    - Depolarization of CN VIII
  - If stereocilia bend away from the kinocilia
    - Hyperpolarization of CN VIII
  - Endolymph moves cupula in response to head movement
  - A resting firing rate is maintained
Orientation of the Canals

Right AC
Left PC
Right PC
Left AC

PURPOSE OF SCC:
VESTIBULO-OCULAR REFLEX (VOR)
OTOLITHS

- 2 globular cavities;
- Macula = receptor area
- Detect linear acceleration
- Utricle
  - Oval with macula in horizontal position
    - Detects linear (forward-back), lateral head tilt (roll), gravity
- Saccule
  - Inferior to utricle, macula in vertical position
    - Detects up-down movements, gravity, nod (pitch)
Utricle

- Arranged horizontally
- Adequate stimulus: linear acceleration & gravity
- Responds to pitch & roll
  - Nod head (pitch)
  - Tip head side to side (roll)
- Responds to linear mov’t such as forward/back or side/side
- Utricular pathways provide perception of vertical and horizontal
  - Subjective Visual Vertical

Saccule

- Arranged vertically
- Adequate stimulus: linear acceleration & gravity
- Responds to roll head movements
- Responds to linear movements such as up/down like elevator
- Also responds to sound
  - Vestibular Evoked Myogenic Potential
Postural control

Gaze Stability

Angular acceleration

Linear acceleration

Gravity

Visual, proprioceptive, tactile, auditory inputs

Central Nervous System Processing

Correct orientation

Postural control

INPUT:

OUTPUT:
Transduction: Mechanical energy (forces) becomes electrical energy

Depolarization and Hyperpolarization

40-70 stereocilia & 1 kinocilium per cell
Vestibular Nuclei

1. Oculomotor nu. (III)
2. Trochlear nu. (IV)
3. Pons
4. Fourth Ventricle
5. Abducens nu. (VI)
6. Vestibular nu. (VIII)
7. Medial Longitudinal Fasciculus

http://anatomy.uams.edu/anatomyhtml/atlas_html/n2a4p4.html
As the head turns one way, the eyes turn the other.

Notice how the two sides communicate to get the proper eye mov’t

VOR

- Produces a slow phase eye movement in the opposite direction but at the same velocity and amplitude as the head movement.

- If I turn my head quickly to the right, the VOR causes a slow phase eye movement to the left.
**Gain of the VOR**

If eye movement velocity matches head movement exactly, the gain is 1

- Gain = Velocity of eye movement / velocity of head movement
- A peripheral vestibular lesion decreases the gain of the VOR.
- Causes oscillopsia (blurry vision) during head mov’t
VOR

- What if you **WANT** to look in a new direction?
- The VOR can be cancelled out by the cerebellum
  - cerebellum adjusts the **GAIN** of the VOR
CENTRAL VESTIBULAR PATHWAYS

Peripheral Vestibular Receptors

4 Vestibular Nuclei

Medial Longitudinal Fasciculus: III, IV, VI

MVST, LVST

thalamo-cortico pathway

Vestibulo-cerebellum

Reticular formation

Gain of eye/body mov't

Postural Control

Perceived orientation

Autonomic response

Vestibulo-Ocular Reflex

Vestibulospinal reactions

Otoliths

SCC

Cerebellum

Vestibular Nuclei

Medial Vestibulospinal Tract

Lateral Vestibulospinal tract

Motor Neurons of Spinal Cord for Postural control and head control
Vestibulospinal pathways

Vestibular Pathways

- Oculomotor nuc.
- Trochlear nuc.
- Abducens nuc.
- Superior vestibular nuc.
- Lateral vestibular nuc.
- Medial vestibular nuc.
- Inferior vestibular nuc.
- Medial vestibulospinal tract
- Lateral vestibulospinal tract.
**Thalamico-cortico pathway**

- Axons from the vestibular nuclei travel to the ventral posterior intermediate nucleus of the thalamus, then to the vestibular cortex
- Awareness of head position
- Perception of vertical and horizontal
  - Utricular pathways
CENTRAL VESTIBULAR PATHWAYS

Vestibular-autonomic pathway

- Excessive input into the reticular formation will cause nausea, vomiting, altered consciousness.
- Vestibular Nu. project to:
  - Locus ceruleus (stress/panic)
  - Nu. of solitary tract (nausea)
  - Area postrema (vomiting)
  - Amygdala (emotional memory); parabrachial nu. (arousal); infralimbic cortex & hypothalamus.
Postural control

Gaze Stability
Correct orientation
Postural control

INPUT:
Angular acceleration
Linear acceleration
Gravity

Visual, proprioceptive, tactile, auditory inputs

SCC

Central Nervous System Processing

OUTPUT:

Balance Control

Sensory

Where am I?

- Determination of Body Position
- Compare, Select and Combine Senses
- Environmental Interaction

Motor

What am I going to do?

- Choice of Body Movement
- Select and Adjust Muscle Contractile Patterns
- Generation of Body Movement

- Visual System
- Vestibular System
- Somato Sensation
- Ankle, Thigh
- Trunk, Neck
- Eye, Head

http://resourcesonbalance.com/clinical_info/BalanceControl.aspx
Gaze stabilization during head mov’t

Vestibulo-ocular reflex (VOR)
- Requires a working vestibular system
- Works during fast head movements
  - >100 deg/sec

Smooth Pursuit
- Requires a working oculomotor system (central) but not vestibular
- Works during slower head movements
  - < 100 deg/sec

**We move the head much more than 100 deg/sec and 2 Hz during most daily activities.**

Nystagmus
- Involuntary back and forth movement of the eye
- Named according to the fast phase
  - Right beating, left beating, up beating, down beating
  - It always beats toward the side that is more neurally active
- Example:
  - Spin to the right, right SCC is depolarized and left is hyperpolarized.
  - Right side is now more neurally active so nystagmus will beat to the right.
    - Slow phase eye movement to the left, fast phase to the right
Development of Gaze Stability and Postural Control

<table>
<thead>
<tr>
<th>GAZE STABILITY</th>
<th>POSTURAL CONTROL</th>
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<tbody>
<tr>
<td>• Ability to see with head movement</td>
<td>• Ability to keep the body balanced</td>
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<tr>
<td>• Requires vestibular, oculomotor, visual systems</td>
<td>• Requires vestibular, vision, somatosensory, musculoskeletal systems</td>
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Development of the Vestibular System

- Develops from ectoderm (like the eye)
  - First trimester
- VOR – present at birth, rapidly develops over first 6 months
  - Essentially adult-like by age 4 years
- Labyrinthine righting (tonic responses) – in utero
  - Head righting – as soon as strength allows

- Nandi, 2008

Development of Saccades

- Saccade: rapid eye movement from one target to another
- Velocity: Develops throughout childhood and adolescence, peaking at age 15 years
- Accuracy: hypometric in infancy, develops with age, declines when elderly
- Latency: decreases from age 3-14 years, stable until age 50 yrs, then increases
- In general, develops until age 15 years.
Development of Smooth Pursuit and Optokinetic Nystagmus

- Smooth pursuit: requires a moving target
- Optokinetic Nystagmus: involuntary pursuit
  - Present at birth
- Voluntary pursuit: not present until 2 months
- Not consistent until 8 months, matures into adolescence

Development of Vision

- 1 month: focus on object 3 feet away
- 3 months: eye/hand coordination to bat an object
- 5-8 mths: depth perception develops
- Binocularity and fusion develop by 3-4 years
- Convergence to 6cm by age 7
Inter-dependence of Systems

- Systems that work together
  - Must consider
    - Development of each component
    - Effect of 1 on development of each
    - Development of output
      - Balance – vestibular, vision, somatosensory, musculoskeletal
      - Gaze stabilization – oculomotor, vision, vestibular

Developmental Implications for Function

- Interdependence of systems that work together for function
  - Visual fixation
    - Retinal & non-retinal information
    - Vestibular input
    - Lesion = oscillopsia & impairs reading
  - Postural control
    - Vision, somatosensory, vestibular
    - Lesion – poor balance, motor development

With lesion of 1, effect noted on functional effectiveness of others!
Balance Function – Development

- Orient in space
  - Vision & vestibular – righting – 1-2 mos
  - Orientation within any posture
    - Step-like emergence
  - Identification of verticality –
    - w/in 2 months, head erect
    - Dep. upon vision & vestibular systems
- Attain, hold and move w/in a posture
  - Developmental sequence – evolves
  - Depends upon experience w/in a posture

Balance: developmental milestones (PDMS)

- Static:
  - Assume: sit (6-8 m), stand (10 m)
  - Maintain w/challenge: sit (8 m), stand (10-15 m)
- Dynamic:
  - Move within posture: scoot 6-10 mos, walk (10-18 m)
- Advanced standing:
  - SLS EO: 3s: 3 yr; 6s: 4yrs; 10s: 4 yr 6 mo
  - SLS EC: 3s: 5 yr; 8s: 6 yr
  - Turn 180 degrees – 4 yrs 6 mos
  - Balance beam (3.5 in): 4 steps @ 4 yr; 8 ft @ 4.5 yrs; tandem walk 6 yr
  - Walk on straight line: 5 years
**Maturation of Motor Responses:**

- Dependent upon experience and practice
- Neuromuscular response - sequence initially proximal-distal
- Physiologically measured responses
  - short latency & long latency responses adult-like between 3 and 4 years (EMG)
- *Absence of vestibular function causes delayed onset of walking*

**Maturation of Integration Abilities:**

- Sensory organization
  - Integrate multi-sensory input
  - Re-weight information as needed
- Critical period = 4 - 6.5 yoa
  - Shift from reliance on vision to reliance on somatosensory
  - increased variability
  - cannot resolve conflicts of sensory cues
- Use of vestibular system for postural control not adult-like until after 15 yoa
SOT Child vs Adult

- Age differences: 3-4 yrs, 4-6.5 yrs, 7-8yrs
- Calculated sensory effectiveness ratios

Rine et al 1998; Hirabayashi 1995
Vestibular, Somatosensory & Vision Effectiveness ratios

Vestibular Ratio (5/1)
- Adult (17 yrs) = 0.88
- 3-4 yrs = 0.21
- 4-6.5 yrs = 0.23
- 7-8.5 yrs = 0.50

Vision Ratio (4/1)
- Adults (13-15 yrs) = 0.88;
- Child = 0.52

Somatosensory (2/1)
- Adults = 0.94;
- Child = 0.89

Children: Adult-like use of somatosensory information for balance by age 3

Longitudinal SOT Scores – Children
Casselbrant et al 2010

- 127 children tested annually (3-9 years); some lost to attrition
- SOT testing
  - Mean equilibrium inc linearly as fx of age
  - 20-25% of 3 yr olds LOB on #5 and #6, only 6% by age 8
  - No LOB #1-3, less than 4% on #4
Summary: Development of Gaze Stability and Postural Control

• By age 1 year, children have the use of the VOR for gaze stability
  • As they move their heads in function, should be able to see clearly.
• By age 3 years, children should be able to use somatosensory, vision and vestibular information for balance
  • However, they will not be able to resolve conflict until after age 6 years
  • Vestibular not mature until adolescence.
VESTIBULAR RELATED DIAGNOSES IN CHILDREN

PERIPHERAL

SNHL

SNHL

LATE PRE-TERM

SNHL

OME

SNHL

CMV

SNHL

mTBI

SNHL

CANCER

SNHL
Do children have vestibular related deficits/diagnoses?

- TBI
- BPVC
- Migrainous vertigo
- Chronic otitis media
- Vestibular neuritis
- Concurrent with SNHL
- Fistula
- Ototoxicity
- Labyrinthitis

- Pendred’s
- 2^o cochlear implant
- Enlarged vestibular aqueduct
- Schwannoma
- BPPV
- Central lesions
- Meniere’s
- Congenital CMV
Epidemiology Studies

- Anoh-Tanon et al (2000)
  - 523 (5 yr) pediatric pts seen w/ complaints of vertigo and imbalance referred for otolaryngological tests
  - 27 had normal vestibular tests, but abnormal ophthalmological exams (vergence insufficiency, latent strabismus)
  - 496 had vestibulopathy (95%)


Vertigo and Imbalance
(Riina et al 2005 - Helsinki)

5 year period – school age child visits to otolaryngology (n=119)

<table>
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<tr>
<th>Condition</th>
<th>Frequency</th>
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<tbody>
<tr>
<td>BPVC</td>
<td>19%</td>
</tr>
<tr>
<td>TBI</td>
<td>5%</td>
</tr>
<tr>
<td>Migraine</td>
<td>14%</td>
</tr>
<tr>
<td>Vestibulopathy</td>
<td>5%</td>
</tr>
<tr>
<td>Neuronitis</td>
<td>12%</td>
</tr>
<tr>
<td>Meniere’s</td>
<td>2%</td>
</tr>
<tr>
<td>OME</td>
<td>10%</td>
</tr>
<tr>
<td>Meniere’s related</td>
<td>2%</td>
</tr>
<tr>
<td>Psychogenic</td>
<td>5%</td>
</tr>
<tr>
<td>BPPV</td>
<td>&lt; 1%</td>
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Electronystagmography finding in children with peripheral and central vestibular disorders

Angelo Salami, Massimo Dellepiane, Renzo Mora*, Giuseppe Taborelli, Barbara Jankowska

*ENT Department, University of Genoa, Genoa, Italy
• 23 children. ER. Vertigo. 2-12 yoa
• n=19 (83%) with central vertigo
• DX: Post-traumatic, meningitic, toxic, migrainous, psychogenic
  • 5 had spontaneous nystagmus; 18 had positive findings on rotary chair testing (11 HYPO; 7 HYPER; 1 NML)
  • n=11 asymmetrical with optokinetic testing
• n=4 (17%) with peripheral vertigo
• DX: Viral, BPVC, neoplastic
  • 1 (viral) with spontaneous nystagmus
  • All with + findings on RC (3 HYPO; 1 HYPER)
  • All symmetrical with optokinetic testing

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**The Predominant Forms of Vertigo in Children and Their Associated Findings on Balance Function Testing**

Devin L. McCaslin, PhD*, Gary P. Jacobson, PhD,
Jill M. Gruenwald, Aud

doi:10.1016/j.otc.2011.01.003
**Pediatric Migraine Equivalents**

- Pediatric migraine often presents very different from adult migraine and changes during puberty.
- The child with migraine will often have temporary vestibular symptoms such as vertigo, nausea, disequilibrium with or without headache.
- These symptoms can mimic a peripheral problem and can cause delayed gross motor development.

  - Al-Twaijri and Shevell 2002

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**Total Subjects**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Count</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Migraine</td>
<td>116</td>
<td>16.89%</td>
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<tr>
<td>BPVC</td>
<td>133</td>
<td>19.36%</td>
</tr>
<tr>
<td>Otitis Media</td>
<td>22</td>
<td>3.20%</td>
</tr>
<tr>
<td>Viral Infection</td>
<td>98</td>
<td>14.26%</td>
</tr>
<tr>
<td>Trauma</td>
<td>103</td>
<td>14.99%</td>
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McCaslin et al. 2011: 9 EPI STUDIES LOOKING AT MOST FREquent CAUSES OF PEDIATRIC DIZZINESS
<table>
<thead>
<tr>
<th>Type (n=108)</th>
<th>Onset</th>
<th>Symptoms</th>
<th>Resolve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benign Positional Vertigo (38%)</td>
<td>1-3 yrs</td>
<td>Brief episodes of vertigo (1-5 minutes) + unsteadiness, pallor, fear</td>
<td>2 years</td>
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<tr>
<td>Acephaligic migraine (28.7%)</td>
<td>5-12 yrs</td>
<td>Typical migraine visual aura lasting &lt; 10 minutes. Micropsia or metamorphopsia</td>
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<td>Abdominal migraines/ cyclical vomiting (18.5%)</td>
<td>4-10 yrs</td>
<td>crampy, abdominal pain or nausea and vomiting; pallor</td>
<td>2 years</td>
</tr>
<tr>
<td>Benign paroxysmal torticollis (10.2%)</td>
<td>infancy</td>
<td>Torticollis with or without associated pallor, vomiting and behavior changes</td>
<td>2-5 yrs</td>
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<tr>
<td>Acute confusional migraine (4.6%)</td>
<td>Late childhood to adolescence</td>
<td>Often preceded by minor head trauma. Confused and agitated; memory disturbance; 8 hrs; may have headache</td>
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**O’Reilly et al. 2012**

- Prevalence of BPVC and migraine in school children is 2-10.6%  
- 240 medical charts reviewed of kids seen in Balance/Vestibular Lab and Gait Lab  
  - 39 diagnosed with BPVC or migraine.  
- No peripheral vestibular abnormalities  
- Minor abnormalities of static balance (58%), gait (61%) and gross motor skills (69%)  
- 59% with family history
Trauma - mTBI

- CDC: 500,000 ER visits/year (0-14)
- HA, cognitive impairment, sleep disturbance, changes in personality, dizziness/vertigo
  - Whiplash, fracture of temporal bone or labyrinth
- 30-80%: gaze instability and balance problems (Alsalaheen BA et al 2010)

mTBI: Importance of Measuring Vestibular and Vision

- 30 areas of the brain and 8 of 12 cranial nerves deal with vision
- Balance is derived from multiple sensory inputs from vestibular end-organs, the visual system, and the somatosensory and proprioceptive systems
SYMPTOMS OF MILD TBI –

Children’s of Alabama Concussion Database

M. Swanson, et al. 2017
34 children 4-18 yoa
Less dramatic than adults
14 (41%) with vestibulopathy (spont. nystagmus)
20 (59%) with BPPV (rare in children)
  • Posterior or horizontal canal
  • 5 had 2nd vertigo attacks within 4 years

Congenital Cytomegalovirus

  • 0.5-1.0% of infants are infected annually in the US (Kenneson, 2007) (20-40,000/year)
  • Non-genetic cause of SNHL in children (Britt, 2011)

  • Preliminary evidence: peripheral VH and balance dysfunction (Zagolski 2008; Karltop 2014)

  • Histopathologic studies - extensive infection in the vestibular organ (Teissier 2011; Gabrielli 2013)
Cytomegalovirus: HL & VD (Bernard, Wiener-Vacher et al 2015)

- Retrospective study: 52 children with congenital CMV & SNHI
- Tested:
  - audiological
  - Vestibular: clinical, caloric, rotary, OVAR, VEMP
- 48 (92.3%) had HL and VD
- 33.3% complete bilateral VD
- 43.7% partial bilateral VD
- 22.9% partial unilateral VD
- Serial testing: 50% deteriorated VD

Chronic Otitis Media

- 10% children < 1 yoa
- Casselbrant et al 2008:
  - Most had abnormal rotary and VEMP tests
  - Delayed motor development
  - Failed multiple conditions on posturography testing
  - Worse in children with chronic OME, multiple sx
  - Some, not all improved functional abilities after sx
- Mostafa et al (2013)
  - 30-70% have persistent deficits in vestibular function
Ototoxicity

- Medications are known to destroy vestibular receptors
  - High dose antibiotics/aminoglycosides
    - Gentamicin induced in children with CF
  - Chemotherapies (Knight et al 2005)
    - 61% Rx with platinum chemo, experienced loss of hearing to some degree (vestibular not tested)
    - Rx with cisplatin: 10-85% irreversible ototoxicity

Ototoxicity – Cystic Fibrosis


- Increased survival - intensive Rx of chronic infections with aminoglycoside antibiotics
  - Cumulative dose over lifetime n=12 > 5 yrs with CF, no Hx of TBI, no familial Hx HL
  - 2 control grps = children w/CF no ototoxic exposure and those without CF
  - Tested otoacoustic emissions (OAEs) & pure-tone audiometry (PTA)
  - History of gentamicin exposure had a significant effect on OAE results (P<0.05).
Children with hearing loss (HL)  
Huygen et al (Int’l J of Ped Otorhino 1993)

- 121 children in school for the deaf  
- 41% had VH confirmed by testing  
  - Only canals tested  
  - Worse in those with hearing threshold > 90dB, & those with acquired loss (e.g. rubella, meningitis).  
  - Kernicterus (CNS damage 2 to jaundice)  
    - associated with vestibular hyper-reactivity

Children with Sensorineural Hearing Loss (SNHL).  
Tribukai et al. 2004

- Tested canals (calorics) and otoliths (SVV and VEMP) (n=36)  
- 30% w/ caloric hypo or areflexia  
  - 24% w/ caloric asymmetry  
- 22% bilateral weak or absent VEMPS; 19% unilateral  
- 31% positive Subjective Horizontal  
- Of the 33 who completed all 3 tests, only 10 (30%) were judged normal  
- Hearing > 90dB = normal; 100-120 dB= otolith dysfunction; no correlation b/t SCC & hearing
Rotary & VEMP Testing – children w/HL (Maes et al 2014)

- 48 children (4-12 yrs; Mean= 8y) typically developing
- 39 children (3-12 yrs; Mean= 7.66y) Bilateral SNHL
- Test: Rotary and VEMP (no fx tests)
- Results:
  - 74% SNHL had some VD (60% cVEMP only; 49% rotary only

Cochlear Implants

- Many with SNHL receive bilateral CI
  - As young as 6 months. No vestibular testing.
  - More than 80% reduced or lost otolith fx
  - 60% had reduced gain on VOR test
- Ito (1998) reported 38% of adult patients had vestibular dysfunction following CI.
- Limb et al (2005) reported 982 cases (442 children)
  - 52 (5%) had severe dizziness post op (BPPV or unilateral loss of fx)
Cochlear Implants

• Jacot et al (2009)
• Followed 224 children receiving implants
  • 50% had normal function prior to sx; 20% complete bilateral areflexia, 22.5% unilateral hypo, 7.5% bilateral hypo
  • Post CI: vestibular fx changed in 51% of ears with previous normal function (hyper or hypo)!

Vestibular Fx and Cochlear Implantation Fina et al (Otology and Neurology, 2003)

• Case control study (n=75)
• 75 children participated
• Recorded symptoms after implantation
  • N=29 (39%) experienced dizziness
    • N=4 acutely and 25 delayed (median=74 days)
• Chronic changes in the inner ear
• Importance of screening for vestibular dysfunction post cochlear implant.
Other Primary Causes of Vestibular Dysfunction in Children

- Late prematurity (12% live births in U.S.; 375,000 per year)
- Vatovec et al (2001): correlation between VH and neurological risk
- Ecevit et al (2012): found significant delays in VEMP response when comparing late preterm to term infants.

Incidence of Complaints of Dizziness (Li et al. 2016)

- 2012 National Health Interview Survey: Child Balance Supplement
  - 10,954 children 3-17 years of age
  - 5.7% reported ‘dizziness’
    - Estimated to impact 3.3 million U.S. children
  - Only 26% received health care
  - Only 20% had HL
Prevalence: Birth to 5 ya
(24,999,344 in U.S.)

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<tr>
<th></th>
<th>VOR</th>
<th>VSR</th>
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<tr>
<td>Late preterm</td>
<td>2%</td>
<td>4.8%</td>
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<tr>
<td>Chronic OME</td>
<td>18-30% or 4.5 – 7.5 million</td>
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</tr>
<tr>
<td>Sensorineural hearing loss</td>
<td>0.11% or 27.5 thousand</td>
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<tr>
<td>TBI / concussion (50%)</td>
<td>0.02% or 287 thousand</td>
<td>unknown</td>
</tr>
<tr>
<td>Children with school difficulty or autism (mild)</td>
<td>17% or 5.25 million</td>
<td>unknown</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>37-49% or 9.25-11.75 million</strong></td>
<td><strong>22-34.17% or 5.5-8.5 million</strong></td>
</tr>
</tbody>
</table>

Balance Disorders – Main etiologies
(Sommerfleck, Macchi, Weinschelbaum et al 2016)

- Retrospective, cross-sectional study
  - N = 206 children 1-18 ya seen by otolaryngology; grouped by age (1-5, 6-11, 12-18)
  - c/o dizziness, imbalance, vertigo
  - Otoneurological exam: V-HIT

- Results – diff. results by age!
  - 42.2% reported vestibular symptoms & headaches
    - 39% met diagnostic criteria of vestibular migraine (VM),
    - Family Hx migraine 75.5% (those with VM)
Pendred’s Syndrome

• Genetic disorder, resulting in HL
  • Gradual, in stages (often remit and relapse)
  • Thyroid typically also affected (goiter)
  • 40% have vestibular hypo-function

Usher Syndrome

• Rare genetic disorder – HL and blindness
  • Retinitis pigmentosa – gradual loss of vision
  • Type I
    • born profoundly deaf, lose vision in first decade; balance difficulties & walk late (vestibular loss)
  • Type II
    • not born deaf, but hearing loss; no balance problems; lose vision later (2nd decade)
  • Type III: gradual loss of hearing & vision; they may or may not have balance difficulties.
Cogan’s Syndrome

- Autoimmune eye inflammation and HL
- Usually occurs after recover from URI
- Eye infection, imbalance and/or dizziness
- With damage to CN – loss of hearing and vestibular hypofunction.

Importance of Saccule Fx

- Shall (2009):
  - 50% cochlear implants; 2/3 had no VEMP responses (saccule fx)
  - Walking and balance worse in those with loss at birth or within first year vs later
- Weiner-Vacher:
  - Saccule fx maturation correlates with onset of walking in infants
Torticollis

- Reason for head tilt
  - Ocular tilt reaction
- Tonic imbalance of muscle activity both in the neck and in the extraocular system
  - Head and eyes deviate the same direction
    - Related to the torticollis
    - A central disturbance of posture
- No other CN VIII symptoms
- Differing types of torticollis may involve different vestibular pathways
- Bronstein et al. 1986; Munchau 2001

Congenital Torticollis and Saccular Dysfunction (Hallberg et al. 2013)

- JAMA Otolaryngol Head and Neck Surg. 2013
- Case report of an 18 mth old with torticollis
  - Treated with PT for stretching/positioning
  - Continued to demonstrate postural head tilt to left, rotate to right
- Normal ophthalmological/neurological exam
- Some torsional nystagmus noted by PT with certain head positions
- Normal rotary/caloric tests
- Normal hearing test
- VEMP: 69% asymmetry with left weaker than right
- Did 1 year of vestibular PT (focus on saccule function)
  - VEMP: 20% asymmetry (normal)
**Scoliosis**

- Postural instability (Haumont 2011)
  - Patients with greater Cobb angles had more postural instability (SOT)
  - Altered proprioceptive information; less efficient central processing; less efficient strategy of muscle activation (top down – hips)
- Oculomotor Deficiency if angle >15° (Lion 2013)
  - High latency saccades with temporal uncertainty & low velocity
  - Slower visual vestibular ocular reflex (VVOR)
  - Normal VOR

---

**Scoliosis (Cakrt 2011)**

- 23 adolescents with idiopathic scoliosis (mean age 14.5 +/- 2.5) & 23 age matched healthy subjects.
- Bucket test for SVV: different between groups
- Perception of vertical is altered in idiopathic scoliosis.
- Functional asymmetry or disturbance at some level in the vestibulospinal reflex, labyrinth, vestibular pathways in the brainstem.
Cakrt 2011

RESEARCH ARTICLE

Lateral Semicircular Canal Asymmetry in Idiopathic Scoliosis: An Early Link between Biomechanical, Hormonal and Neurosensory Theories?

Martin Hitier1,2,3,4*, Michèle Hamon5, Pierre Denise5, Julien Lacoudre1, Marie-Aude Thenin5, Jean-François Mallet5, Sylvain Moreau1,2, Gaëlle Quarck4

PLOS ONE | DOI:10.1371/journal.pone.0131120  July 17, 2015

• N=18 with adolescent idiopathic scoliosis and 9 controls (14-17 yoa)
• Cobb angle 10-50 deg
• MRI, caloric, rotary chair
Lateral SCC asymmetry in idiopathic scoliosis: an early link between biomechanical, hormonal and neurosensory theories. Hitier et al. 2015.

PLOS ONE | DOI:10.1371/journal.pone.0131120  July 17, 2015

- N=18 with adolescent idiopathic scoliosis and 9 controls (14-17 yoa)
- Cobb angle 10-50 deg
- MRI, caloric, rotary chair
- Looked at lateral SCC orientation and position of other canals relative to midline.
- Left lateral SCC: more vertical in scoliosis
- Correlated with position of the vestibule
- The more vertical, the further the vestibule was from midline
- No correlation between side of curve and canal orientation
- Thoracolumbar: more marked asymmetry of left vs right

3 theories for AIS.
Hitier et al. 2015

- Biomechanical
  - Early asymmetry exists before the spinal deformity.
- Endocrine
  - Vestibular anomalies interact with hormones before puberty, contributing to AIS
- Neurosensory
  - Vestibular abnormality influences brain maturation (i.e. postural control)
Summary

• Balance and/or gaze stability impairments could be related to aberrant peripheral or central vestibular function.
• Importance of early screening and diagnostic testing
• If detected early, interventions could be initiated to improve activity and participation.

Diagnostic and Clinical Tests of Vestibular & Oculomotor Function
OBJECTIVES

• Discuss the clinical significance of diagnostic tests of oculomotor and vestibular function
• Appreciate how diagnostic tests can be modified for young children.
• Value the role of the audiologist and optometrist in the diagnostic examination

EYE MOVEMENTS ARE MEASURED WITH VIDEONYSTAGMOGRAPHY (VNG) OR ELECTRONYSTAGMOGRAPHY (ENG)
MEASUREMENT OF EYE MOVEMENTS

- VNG can measure horizontal, vertical and torsional eye movements
  - Can be scary for young children
- ENG does not measure vertical or torsion and has drawbacks
  - Less scary for young children
Oculomotor Examination – WHY?

- Central neurological pathologies (e.g. TBI, CP, myelodysplasia, tumor, etc.) may damage visual and oculomotor pathways in the brain or areas of the brain that control vision and eye movements.
- It is critical to test for impairments in the visual system that may impact balance and ocular control.
- *OM testing is done before tests of peripheral vestibular function - if abnormal, vestibular tests may not be valid.*

What may cause oculomotor abnormalities in children?
Causes of OM abnormalities

- Cranial Nerve Lesions
- Muscle Weakness
- Lesions of the Medial Longitudinal Fasciculus
- Lesions of the Cerebellum or Vestibular Nuclei
- Lesions to the Cortical Eye Fields

Cranial Nerve Lesions
Weakness (strabismus)

http://www.allaboutvision.com/conditions/strabismus.htm

Lesions of the Medial Longitudinal Fasciculus (Intranuclear Ophthalmoplegia)

http://anatomy.uams.edu/anatomyhtml/atlas_html/n2a4p4.html
CORTICAL EYE FIELDS

VEST = Vestibular cortex
FEF = Frontal eye fields
SEF = Supplementary eye fields
PEF = Posterior eye field
PFC = Prefrontal cortex


Lesions of the VN or Cerebellar pathways
Diagnostic Tests of OM function

- Smooth pursuit from 0.1 to 1 Hz (limit of pursuit)
  - Horizontal and vertical
- Saccades (horizontal and vertical)
  - Random & Predictive
- Anti-Saccades (mTBI)
- Optokinetic Nystagmus
- VOR Cancellation

OCULOMOTOR TESTS

- Saccades
- Smooth Pursuit
- Optokinetic Nystagmus

Saccades

- Quickly switch vision from one object to another
- Fastest movement in the body
  - Up to 700 deg/sec
- You cannot see during a saccade
- Voluntary saccades (you decide to move your eyes):
  - Command originates in frontal eye fields and parieto-occipital-temporal association cortex & projects to superior colliculus.
  - Horizontal saccades: driven by PPRF to CN VI and III
  - Vertical saccades: driven by midbrain RF to CN III and IV
- Reflexive saccades (you move your eyes to react to something)
  - superior colliculus to CN (III, IV, VI)
- Anti-Saccades: involves moving the eye opposite of target and may be a biomarker for mTBI

Clinical Testing of Saccades

• Hold your finger approx. 15 degrees to one side of your nose. Ask the patient to look at your nose, then quickly shift the eyes to look at your finger, repeating several times. Do this from the left, right, up and down. You are looking for the number of eye mov’t it takes for the patient’s eyes to reach the target.
SMOOTH PURSUIT (LATENCY AND ACCURACY)

- Allows you to follow a moving object
  - Stimulus is a moving object
  - Command originates in the visual cortex
  - Many neural areas are involved
    - Temporal and frontal eye fields, pons, vestibulocerebellum, vestibular nuclei, CN VI and III for horizontal
    - From VN to Midbrain RF then CN III and IV (for vertical)
  - Only able to reach velocities of 100 deg/sec and 1 Hz, even with training
    - Gaze stability during daily function cannot be handled by the pursuit system
BASELINE AND POST-mTBI SMOOTH PURSUIT AT 1.00 Hz

Clinical Smooth Pursuit

• Hold the patient’s head or chin stationary.
• Have the patient follow your **slowly** moving finger horizontally (from center 30 degrees right and then to 30 degrees left), and then vertically (center to 30 degrees up to 30 degrees down).
• You may need to hold the eyelids up in order to see the downward eye movement clearly. Hold the pen or finger at least 12” away from the patient’s eyes.
Clinical Smooth Pursuit

• **Normal response**: Smooth, conjugate eye movement. The key is to move your finger at the correct speed (about 20 deg/sec). If you move your finger too fast, the eye movement will become jerky. Also, do not move the finger past 30 degrees.

• **Abnormal response**: Saccadic or jerky eye movement. Note the direction of pursuit when it occurred. Normal vertical eye pursuit is often interrupted by a saccade.

• **Document the response**: e.g. normal; slow; jerky

• **Eye range of motion** can examined at the same time

OPTOKINETIC REFLEX

• Self motion or object motion can elicit optokinetic nystagmus.
  
  • Involves pursuit and saccade opposite of stimulus motion
    
    • E.g. standing in front of a moving train
  
• Complex cortical and subcortical sensorimotor network and bilateral pathways

"Br J Ophthalmol 2000 84: 451-455"
Clinical Optokinetic Nystagmus (OKN)

- OKN tests many neural substrates. It is NOT a vestibular test, but a test of how well the eyes follow moving objects. If you look at the eyes of someone who is watching a train go by, you might see OKN.
- Move a striped cloth in front of the eyes. You should see nystagmus opposite to the movement of the stripes.
Near Point of Convergence

• Poor convergence and/or accommodation can lead to difficulty and headaches while reading.

• Hold a pen 2 feet away from the child’s face. Ask him/her to focus on the pen while you move it forward toward the bridge of the nose. Normal response: convergence of the eyes with pupillary constriction. Abnormal if unable to converge to at least 6cm.

Convergence Insufficiency Symptom Scale
Valid, Reliable Instrument


Eye Alignment

- The ability to look straight forward is the job of intact cranial nerves and ocular musculature.
- **Tropia** is deviation of one eye from forward gaze when both eyes are open.
- **Phoria** is deviation from forward gaze, apparent when only when the person is looking forward with one eye (the other eye is covered).
- To test eye alignment, do the cover test (for tropia) and the alternating cover test (for phoria).
Alignment Testing ("Modified Thorton")
> 6 = refer to optometry
How to know when to refer to optometry or pediatric eye care

NPC > 6 cm – refer to optometry
Static Visual Acuity

- Have the child wear corrective lenses if usually worn.
- Place the child at whatever distance required of the chart you are using (our chart is for testing at 3 meters or 9.84 feet). Print charts from http://www.i-see.org/eyecharts.html
- The child should read the symbols until they begin to miss
- The line above this (or the line where all are correct) is considered their visual acuity.
- **Snellen notation**: 20/40 is interpreted as: the child can read it from 20’ but most people could read it from 40’ (so vision is worse than normal)
- **logMAR notation**: allows for use in statistics since each line differs by 0.1 logMAR. It is calculated by taking the $\log_{10}$ of the fraction. For example, 20/20=1 and the log of this is 0.

Visual Acuity
VOR Cancellation

- VOR cancellation is the ability to keep the eyes focused on a target while the head is moving if the desire is to look in the direction of head movement.
- To test, have the subject look straight ahead as you move the head slowly right and left.
- You can also have them look at their own thumbs and turn en bloc.
- A normal response is the ability to keep the eyes on the target.
- An abnormal response is nystagmus.

Subjective Visual Vertical and Horizontal - Static

- The child uses joystick buttons to set a laser light bar to perceived vertical and horizontal.
- Must have no other visual reference
- If utricular pathways are damaged, will see SVV abnormality
- Normal is within 2 degrees of true vertical and horizontal
- Clinically, the bucket test can be used.
BUCKET TEST OF SVV

- Have the child close the eyes and put the bucket over the child’s face, turn the line a random direction
- Tell “say now” when the line is straight up and down
- Do 10 trials (5 to each side)
RELIABILITY

ICC = 0.74

< 2 DEGREES OFF

Diagnostic tests of canal function
Diagnostic tests of canal function

• Purpose: objectively quantify the status of the vestibular system
• determine which part of the peripheral vestibular system has pathology
• Caloric irrigation (horizontal canal)
• Rotary Chair (horizontal canal)
  • Sinusoidal Harmonic Acceleration
  • Trapezoidal (Step) Tests
• Video High Impulse Test (VHIT)
  • Tests each canal at high frequencies of head movement

Water or Air Caloric Testing

• Measures the HSCC and superior vestibular nerve.
• Cools (inhibits) or Warms (facilitates) endolymph which will cause the cupula to move toward or away from the utricle resulting in nystagmus.
• It is the gold standard test to determine asymmetry of responses.
• May be frightening for young children, but can be done.
Water or Air Caloric Testing

- The right and left sides are compared to determine asymmetry and directional preponderance
  - 25% asymmetry is abnormal in most labs
  - Average peak velocity gain (eye velocity/head velocity) is recorded for each of 4 irrigations (right and left warm, right and left cool).
  - This test mimics low frequencies of head movement (0.002-0.004 Hz)
  - **COWS** (cold opposite, warm same)
    - Cold water causes the endolymph to sink so the cupula deflects away from the utricle (hyperpolarization)
    - Warm water causes the opposite reaction (depolarization)
    - Water is 7 degrees Celsius above or below body temperature


http://www.d.umn.edu/~jfitzake/Lectures/DMED/InnerEar/IEPathology/CaloricTest.html
# Peak Slow Component Eye Velocity

<table>
<thead>
<tr>
<th>Jonkees Formula</th>
<th>Total Response</th>
<th>Relative Vestibular Reduction (RVR)</th>
<th>Directional Preponderance (bias in the system)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 20 deg/sec indicated bilateral hypofunction</td>
<td>RC + LC + RW + LW</td>
<td>[(LC + LW) - (RC + RW) \times \frac{100}{(LC + LW) + (RC + RW)}] &gt;25% is abnormal</td>
<td>[(LW + RC) - (RW + LC) \times \frac{100}{(LW + LC) + (RW + RC)}] &gt;25% is abnormal</td>
</tr>
</tbody>
</table>

---

**Caloric Summary**

Rotary Chair

- Measures horizontal SCC and superior vestibular nerve function
  - Gold standard to diagnose bilateral hypofunction
- VNG or ENG: used to determine VOR gain and phase in response to rotational stimuli in the dark.
- Sinusoidal stimuli (chair moves side to side) are tested at 0.01-1.28 Hz at 50-60 deg/sec.
- Trapezoidal testing (chair spins) is typically done at 100 deg/sec for 60 sec.
- Outcomes are gain (eye velocity/head velocity) phase (timing b/t response and stimuli) and time constant: how long does it take for the response to decrease to 37% of its initial value?
- Published norms for children: Staller 1986; Casselbrant 2010; Valente 2007; Charpiot 2010; Maes 2014
Slower Sinusoid (0.04 Hz)
1.28 Hz sinusoid

Interpretation

• Phase (timing of the response)
  • Abnormal increase in phase lead or short time constant (<10 sec)
    • Hypofunction
      • Pathology in labyrinth, CN VIII or Vestibular nuclei
  • Abnormal decrease in phase lead or long time constant (> 25 sec)
    • Cerebellar involvement (vestibulocerebellum)

• Gain (strength of the response)
  • Decrease in gain
    • Bilateral peripheral vestibular hypofunction

• Asymmetry
  • Bias in the system...that spinning one way produces nystagmus easier than spinning the other way
Rotational Chair Summary
VOR Summary

STEP test @ 100 deg/sec
Visual and Vestibular Interaction

- Central visual and vestibular systems:
- VOR Cancellation Test
  - Chair moves sinusoidal while the subject looks at a laser dot
    - ability to suppress the VOR centrally
- Visual Enhancement Test
  - Chair moves sinusoidally with OKN lights on
VOR ENHANCEMENT AND CANCELLATION

Video Head Impulse Test (vHIT)

- Goggles measure head and eye movement to a rapid head thrust
- Can test the horizontal, anterior and posterior canals
- Software tells the clinician if the head impulse was adequate
- Can determine asymmetries
- Functional head movement frequencies
- Several companies
  - GN Otometrics, Synapsis, Micromedical, Interacoustics

JANKY AND GIVENS / EAR & HEARING, VOL. 36, NO. 6, e364–e372
Video Head Impulse Testing (V-HIT)


http://www.icsimpulse.com/
Computerized DVA

- A functional test that requires intact vestibular and oculomotor systems
  - ONLY the vestibular system can stabilize gaze for ADL function
- Measures visual acuity with head movement greater than 2 Hz (120 deg/sec).
- Static acuity is obtained
- Dynamic Acuity:
  - Rate sensor is worn on head, glasses are worn if usual
  - Head is passively or actively rotated & optotype appears only if head moves at 120-180 Hz.
  - Optotypes get smaller and smaller until unable to be seen
    - Can set optotype to appear to right or left head movements
    - Difference in acuity is assessed
- Not used to diagnose UVL or BVL but used to determine response to exercises.
Figure 1. Vision optotypes used included (a) Lea, (b) Early Treatment of Diabetic Retinopathy Study, and (c) HOTV. Rine et al. 2013 Li et al. 2014

DIAGNOSTIC TESTS OF OTOLITH FUNCTION

• SACCULE:
  • Cervical Vestibular Evoked Myogenic Potential (CVEMP)
• UTRICLE:
  • Ocular Vestibular Evoked Myogenic Potential (OVEMP)
  • Subjective Visual Vertical
  • Stationary and with Unilateral Off Axis Centrifuge
CERVICAL VESTIBULAR EVOKE MYOGENIC POTENTIAL

- Measures integrity of the saccule or inferior vestibular nerve function
- Measures EMG activity of sternocleidomastoid muscle
- Induce short tone bursts into each ear via earphone
- Sound stimulates the saccule which causes an inhibitory response that is reproducible.
  - Positive wave at 13ms and negative at 23ms
- Peak to peak amplitudes are measured and compared between ears
- Must have intact and healthy tympanic membrane
- Must have baseline firing of the EMG
- If absent, must do bone conduction since it could be secondary to a middle ear problem
VEMP testing

- Reliability: good (ICC = .89)
- Normative: 2 yo and older like adult
- If positive – perform bone conducted stimulus to validate

Ocular Vestibular Evoked Myogenic Potential

- Tests the integrity of each utricle (superior vestibular nerve)
- Electrodes are placed under each eye to measure inferior oblique muscle response to utricular stimulation
- The patient is told to look up to get a baseline rate of firing
- The sound or bone conduction causes an OVEMP response
  - Negative at 10ms and positive at 16ms
# Evidence of VEMP Testing in Children

<table>
<thead>
<tr>
<th>Authors</th>
<th>Participants</th>
<th>Tests</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheykholesami et al. 2005</td>
<td>24 neonates</td>
<td>C-VEMP</td>
<td>Reproducible VEMPs were produced in all but 1 infant with HL</td>
</tr>
<tr>
<td>Kelsch et al. 2006</td>
<td>30 kids with normal hearing aged 3-11 yrs</td>
<td>C-VEMP</td>
<td>Reproducible VEMPs were obtained and well tolerated by all children</td>
</tr>
<tr>
<td>Wang et al. 2013</td>
<td>20 newboms 15 kids 1-3 yrs 15 kids 4-13 yrs</td>
<td>O-VEMP</td>
<td>O-VEMPs found in all kids over 24 months</td>
</tr>
<tr>
<td>Janky et al. 2015</td>
<td>11 kids with CI 12 kids with normal hearing Mean age =13; 6-17 yrs</td>
<td>C-VEMP O-VEMP</td>
<td>No age related changes except for n23 (CVEMP) that prolongs with age</td>
</tr>
<tr>
<td>Bernard and Weiner-Vacher 2015</td>
<td>52 kids with CMV (5 mths-11 yrs)</td>
<td>C-VEMP</td>
<td>Abnormal responses in 78%</td>
</tr>
</tbody>
</table>
### SUMMARY: DIAGNOSTIC TESTS OF VESTIBULAR FUNCTION

<table>
<thead>
<tr>
<th>TEST</th>
<th>STRUCTURE</th>
<th>NERVE</th>
<th>FREQUENCY</th>
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<tbody>
<tr>
<td>CALORIC</td>
<td>HORIZONTAL</td>
<td>SUPERIOR</td>
<td>LOW</td>
</tr>
<tr>
<td>ROTARY CHAIR (SHA &amp; TRAP)</td>
<td>HORIZONTAL</td>
<td>SUPERIOR</td>
<td>MEDIUM AND HIGH</td>
</tr>
<tr>
<td>VHIT</td>
<td>HORIZONTAL, ANTERIOR, POSTERIOR</td>
<td>SUPERIOR</td>
<td>INFERIOR</td>
</tr>
<tr>
<td>SVV (STATIC &amp; DYNAMIC)</td>
<td>UTRICLE</td>
<td>SUPERIOR</td>
<td></td>
</tr>
<tr>
<td>C-VEMP</td>
<td>SACCULE</td>
<td>INFERIOR</td>
<td></td>
</tr>
<tr>
<td>O-VEMP</td>
<td>UTRICLE</td>
<td>SUPERIOR</td>
<td></td>
</tr>
</tbody>
</table>
Subjective History: Symptoms of Dizziness

- Vertigo (sensation of spinning)
  - Like after getting off of a merry go round
  - This would cue you to suspect a vestibular problem OR BPVC (migraine)
- Lightheadedness
  - Feeling like fainting
  - Could be non-vestibular
- Disequilibrium
  - Feeling off balance
  - Could be vestibular or nonvestibular
Reliability and Diagnostic Accuracy of Clinical Tests of Vestibular Function for Children

Jennifer B. Christy, PT, PhD; JoAnne Payne, MA, CCC-A; Andres Azuero, PhD, MBA; Craig Formby, PhD

Department of Physical Therapy, School of Health Professions (Dr. Christy), and Department of Community Health, Outcomes and Systems, School of Nursing (Dr. Azuero), The University of Alabama at Birmingham, Birmingham, Alabama; Department of Communicative Disorders (Ms. Payne and Dr. Formby), College of Arts and Sciences, The University of Alabama, Tuscaloosa, Alabama.

(Pediatr Phys Ther 2014;26:180–190)

<table>
<thead>
<tr>
<th>SUBJECT CHARACTERISTICS</th>
<th>SNHL (n = 20)</th>
<th>TD (n = 23)</th>
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<tbody>
<tr>
<td>Age in years, mean (SD)</td>
<td>8.9 (1.8)</td>
<td>9.5 (2.9)</td>
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<td>Gender, n</td>
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<td></td>
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<td>Male</td>
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<td>Bilateral profound</td>
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<td>Bilateral severe/profound</td>
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<td>Bilateral moderate/severe</td>
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<td>Etiology of hearing loss, n</td>
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<td>Connexin 26</td>
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<td>Enlarged vestibular aqueduct syndrome</td>
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<td>Pendred syndrome</td>
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<td>Goldenhar syndrome</td>
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<td>Heredity</td>
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<td>Unilateral right</td>
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<td></td>
</tr>
<tr>
<td>None</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>
Vestibular Assessments in Children With Global Developmental Delay: An Exploratory Study

Elizabeth Dannenbaum, PT, MSc; Victoria Horne, PT, MSc; Farwa Malik, PT, MSc; Myriam Villeneuve, OT, MSc; Lora Salvo, PT, BSc; Gegov Chilingaryan, MPH; Anouk Lamontagne, PT, PhD


Characteristics of Participants With Global Developmental Delay
(n = 20)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complications at birth</td>
<td>8 (40.0)</td>
</tr>
<tr>
<td>Hearing impairment</td>
<td>2 (10.0)</td>
</tr>
<tr>
<td>Mild intellectual delay</td>
<td>1 (5.0)</td>
</tr>
<tr>
<td>Dyspraxia</td>
<td>6 (30.0)</td>
</tr>
<tr>
<td>ADHD</td>
<td>3 (15.0)</td>
</tr>
<tr>
<td>Hypotonia</td>
<td>7 (35.0)</td>
</tr>
<tr>
<td>Autism spectrum</td>
<td>1 (5.0)</td>
</tr>
</tbody>
</table>

Abbreviation: ADHD, attention-deficit hyperactivity disorder.

The presented deficits are not mutually exclusive (ie, a child could have more than 1 impairment).
Resting or Gaze Evoked Nystagmus
• Observe eyes with fixation present & removed
• Nystagmus will beat toward the most neurally active side
  • If a peripheral lesion, nystagmus will:
    • not change directions
    • decrease with fixation
• If the nystagmus is direction changing, has no torsional component or is up or down beating, suspect a central problem.

Degrees of nystagmus

1st

2nd

3rd
Post Head Shaking Nystagmus

- Useful to diagnose a unilateral peripheral vestibular lesion (or asymmetry)
- This test should be done with fixation removed (goggles)
- Have the patient close the eyes
- Oscillate the head 20 times at 2 Hz (quickly).
- Upon stopping the oscillation, have the pt open the eyes and observe nystagmus
- **Unilateral lesion**: will see nystagmus to the most neurally active side
- **Bilateral lesion or normal**: will see no nystagmus

Head Impulse Test

- Hold the child’s head in your hands and tell them what you are going to do.
- Don’t forget to ask about any neck pain or pathology.
- Have the child fixate on your nose as you slowly turn the head side to side. Tell the child to “keep your eyes on my nose”
- Quickly and unexpectedly move the patient’s head to one side, then the other.
Head Impulse Test

- A positive test is a corrective saccade to re-fixate the gaze on the target
  - the VOR is not allowing the eyes to remain on the target
- An effective way to do this with children is having them look in the mirror at a sticker as you move the head quickly
- Can also move out to in
- Think about “flicking child’s eyes off of your nose” 😊

HEAD IMPULSE TEST (CHRISTY, 2014)

RELIABILITY

ICC = 0.73

SENSITIVITY

75%

SPECIFICITY

77%

POSITIVE RESPONSE

> 2
Emory Clinical Vestibular Chair Test, modified (m-ECVCT)

- Rotate with eyes closed at 0.5 Hz for 30 seconds (set metronome to 60 – 1 rotation every 2 seconds)
- As soon as the chair stops, put goggles on and time nystagmus until it is significantly reduced or stopped.
- Rest twice the duration of the nystagmus, then do the other side

mECVCT
(CHRISTY et al. 2014)

CUTOFF SCORE: 29.2 SEC
SENSITIVITY: 63%
SPECIFICITY: 100%
RELIABILITY: ICC = 0.95
ECVCT- room light

• Similar methods, but have them look at a white sheet (Christy) or visor (Dannenbaum)
• Cut-off score = 15.3 sec (total R+L) – Christy, 2014
  • Sn=0.75; Sp=0.58 – for VH
  • Kids with global dev delay: 24.6 (right) 24.9 (left)
• Test-retest reliability: ICC=0.88 (Christy, 2014); 0.78-0.82 (Dannenbaum, 2016)
• Inter-rater reliability: ICC=0.37 (left); 0.40 (right) (4 raters; Christy, 2014)
• Correlated with mECVCT-fr (r=0.59)

Time the nystagmus
Time the nystagmus

Clinical Tests of Gaze Stability

- Importance of gaze stability for children?
  - Sports, walking, school activities, reading, play
  - Dynamic Visual Acuity (DVA)
    - Ability to see while the head is moving at a frequency of > 2Hz
  - Reading Acuity
    - Ability to see to read print of normal size at a functional speed
A clinical test of dynamic visual acuity for children

Rose Marie Rine*, Jennifer Braswell

- Do a static vision test & record the line of all correct
- Rotate the head at 2 Hz (to the beat of a metronome if needed). Turn the head at least 30 degrees to each side. Tell the child to “relax and let me move you”
- Stop when the child starts to miss optotypes
- A three or more line decrement between static and dynamic acuity may indicate a vestibular lesion.
- Big practice and motivation effect (tell them to guess)

DYNAMIC VISUAL ACUITY (CHRISTY, 2014)

CUTOFF SCORE: 10
SENSITIVITY: 88%
SPECIFICITY: 69%
RELIABILITY: ICC = 0.81
MDC 90: 8

DYNAMIC VISUAL ACUITY (CHRISTY, 2014)
n=14 with normal vestibular function; n=11 with VH; n=100 healthy kids; ICC= 0.84 and 0.94 (intra and inter-rater); Sn/Sp=100%

Evidence that vestibular hypofunction affects reading acuity in children

Jennifer Braswell\textsuperscript{a,*}, Rose Marie Rine\textsuperscript{b,1}

\begin{itemize}
  \item The child reads or signs groups of words as they become progressively smaller
  \item Time the child, and determine the point at which the child starts to slow significantly (critical print size)
  \item Continue to let the child read until they can no longer see the words (reading acuity)
\end{itemize}

MNRead chart

My father takes me to school every day in his big green car

Everyone wanted to go outside when the rain finally stopped

They were not able to finish playing the game before dinner

around two find ran could sit funny her where myself are kind saw after him help green out little see every

before off very may drink you found hot which always let keep its white yes want laugh red yellow use sleep pretty too hold who small for round got eight please and show ask under big take brown ten better eat black

better red help off under use round got which little find use after him take sleep out myself you brown

around for very and laugh eat green hot funny pretty you show sun wise her hold found ask yellow hot drink

please too must big many to small are eight better at kind use black not keep could also always see when
Reading Acuity Testing

Measures:
- Reading Acuity (logMAR)
- Critical Print Size (logMAR)
- Critical Reading Speed (WPM)

n = 5 hypo; 9 normal VF; 43 TD
All subjects with SNHI

- Cutoff score: 0.20
- Sensitivity: 88%
- Specificity: 92%
- Reliability: >0.75
MODIFIED CLINICAL TEST OF SENSORY INTERACTION ON BALANCE (MCTSIB)

- The child stands barefoot, feet together, arms across chest for 30 sec (up to 3 trials)
  - 4 conditions:
    - 1. Stable floor, eyes opened
    - 2. Stable floor, eyes closed
    - 3. Foam, eyes opened
    - 4. Foam, eyes closed
- Stop timing if the child opens eyes, drops arms, takes a step, or uses a hip strategy
- Add the # of seconds for the 4 conditions (120 total)
- < 110 is the cut-off for potential vestibular related problem

Christy 2014

All 4 conditions: max score = 120

- Cut-off Score: 110 sec
- Sensitivity: 88%
- Specificity: 85%
- Reliability: ICC = 0.74
- MDC90: 16.75 sec

Condition 5 only: max score = 30

- Cut-off Score: 20 sec
- Sensitivity: 88%
- Specificity: 92%
- Reliability: ICC = 0.056
Clinical Testing

- Identify that a balance or motor problem exists.
- If yes, determine the reason:
  - Musculoskeletal
  - Somatosensory
  - Motor Control
  - Coordination
  - Oculomotor
  - Peripheral Vestibular

FUNCTIONAL TESTS OF THE VESTIBULAR SYSTEM (determine response to treatment)

- DYNAMIC VISUAL ACUITY
  - GAZE STABILITY

- MODIFIED CLINICAL TEST OF SENSORY INTERACTION ON BALANCE
  - POSTURAL CONTROL
INTERVENTION STRATEGIES FOR CHILDREN WITH DIZZINESS & GAZE INSTABILITY

Jennifer Christy, PT, PhD
OBJECTIVES:

- Discuss mechanisms of recovery for vestibular hypofunction
  - Compensation
  - Adaptation
  - Substitution
  - Habituation

- Describe exercises to improve gaze stability & decrease symptoms

Horak 1992; Krebs 1993; Han et al. 2011; Schubert 2008

GOALS/OUTCOMES:

- Improve gaze stability
- Decrease motion sensitivity

- INTENSE!
- DAILY ROUTINE!
Gaze stabilization during head mov’t

Vestibulo-ocular reflex (VOR)
- Requires a working vestibular system
- Works during fast head movements
  - > 100 deg/sec

Smooth Pursuit
- Requires a working oculomotor system (central) but not vestibular
- Works during slower head movements
  - < 100 deg/sec

We move the head much more than 100 deg/sec during most daily activities.

Grossman et al. 1988 (n=20 subjects; 21-61 yrs)
Vision and motor development (Franchak, 2010)

- Vision: allows prospective control of limb placement
- How often do kids use foveal vs peripheral vision to guide obstacle navigation?

Children fixated their gaze on the object of interest, rather than the obstacles, even more than adults.

Peripheral vision was sufficient for obstacle navigation in kids and adults.

Head movement during walking and crawling (Kretch, 2014)

- TD walkers (13 mo) kept head stable with fewer deviations in head pitch angles than crawlers
- Crawlers: focus on the ground and their hands
- Walkers: focus on the room and surroundings – distal parts of the environment
  - Visual access increases engagement with objects and people during development
  - Coding of locations relative to distal landmarks – 21 months
    - Requires that objects are clearly seen
Recovery: Static Compensation

Following unilateral vestibular hypofunction:
• Rebalance of resting activity of neurons in the vestibular nucleus
  • Intrinsic neurochemical & synaptic qualities of neurons
  • Takes place in the absence of vision

Recovery: Functional Compensation (Dynamic Compensation)

• Reprogramming of eye movements & postural responses to movement
• Requires challenges to the system
  • Movement
  • Error signals
• Independent of static compensation
Mechanisms of recovery: ADAPTATION

- The capability of the vestibular system to make long term (plastic) changes in the neuronal response to head movement
  - Goals:
    - Decrease retinal slip
    - Improve postural stability
  - Rebalancing of neural activity
  - VOR adaptation
  - To get adaptation, must have retinal slip
    - Vestibular exercises
    - Adequate head mov’t
**Schubert 2008**

- Showed that adults with UVL improved aVOR gain following vestibular rehabilitation exercises
- DVA also improved
- Measured with bite block and scleral coil contacts

**Mechanisms of recovery:**

**SUBSTITUTION**

- The substitution of alternative strategies to replace the lost or compromised function
- Cervico-Ocular Reflex
- **Central preprogramming of Saccades**
- Suppression of perception of oscillopsia

Shelhamer, 2000; Schubert, 2008

IT IS PROBABLY NOT:

- Cervico Ocular Reflex
  - Gain: 0.07-0.2 (Schubert 2004)
  - Dynamic range: <0.1 Hz
- Smooth pursuit
  - Pts with BVL showed gain at the upper end of normal range
  - Did not exceed normal peak velocity (100 DEG/SEC)
  - Unable to train above this velocity

WE THINK THAT IT IS:

- Central pre-programming of saccades:
  - High velocity slow phase eye mov’t
  - Minimizes gaze error in predictable situations
  - Adult patients with UVL and BVL increased the # of pre-programmed saccades following VR.
  - Dynamic visual acuity improved
  - Measured with bite block and scleral coil contacts
Mechanism of Dynamic Visual Acuity Recovery With Vestibular Rehabilitation

Michael C. Schubert, PT, PhD, Americo A. Migliaccio, PhD, Richard A. Clendaniel, PT, PhD, Amir Allak, BS, John P. Carey, MD

Arch Phys Med Rehabil Vol 89, March 2008

A

Pre Recovery UVHr

aVOR Gain = 0.68 ± 0.04
CS Ratio = 2.7

Post Recovery UVHr

aVOR Gain = 1.02 ± 0.13
CS Ratio = 0.64
B

Pre Recovery UVHc 58

aVOR Gain = 0.57 ± 0.09
CS Ratio = 0.84

Post Recovery UVHc 58

aVOR Gain = 0.61 ± 0.08
CS Ratio = 0.94

C

Pre Recovery BVHc

aVOR Gain = 0.48 ± 0.1
CS Ratio = 0.92

Post Recovery BVHc

aVOR Gain = 0.85 ± 0.06
CS Ratio = 1.08
Mechanisms of recovery:
HABITUATION

- Long term reduction of a response to a noxious stimulus (specific mov’t) brought about by repeated exposure to the provocative stimulus
- Vestibular asymmetry leads to sensory mismatch (symptoms)
  - Poor tolerance of mov’t or afferent input
  - Examples: optokinetic stimulation for someone with visual vertigo; swinging or spinning a kid to get them “used to” the movement

HABITUATION

- Non-permanent decrease in response to a repeated benign stimulus
  - Synaptic activity decreases
  - # of connections decrease
  - Develop exercises that provoke mild to moderate symptoms and do them several times a day.
  - Should produce symptoms but not too much
Experiment on aplysia (sea slug)

Decrease in # of transmitter vesicles released from presynaptic terminals (less glutamate released)

Enhancement of synaptic inhibition is another mechanism.

The effect (memory) depends on how long the stimulus lasts, and how the stimulus is delivered: massed vs spaced training
Promote gaze stability:

- Adaptation exercises
  - must get retinal slip and error signal
  - Requires some vestibular function (e.g. UVH)
  - Adapting at the level of the vestibular nuclei
- Substitution exercises
  - To promote central preprogramming
  - Does not require remaining function (e.g. BVH)
  - Substituting other neural strategies
- Habituation exercises
  - To decrease symptoms (if present)

Horak 1992; Krebs 1993; Han et al. 2011; Schubert 2008

GAZE STABILIZATION EXERCISES

1. Repetition (3X/day minimum for 6-12 weeks)
2. Error signal (ADAPTATION)
3. Voluntary head movement
   - Yaw and Pitch
   - Small Amplitude
   - Neck soreness
   - Exercises might make them dizzier
4. Active participation
5. Goal oriented and specific
   Hall 2016
Treatment considerations ADAPTATION

- Must produce an error signal
- Be patient, it takes time
- Exercises may provoke symptoms
- Work at the upper limit of ability
- Make it a game, incorporate into life

Adaptation exercises

- X1 viewing
  - View a small object (letter, number, picture)
  - Move head side/side or up/down
    - Must maintain focus
    - Remember smooth pursuit works at < 2Hz
    - Try to complete for a full minute, work up to 2 minutes
- X2 viewing
  - Moving card and head in opposite directions
  - More advanced
  - May be difficult for BVL
Variables to Change

- Background Complexity
  - Use wrapping paper/game boards/powerpoint slides
- Speed of head movement
  - Cue them that the image should almost go out of focus
  - Have the child identify each optotype
- Base of support & surface
  - Sit, stand, walk, foam, tandem, single legged stance
- Distance of Target
  - Near target (arm’s length)
  - Far target 10’

Variables to Change

- Optotype Size
  - Begin large and progress to small
- Optotype Form
  - Letter, Word, Picture, Group of Words
- Time of Exercise
  - Progress to 2 minutes
- Frequency
  - Begin 2X/day, progress to 5X/day
- Only change 1 at a time!
Considerations:

- Image must be stable
- Observe the eyes
- If progressing one variable, may need to modify another
- Avoid overstimulation

Substitution exercises

- Eye-Head Movement Between 2 Targets
- Imagined (remembered) Targets
EVIDENCE FOR EFFECTIVENESS

- Clinical Practice Guidelines (Hall, 2016)
- Level of Study
  - Level I (RCT) vs Level IV (case study or series)
- Rigor of Study
  - Control for confounding variables
- Dose of Intervention and Progression
- Outcome Measures

DOSE: ACUTE VESTIBULAR HYPOFUNCTION
Exercises began on 3rd post-op day

<table>
<thead>
<tr>
<th></th>
<th>Herdman et al. 1995</th>
<th>Enticott et al. 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td>Acute UVH (n=19) from vestibular schwannoma surgery</td>
<td>Acute UVH (n=65) from vestibular schwannoma surgery</td>
</tr>
<tr>
<td>Main Finding</td>
<td>Improved subjective dizziness and balance</td>
<td>Reduced perception of dizziness and imbalance</td>
</tr>
<tr>
<td>Frequency of GSE</td>
<td>5X/day</td>
<td>4-5X/day</td>
</tr>
<tr>
<td>Duration</td>
<td>1 min of each GSE for a total of 20 min/day</td>
<td>1 min of each GSE sitting and standing in pitch and yaw (16-20 min/day)</td>
</tr>
</tbody>
</table>
**DOSE: CHRONIC UVH or DIZZINESS & NORMAL VESTIBULAR FUNCTION**

3X/day (12 minutes total) minimum

<table>
<thead>
<tr>
<th>RCT</th>
<th>Herdman et al. 2003</th>
<th>Hall et al. 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td>UVH (n=23)</td>
<td>Dizziness (n=37) *normal VF</td>
</tr>
<tr>
<td>Main Finding</td>
<td>Improved DVA</td>
<td>Reduced fall risk &amp; improved DVA</td>
</tr>
<tr>
<td>Frequency</td>
<td>5X/day of GST</td>
<td>3X/day of GST</td>
</tr>
<tr>
<td>Week 1 total time</td>
<td>20 min</td>
<td>12 min</td>
</tr>
<tr>
<td>Week 2 total time</td>
<td>30-40 min</td>
<td>18 min</td>
</tr>
<tr>
<td>Week 3 total time</td>
<td>28 min</td>
<td>27 min</td>
</tr>
<tr>
<td>Week 4 total time</td>
<td>28 min</td>
<td>24-27 min</td>
</tr>
<tr>
<td>Week 5 total time</td>
<td>36 min</td>
<td></td>
</tr>
</tbody>
</table>

**DOSE: BILATERAL HYPOFUNCTION**

3X/day (20 minutes total) minimum

<table>
<thead>
<tr>
<th>RCT</th>
<th>Herdman et al. 2007</th>
<th>Krebs et al. 1993</th>
<th>Rine et al. 2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td>N=13</td>
<td>N=8</td>
<td>N=21 children (3-8.5 yrs)</td>
</tr>
<tr>
<td>Main Finding</td>
<td>Improved DVA</td>
<td>Improved gait speed, postural stability and DHI</td>
<td>Improved motor development and balance</td>
</tr>
<tr>
<td>Dose</td>
<td>4-5X/DAY GSE for 20-40 minutes total</td>
<td>1X per week clinic; 1-2X/DAY for 8 weeks HEP</td>
<td>3X/week for 30 min sessions in school. No HEP</td>
</tr>
<tr>
<td></td>
<td>20 min/day of balance and gait</td>
<td>10-16 different exercises in each “phase” of Rx (at least 20 min/day. Included GSE and balance/gait</td>
<td>Modified ex as done in Krebs for children</td>
</tr>
</tbody>
</table>
Review

- What is the rationale for doing X1 and X2 viewing exercises?
- What is the rationale for doing eye-head movement and imagined target exercises?
- What outcome measure will you use to determine changes due to intervention?
- How much should the child change to say that it was a true change?

Fun ideas to promote adaptation

- Read a favorite book while turning the head in sitting or standing (yaw and pitch)
  - Read while bouncing on a ball
- Place small pictures/words on the wall and furniture. Tell the child which one to go find and time them (try to go faster)
- Jump on mini trampoline while reading flash cards or a book
- Walk or run and chase someone while reading flashcards (flash them quickly)
- Sit and spin: flashcards
Other ideas to promote substitution for gaze stability

• Eye-head b/t 2 targets
  • Put a picture on the wall (home base). Have the child turn eyes and nose to the home-base picture. When you say “go” you quickly flash a word or picture and the child quickly generates a saccade and head movement to identify it.

• Imagined targets
  • Child focuses on a picture or word, closes eyes and you change the word or picture as the child turns around and identifies the new word or picture

Other ideas:

• Letters/pictures on tennis ball – play catch, identify pictures
• Catch falling leaves or falling pictures/numbers
• Anything to get head movement and visual focus!
• Re-test DVA after intervention
Dose: Daily; 3X/day; 2-3 exercises

- Before school:
  - Read a book while turning the head (5 pages)
  - Stand on foam with feet together and close eyes for 10 sec/open eyes for 10 sec (5 times)
  - Read 20 flash cards while turning head up and down
- After school:
  - Jump rope while reading flashcards (2 min)
  - Stand on 1 foot (fingertouch) with eyes closed X 2 min
  - Remembered targets X 2 min

- Before bed:
  - Read book while moving it opposite of head turns (2 min) – difficult!
  - Stand tandem for an entire song while moving arms (5 min)
  - Eye head movement to objects around room while sitting on bed (2 min)

- Follow up weekly to progress. Re-assess after 3 months. It may take longer for kids born with VH.
Habituation

- Determine what motion causes the symptoms
- Find a motion that only provokes moderate symptoms (not too severe, not too mild)
- Do this motion with them 3X/day; 3-5 repetitions.
- If it makes them sick, you did too much.
  - If they aren’t improving, you might be doing too little.

CASE REPORT

Preliminary evidence of improved gaze stability following exercise in two children with vestibular hypofunction

Jennifer Braswell a,⁎, Rose Marie Rine b,1

• 4 children with SNHI and VH
  - 3 with BVH on rotary chair
  - 1 with compensated UVH (inc. phase lead on the right side)
    - All with failure on DVA and RA
• Delayed rx design
  - Test 1: DVA and RA
  - Test 2 (4 weeks later): DVA and RA
  - Test 3 (post-intervention): DVA and RA
Gaze Stabilization Exercises

• 3X/week; 20 minutes; 6 weeks (18 sessions)
  • No home program
• Backgrounds on posters or powerpoint
• Head mov’t in yaw and pitch
• Variables changed at 80% correct responses:
  • Font size (20 point, 16 point, 12 point)
  • Background complexity
  • Speed of head mov’t

Braswell, Rine 2006

Other Exercises

• Walking while viewing background and finding letters
• Reading simple books while standing on compliant surfaces and book is moved
• Sit and spin while identifying letters
Changes in mean CPS and RA

logMAR

CPS RA

test 1 test 2 test 3

Figure 9: Changes in mean DVA score

lines of difference between SVA and DVA

test 1 test 2 test 3

DVA score

Braswell, Rine 2006
Figure 12: Changes in critical print size by subject

Figure 13: Changes in reading acuity by subject
Following intervention:

- CPS improved
  - 6-7.5 point to 4.5-6 point (approaching typical)
- RA improved
  - 4.5-6 point to 3.5-6 point (same as typical)
- children w/ VH: read a smaller print w/ less effort required.

Braswell, Rine 2006

Child with Acquired BVH (17 mths)

- Teacher/ caregivers commented
  - able to read better, even in car

- Implications:
  - If exercises done earlier (before reading begins) may improve reading acquisition
  - May improve gaze stability for sports/other activities that involve head mov’t
Intervention For Balance Impairments: Mechanisms, Activities & Efficacy

Promote Recovery Through:

• Adaptation
• Substitution
• Habituation
• Motor learn/ re-learn
  • Integration /re-weighting
  • Dynamic sensory interaction and use
**Adaptation**

- The capability of the vestibular system to make long term (plastic) changes in the neuronal response to stimulus (head/body movement)
  - Reset system: cerebellum and brain stem changes
  - Includes motor learning
- Goals:
  - Motor – increase ability to use remaining fx; integrate information; re-set the system
    - Improve postural stability, eye-hand co-ordination
    - Improve motor development, decrease falls/LOB
    - Improve alignment

**Vestibulospinal Adaptation**

- Requires an error signal (e.g. loss of balance) but success (e.g. regaining balance)
- Adequate head mov’t while balance
- Adequate body movement (COM or support)
- Movement of self and imposed by environment
- Practice balancing with the varied cues
- Practice under varied demands on sensory re-weighting
- Static and dynamic
Substitution of intact sensory systems

- The substitution of alternative strategies to replace the lost or compromised function (postural control)
- Central preprogramming & learning
  - Anticipate
  - Push the use of vision for balance
  - Push the use of somatosensation and strength for balance
- Train – sensory re-weighting or integration

Substitution exercises

- Teach them to use VISION
  - Visual focus is stable
  - Surface is unstable

- Teach them to use SOMATOSENSORY
  - Strengthen use of muscle information
  - Sit on T stool – FEET ON STABLE FLOOR
  - Stand on stable floor (eyes closed, busy visual environment)
  - Impose cognitive task while balancing
  - Teach them to focus on feeling the floor and getting their COM in a stable position
Substitution exercises - somatosensory

- Sit - On T stool/ball – use ankles – control tummy position
  - Progression - with concentration – without (talk, sing)
  - Progress - Increase demands on vision and move arms (watch moving object, Simon-says, etc)
  - Progress - Moving head/feet
- Stand - force to use then progress (keep tummy over feet)
  - Modify support (tandem, sls, etc but on stable surface)
  - Busy surround or head moving while on stable surface

Substitution exercises - vision

- Balance with fixation on item at eye height
  - Modify support (feet together, tandem, single limb)
  - Modify surface – foam, tilt board
- Progression
  - Posture – begin in one that is stable – challenge it (sit, moving on rocker board or scooter board)
  - Speed of movement - increase
  - Postural challenge - next posture (high kneeling, standing)

*Strengthen the vision system functional effectiveness in balance!
Balance Exercises to push the use of vestibular information

- Unstable surface
  - e.g. foam, bosu, tandem, single legged stance) and
- Absent or unstable visual surround
  - e.g. eyes closed, busy environment, window with traffic, large screen TV with action movie).
- Will be difficult for Bilateral but need to practice!

Substitution

- Central preprogramming
  - Teach to anticipate, using other sensory systems
  - Balance training
  - Anticipatory postural adjustments
- If Bilateral Loss: visual and somatosensory cues are needed
  - Light is needed (night in house)
  - Carry pocket flashlight
  - Be careful/aware on uneven terrain
Habituation (motion sensitivity, CNS, acute UVL)

- Vestibular asymmetry leads to sensory mismatch (symptoms)
  - Reduce dizziness, improve balance
  - Motion sensitivity (vision + vestibular)
  - Gradually changing this, introduce aggravating conditions - gradual

Summary: Balance Training

- Sensory – push systems left
  - Train, substitute and habituation
  - In child – not developed unless train!
- Motor – strengthen & practice
- Integration – training needed for children
- Challenge with varied sensory conditions
- Decrease sensitivity to movement/visual stimulus
Treatment: push the systems

- Controlled studies have demonstrated significant improvements w/rehabilitation
  - Static/dynamic exercises
  - Gradually increasing difficulties
    - Learning, motor coordination
  - ‘Desensitize’ to provoking stimuli
    - Visual
    - Surface
    - sound

Therapy Intervention

- Build confidence
  - Anxiety or avoidance of tasks
    - Playground or playing w/others
- Treat the identified impairments in a balance environment
- Manipulate the task demands so as to challenge but not exceed the capabilities
Therapy Intervention & Progression

- Manipulate the task demands (change one at a time)
  - Seated → standing → moving
  - Alter base of support
  - Self-paced → Externally paced
  - Add a secondary task
    - Cognitive – e.g. walk & sing or talk
    - Motor – walk while carrying something

- Manipulate the environmental constraints
  - Support surface
    - Firm → Foam → Moving
  - Visual input
    - Reduce → Enlarge → Distort → Remove
  - Find what really challenges your patient
    - But make it successful & fun!
Be Creative

• M-L or A-P sway
  – Firm/foam surface
  – Head still/turns
• March in place on foam
  – Stationary
  – 4-corner turns
• Toss object hand-to-hand
  – Balloon/tennis ball
  – Standing/walking
• Walk while carrying objects
  – Single item, multiple or stacked
• Kick ball stationary, moving
• Promote hip/ankle strategies
  – Simon says
  – Sway to music or imitate tree branches moving in the wind

Efficacy of Intervention for Children with Bilateral Vestibular hypofunction?

• Participants:
  • 24 children with SNHI since birth
• Exclusion: cognitive, orthopedic or other neurological impairment
• Screening: DTR’s, cranial nerve, coordination and vision
• Random assignment to 1 of 2 groups
  • matched for vestibular function & motor development level

Supported by NIH grant # HD37820-02 and Foundation for Physical Therapy
**Methods:**

- Controlled, wait-listed design
- Pre- and post-intervention tests of motor development & postural control
- Intervention:
  - Exercise 12 weeks – placebo 12 weeks = EP
  - Placebo 12 weeks – exercise 12 weeks = PE

**Test 1 – intervention – Test 2 -- intervention – Test 3**

**Instrumentation:**

- Gross Motor Scale of Peabody Developmental Motor Scales
- Posturography testing
  - Sensory conditions (SOT); 2 trials; sensory ratios
  - Dynamic perturbation test (DPT)
    - 4 degree tip
    - 4 trials

**Testers - blinded to group placement**
Intervention

- Under direction of PT, by aide
  - 3 X weekly, small groups (2-3)
  - PT – weekly review, advance activities at 80% success
- Activities to facilitate:
  - Vision and somatosensory function
    - Substitution
    - Adaptation
  - Learning & integration

Intervention: 4 Activity Categories

- Balance training
- Visual-motor training (substitute)
- Eye-hand coordination (train & substitute)
- General motor planning

**Activity from 3 categories in each session
Emphasis on balance, visual motor training
Modification for age – step-like progressions (@ 80% criterion)
Progression Examples
80% criterion

• Keep sitting balance while pulled on scooter board
  • Straight line circling
  • Progress to high kneel – stand
• Sit on t-stool, hands on knees, visual fixation on therapist
  • Look to different targets in area
  • Move hands – (clapping game)
  • Marching

Balance Training:

• Proprioceptive training, and balance
  – Different postures
  – Different surface compliance
• Ex: scooter board, thick mat, tandem walk on compliant surface; SLS, balance beam, walk line, t-stool, sit/kneel on moving scooter board
Visual –motor training

- Adaptation & substitution: vestibular rehab
- Visual stabilization w/ head and/or object movement
- Increase complexity of object, background
- Ex: Swing, sway boards, pics on balloons

Eye Hand Coordination:

- Eye-hand or –foot
- Varying target size, shape, distance
- Varying postural demands
- Ex: balloon badminton, target games
Motor Planning

- Body movement in space
- Organize in various postures and planes
- Ex: hopping over, crawling, obstacle course, galloping

Analysis

- Repeated measures ANOVA on all tests
- Exploratory analysis of vestibular test results – effect on efficacy of exercise?
**Results:**

**Test 1 (pre-intervention)**

- **Motor:** below norm all but Reflex ($p < .01$)
- **SOT:** Lower on SOT-3, -4 & somatosensory and vision ratios ($p \leq .05$)
- **DPT:** increased latency and amplitude of TA ($p \leq .03$); altered relative latency ($p = .04$) – most lost balance

*as compared to typically developing peers*

**Results: Test 2 (post-intervention)**

- **Improvement of motor development** (EP not PE group)
  - Raw scores ($p \leq .04$) all subtests
  - AE scores – previously similar, now differ
Results: Test 2 (post-intervention)

- Improved sensory organization (EP not PE group)
  - somatosensory ($p = .01$)
  - Like normative sample!
- DPT: strategies not changed

Results: Test 3 (post-intervention)

- Motor Development –
  - PE not EP improved ($p = .01$)
  - Gain reversal of AE
- Developmental quotients altered ($p = .01$)
  = AE pre-test/ chronological age @ pre-test vs post-test
Results: Test 3 (cont’d)

- SOT gains, continued for both (combine scores)
  - Vision & somatosensory ratios improved ($p < .04$) and like normative sample

- TA amplitude and latency larger
- Falls/steps 21 (85%) pre, only 4 (16%) post
- New alternative strategy: previously inactive hamstrings activated
Discussion/conclusion

- Exercise intervention:
  - improved function, trend = arrest the delay: related to improved sensory organization & alternative postural strategies
- At withdrawal of exercise – reversal
  - Increased intensity vs duration
  - Require practice, error correction and pre-cursor skills established
- Lack of relationship w/vestibular test:
  - Limitation of testing – omits otolith test (related to acquisition of walking in norms)

Conclusion

- Important to consider the impact of a peripheral or central vestibular deficit for pediatric patients
- Interventions use the same principles but must be modified for kids
- Be creative with the HOME PROGRAM (transfer package)
  - Make it FUN!
Cases

1. 2.5 year old with cytomegalovirus associated developmental delays
2. 11 year old ambulatory child with cerebral palsy
3. 5 year old ambulatory child with myelodysplasia and type II Chiari malformation
4. 8 year old child with developmental coordination disorder
5. 17 yo with SMA and positional vertigo
6. 18 yo with post-concussion syndrome
Testing - Case #1 CMV

- Oculomotor tests (noted during play because of age):
  - Inability to smoothly follow consistently
  - Tends to use saccades to focus eyes
  - Eyes appear to be conjugate with no malalignment

- Vestibular tests:
  - Positive head thrusts bilaterally (mirror method)
  - No nystagmus after spinning, no evidence of vertigo or motion sensitivity

- Equilibrium reactions:
  - Delayed tilting response
  - Protective extension present

- Somatosensory:
  - No apparent deficits with sensation; unable to test proprioception

- Motor:
  - Limited ankle DF bilaterally and grade of 1+ on Ashworth Scale
    - Child wears bilateral SMO’s in shoes
  - LE strength appears to be good
    - Not formally tested due to age

- Balance:
  - Cannot stand independently but able to stand with very little assistance (finger to the back or 1 hand held assistance)

- PDMS-II reveals that he is functioning well below age appropriate for gross motor
Case #1 - CMV

- Following the evaluation, the child was noted to have balance problems and motor delays due to the following:
  1) Poor oculomotor abilities (central visual problem)
  2) Poor vestibular function (possibly peripheral hypofunction)
  3) Slight spasticity in the ankles (central deficit of the motor system)

Therefore, interventions should focus on the individual deficits as well as the integration component for balance.

Ideas - CMV

- While sitting on a swing that is moving side to side show him various animal stickers and see if he will identify the "dog" "cat" or other animal.
  - Can also do while spinning him in office chair
- While walking in a walker or supported on a treadmill, have him reach out and pick up small objects such as cheerios or stickers (focus during head movement and EHC).
- Work on independent standing while having him watch a video, progress to watching while walking on treadmill
- Work on visual following while supported on a stability ball (move toys side to side/up and down/ present them at various places in the visual field to promote saccades)
- Stand on an incline with knees straight (stretch)
- Work barefoot (strengthening the feet & ankles).
- Work on various surfaces in standing (push somatosensory and vision)
Case #2-CP

- An 11 year old ambulatory child with CP presents with balance problems.
- Her goal is to be able to take dance lessons with her friends.
- She has received PT for most of her life to include several intense therapy sessions (i.e. 3 weeks of “boot camp” like therapy).

Tests-CP

- Oculomotor:
  - Strabismus noted (eyes not aligned when looking straight ahead)
  - Smooth pursuit is intact
  - Saccades: overshoots target 5/10 times
- Vestibular:
  - Must be viewed with caution, due to the abnormal OM exam
  - Negative head thrusts bilaterally
  - Normal DVA test
  - Post rotary nystagmus: 15 seconds R/ 10 sec L
Tests-CP

• Somatosensory:
  • Inconsistent responses with movement/position sense of toe/ankle
  • Intact light touch

• Motor:
  • Overall LE/UE weakness, right weaker than left
    • Right side, inability to move against gravity
    • Inability to do toe raises, sit ups, or trunk/hip extension
    • Ankle dorsiflexion, poor responses bilaterally
    • Modified Ashworth grade of 2 on the right, 1+ on the left
    • Poor posture noted on plumb line

Tests-CP

• Functional Reach=5 cm
• Falls using protective extension with nudge test
• MCTSIB: falls when standing on foam with eyes closed and uses a hip strategy to stand on foam with eyes open.
• Unable to do single legged stance
• The BOT-II subscale was too difficult
• PBS score=40
Case #2: CP

- Recall that this child’s balance problems are due to:
  1. Oculomotor deficits (central visual problems)
  2. Somatosensory/motor deficits (central in nature)
  3. Inability to use vestibular information when vision is taken away

Ideas

- Proprioceptive awareness activities such as the Brain Dance techniques discussed earlier
- While she is sitting or standing still, move a toy or object and make her follow only with her eyes.
- Present objects quickly and unexpectedly to see how quickly she will move her eyes to them.
- Work specifically on teaching her to focus her eyes while standing and especially during challenging situations.
Case #3: 5 year old child with Myelodysplasia & Chiari Malformation

- The level of the spina bifida is L5
- The child walks with bilateral quad canes and has a wheelchair for very long distances
- The child would like to be able to walk without her canes

Tests-Myelodysplasia

- Oculomotor:
  - Smooth pursuit, saccades & vergence are intact
- Vestibular:
  - Positive head thrust bilaterally
  - 2 beats following m-ECVCT
  - Bucket test was normal
  - Abnormal DVA test
Tests-Myelodysplasia

- Somatosensory:
  - Impaired light touch and proprioception below the knee joint
- Motor:
  - Hips: good strength; knees: poor strength; ankles: no movement
  - Knee extension is limited by 10 degrees bilaterally to straight leg raise
  - Ankle DF ROM is WNL but low tone

Tests-Myelodysplasia

- Able to stand independently but cannot shift weight without falling
- Uses hip/trunk strategies when walking or shifting weight with canes
- Stands with anterior pelvic tilt and flexed knees
- Must wear anterior AFO’s to keep knees from flexing while standing.
Case #3: Myelodysplasia

- Balance problems are due to somtosensory and motor deficits.
- Chiari malformation could cause damage to the vestibular nuclei and therefore the vestibular system is ALSO contributing to the balance problems.

Ideas

- X1 exercises: head turns with focus on letters/numbers
- Sit and spin while identifying letters/objects
- Standing on compliant surfaces such as thick foam or mini-trampoline with eyes open and closed
- Subtle weight shifts with finger-touch then no support. Focus on where the body is in space.
Case #4-Child with DCD

- An 8 year old with developmental coordination disorder would like to be able to play tennis with friends
- The child is ambulatory and attends school
  - He no longer receives PT or OT in school

Tests-DCD

- Oculomotor Tests:
  - Smooth pursuit, saccades, convergence was normal
- Vestibular Tests:
  - Normal head thrusts bilaterally
  - Following spinning, the child had nystagmus and vertigo lasting 30 seconds and required the examiner to stabilize him
  - Normal DVA and Bucket Test
Tests-DCD

- Somatosensory:
  - Intact light touch and proprioception
- Motor:
  - Cerebellar tests were abnormal
    - Overshooting with finger to nose
    - Inability to coordinate RAM or heel to shin
  - Strength was symmetrical and the child was able to hold limbs against resistance
  - Child was unable to extend trunk or do sit ups

Tests-DCD

- Functional Reach = 20 cm
- MCTSIB
  - 20 seconds foam with EC
- Single legged stance
  - 30 seconds with eyes opened
  - 10 seconds with eyes closed
- Nudge
  - No falling, but steps when should be able to fixate (e.g. to a small perturbation)
Tests-DCD

• BOT II – balance subscale
  • Delayed, well below age appropriate, especially on the balance beam tests

Case #4: DCD

• balance problems are probably due to:
  1) Impaired sensory integration
     • hyper-sensitive vestibular input and inability to put everything together for postural responses in challenging situation
  2) Poor tolerance to movement
  3) Impaired coordination (related to poor cerebellar function)
Ideas

- Work on standing and moving while on compliant or challenging surfaces and with busy visual environments
  - E.g. balance on foam in front of a large window that is open to a busy street
  - Walking on a balance beam or line in a busy room (lots of other kids)
  - Stand tandem while playing catch
  - Reach out and tap a sticker on a balloon as you move it back and forth in front of her

Case #5

- 17 year old with SMA
- Referred to you from the MDA clinic since he is experiencing vertigo

How will you begin your exam?
17 y/o with positional vertigo

- Vertigo occurs when he rolls over in bed or sits up in bed
- Non-ambulatory requiring max assist for transfers from his power chair
- Further history:
  - Spinal fusion at age 12 for scoliosis (cervical and thoracic spine)
  - Smooth pursuit and saccades: normal

Case #6

- Pt is a 18 yo female. Pt was a freshman on the University soccer team and sustained a concussion from colliding with another player while practicing with the team about 1 month prior to her initial visit at Outpatient PT.

- Thanks to Brian King, MSPT for this case!
• Pt reports initial symptoms included nausea and headache following the blow to her head.

• Symptoms at time of eval include ongoing headaches, mild nausea at times, and some dizziness. Pt reports triggers for symptoms include bright lights, loud noises, and the stress of doing school work. She is currently having difficulty attending classes and doing school work and is also having trouble sleeping.

• Pt has a previous history of concussion about 8 months prior to this current event and also had a concussion when she was in the 7th grade with loss of consciousness.

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**Headache**

• Current – 6/10 (Headache)
• Highest in past week – 7/10 (Headache)
• Lowest in past week – 4/10 (Headache)

• What tests/measures do you want to do?
BESS

- **BESS**: TOTAL SCORE = 24/60 (# ERRORS IN 20 SEC)

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**Visual Vertigo Analogue Scale**
(Adapted from Longridge et al., 2002)

Indicate the amount of dizziness you experience in the following situations by marking off the scales below.

0 represents no dizziness 😊, and 10 represents the most dizziness 😞.
**VVAS**

- **Visual Vertigo Analogue Scale:**
  - Indicated 7/9 items as positive for causing dizziness as follows:
    - through a supermarket aisle - 3 cm
    - Being passenger in car - 0 cm
    - Being under fluorescent lights - 2.5 cm
    - Watching traffic at busy intersection - 4 cm
    - Walking through shopping mall - 2 cm
    - Going down an escalator - not rated
    - Watching movie at movie theater - not rated
    - Walking over a patterned floor - 1 cm
    - Watching action television - 6.5 cm

- **Functional Gait Assessment** – 27/30
- **Convergence Insufficiency Symptom Scale** – 29/60
- **DVA** – 3 lines of difference
  - **Symptom VAS score** – dizziness following DVA – 2.1 cm
• Balke Treadmill Test (protocol for females):
  - 3.0 mph, increasing incline by approximately 2.5% every 3 minutes
  - On treadmill in the clinic, used 0%, 3%, 5%, 8%, 10%.
  - Pt tolerated all the way to 15 minutes without signs or symptoms (HA or dizziness). HR at 15 minutes was 144:15 min

• Patient’s Physical Therapy consisted of therapy 1x a week. She was instructed on weekly gaze stability exercises at each visit (in standing).
  - She was also instructed on video habituation exercises to help work on her visual vertigo issues.
  - For balance, pt was instructed to work on standing with eyes closed in both single leg stance and tandem stance (firm ground and foam/compliant).
• Week 1 – X1 exercise far and near in pitch and yaw planes
• Week 2 – As above, plus Eyes/Head exercise (about 10 feet back)
• Week 3 – All above, plus X1 with full visual field in yaw plane, and Remembered target in yaw plane
• Week 4 – X1 with full visual field, X2, Eyes/Head exercise, Remembered target, and gait with head turns (all exercises in pitch & yaw plane)
• Week 5 & 6 – exercises as noted above with time frames adjusted

• For cardiovascular endurance: worked on pushing patient up 5 minutes of activity per session by use of treadmill and LE bike.
• Because pt was asymptomatic during the Balke Treadmill test we used a training zone of 70% based on her HR max from age (141 beats/min).
• Pt was able to get to 30 minutes of activity without significant increases in symptoms with this protocol.
• On the day of discharge, pt reported her headaches have not been as frequent, and her symptoms of dizziness have improved when performing exercises in the gym with the team trainer.

• **BESS**: 14/60 (Double leg stance – 0’s; Single leg stance L LE: Firm – 4; Foam – 10; Tandem Firm – 0; Foam 0) (pt reported on this date that she had an old ankle sprain on the L LE and she feels like this may have influenced her score during the Single leg stance part of the test)

• **Functional Gait Assessment** – 30/30
• **DVA** – 1 line of difference

• Also, pt was tested about 1 month prior to discharge on the NeuroCom for the SOT.

• Her SOT composite score was 83 (WNL for age related norms). All 6 conditions were WNL as compared to age related norms.
THANK YOU!

Please come to Jacksonville, FL for the Pediatric Vestibular Competency Course in October, 2017!

- http://www.specialtytherapy.com/