Assessment and Management of Paediatric Balance Issues
Rose Marie Rine, P.T., Ph.D.
Research Professor
University of North Florida

Balance Deficits in Children – what is known?
• CNS lesions
  - Head trauma - motor function deficit;
  - unknown vestibular or postural control
• Cerebral palsy or general motor delay
  - Motor and balance deficits
  - unknown vestibular or postural control mechanisms
• Vestibular deficits
  - Peripheral and central - increasingly identified (OME, BPPV, Meniere's, Migraine, neuritis)
  - Known balance, postural control deficits

Very little research in pediatric balance – needed!!

What we know about balance - adults
• Balance = complex process, multi-sensory & integration + motor
  - Neurological, vestibular or orthopedic problems
  - Static and dynamic balance issues
• Tests
  Functional
  Integrative process - posturography
  Predictive of falls
  Validity for vestibular involvement

Fall risk: meds, CNS, weak, incoordination

Balance impairment is NOT always indicative of vestibular deficit
Balance: Issues in Pediatrics

• Balance
  - Known:
    - Developmental stages; stage like fashion
    - Static & dynamic components - not nec on posturography
    - Integrative fx: 4-6 years critical period
    - Sensory contributions and functions:
      - maturation & change predominant cue for balance
  - Loss w/ peripheral vestibular & central lesions
    - Rx efficacious - w/ peripheral vestibular deficit
    - Dynamic balance related to gait acquisition
  Unknown:
  - predictive fall tests, relationship to general function or vestibular loss; central lesions not studied

Concern for pediatrics? YES!

• Where to begin?
  - Developmental changes and measures
    - Vestibular, balance/postural control, dynamic visual acuity
  - Impairments?
    - Central vs peripheral lesions
  - Testing
    - Balance, motor abilities, vision abilities, vestibular fx
  - Interventions - successful

Balance vs Postural Control

• Balance =
  - The ability to maintain COG/COP within the base of support = static
  - Control movement of COG to maintain a posture = dynamic

• Postural Control =
  - The sensory, motor & integrative mechanisms, substrates & processes required for balance

To appreciate balance – how develop & deficits – must know the determinants = identity deficits in postural control
Sensory – Motor Integration System of Postural Control

Interpretation:
Fall? Need to Respond?

Detect Alignment or error:
Ms-skeletal align, sensory conflict

Activation of synergy:
Specific equilibrium reaction

Detect movement
Muscle Response:
Lean, step crouch

Postural Control

• Age dependant changes in sensory, motor & integrative components
• Comprehensive examination to
  - identify & develop remediation for impairments
  - Dynamic posturography, developmental, sensory screening enables this type of testing.

Understanding developmental changes & inter-modal dependency in function is critical for appropriate evaluation and Rx of children.

Balance Function – development

• Orient in space
  - Vision & vestibular – righting – 1-2 mos
  - Orientation within any posture
    - Step-like emergence –each posture
    - Sit – quadruped – standing
    - Identification of verticality –
      - w/in 2 mos, head erect
      - Dep. upon vision & vestibular systems
      - SVV 4 yrs of age
• Attain, hold and move w/in a posture
  - Developmental sequence – evolves
  - Dep. upon experience w/in a posture
**Balance: developmental milestones**

- **Lift head, align eyes with horizon:** 2 mos
- **Sequence:**
  - **Static:**
    - Assume: sit (6-8 m), stand (10 m)
    - Maintain w/challenge: sit (8m), stand (10-15 m)
  - **Dynamic:**
    - Move w/in posture: scoot 6-10m, walk (10-18 m)
- **Advanced standing:**
  - SLS EO: 3s 3 yr; 8s 4 yrs; 10s 54 mos
  - SLS EC: 3s 5 yr; 8s @ 6 yr
  - Turn 180 degrees - 54 mos
- **Balance beam (3.5 in):** 4 steps @ 4 yr; 8 ft @ 54 mos; tandem walk 6 yr

  - Walk on straight line: 5 years

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**Postural Control Development**

- **Sensory mechanisms in balance**
  - Vision
  - Somatosensory
  - Vestibular
- **Integration/interpretation**
  - Central processes
- **Motor output**
  - Selection
  - Activation of motor
  - Strength
  - Coordination

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**Postural Control Development**

- **Sensory mechanisms in balance**
  - Somatosensory:
    - Adult-like responses in postural control by 3-4 yoa
  - Vision:
    - Binocularity & fusion by 3-4 yoa
    - Adult-like in postural control - adolescent
  - Vestibular (used early, orienting)
    - Rotary chair adult-like after 4 yoa, as is VEMP & SVV
    - Not adult like in postural control until after 15 yrs
Postural Control Development

- Sensory mechanisms in balance
- Integration/interpretation
  - Critical period = 4 - 6.5 yoa
  - Increased variability
  - Difficulty resolving conflicts of sensory cues
  - Adult-like after 15 yoa

Motor output
- N-ms response - sequence initially proximal-distal (Woollacott & Shumway-Cook; Nashner)
  - Physiologically measured responses
    - Short latency & long latency responses adult-like between 3 and 4 years (EMG) (Mowatt, Woollacott & Shumway-Cook)

Sensory – Motor Integration System of Postural Control

? Children

- Interpretation: Fall? Need to Respond?
- Detect alignment or error: Musculoskeletal alignment, sensory conflict
- Activation of synergy: Specific equilibrium reaction
- Receptors: Detect movement
- Muscle response: Lean, step crouch
Testing Components for Children -
How to identify the problem?

- Functional Balance Abilities
- Mechanisms
  - Postural control integration measures
  - Vision & oculomotor test/screen
  - Somatosensory/motor screening
  - Vestibular testing

Functional Balance Testing

- Standardized norm referenced testing (PDMS II & BOTMP II)*
  - Balance sub-tests
  - Eye-hand coordination
  - Milestones
- Functional Reach
- Berg Balance Scale

*Peabody Developmental Motor Scales  
Bruininks-Oseretsky Tests of Motor Proficiency

PDMS - sample
Functional Reach

- Functional Reach: norms for 5yo and up
  - 5-6 yrs: 6.7 in; 7-8 yrs: 8.2 in
  - 9-10 yrs: 10.2; 11-12 yrs: 11.9 in

(Donahue, Turner and Worrell)

**None adjusted for height!**

Adults & children

- Measure:
  - Center of pressure (COP), kinematics and reach @ shoulder & pelvis
  - UE crossed and not

- Results: adjusted for height/arm position:
  - Over 7yo & adults similar
  - To correlate w/COP, UE crossed, measure from pelvis (adult) or shoulder (child)

- Correlate with gait - children with CP
  - Rine & Moore, 2005; Moore & Rine 2007, 2009 (SPGR)

Functional Reach – Control ht & arm position

- Adults & children
- Measure:
  - Center of pressure (COP), kinematics and reach @ shoulder & pelvis
  - UE crossed and not
- Results: adjusted for height/arm position:
  - Over 7yo & adults similar
  - To correlate w/COP, UE crossed, measure from pelvis (adult) or shoulder (child)

Pediatric Berg Balance Testing

- Test balance @ functional not impairment level; not diagnostic.
- 8-12 yo children w and w/o CP (mean age 10)
  - Berg Balance Scale
  - Gross Motor Functional Measure (GMFM)
  - Those with higher GMFM scored higher on Berg
  - 15 min to administer

<table>
<thead>
<tr>
<th></th>
<th>BBS score (56 max)</th>
<th>GMFM (111 max)</th>
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<tbody>
<tr>
<td>Sp hemi</td>
<td>53.2</td>
<td>100.3</td>
</tr>
<tr>
<td>Sp diplegia (aids)</td>
<td>49.7</td>
<td>88.4</td>
</tr>
<tr>
<td>Sp diplegia (no aids)</td>
<td>25.1</td>
<td>37.6</td>
</tr>
<tr>
<td>No motor impairment</td>
<td>95.9</td>
<td>110.9</td>
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</table>

Kembhavi et al. Pediatric Physical Therapy; 2002
Testing Components for Children

- Functional Abilities
- Postural control measures –
  - Integration & sensory-motor output
- Vision & oculomotor testing, screening
- Vestibular testing

Posturography:
SOT & Dynamic testing

Interpretation dependent upon sensory and motor test results

SENSORY ORGANIZATION TEST (SOT) SIX CONDITIONS

1. Eyes Open
2. Eyes Closed
3. Semi-closed Eyes
4. Eyes Closed
5. Eyes Closed with Vestibular Disturbance
6. Eyes Closed with Vestibular Disturbance
Testing Components for Children

- Functional Abilities
- Postural control measures
- Vision & oculomotor testing, somatosensory/motor screening
- Vestibular testing

OM Screen - tracking and ROM
adult like by 2-3 yrs.

Vision Screen - OKN
- Patient to watch vertical stripes pass by
- Observe nystagmus
- Normal = for 1-2 beats
Vision & Gaze Stabilization Testing

- Static & dynamic visual acuity
- HT (vestibular screen) adult-like

Dynamic Visual Acuity

- Dynamic Visual Acuity
  - Acuity w/ head stable 2 trials
  - Acuity with head passively moved 15 degrees R to L @ 2 Hz
  - began @ 20/200 & continued until missed 3/5 optotypes on a given line
  - LogMAR of the line above the stop line recorded.
  - Scores were averaged & calculated:
    - dynamic logMAR - static logMAR
  - > .2 = positive test

Somatosensory Screen

- Light and deep touch, vibratory sense on leg
- Position sense
- DTR's
- Hold against resistance (knee extend, ankle dorsi- and plantar flex)
- Motor Screen RAM
Testing Components for Children

- Functional Abilities
- Postural control measures
- Vision & oculomotor testing, somatosensory/motor screening
- Vestibular testing

Vestibular Testing:

- Canals
  - Post-rotary nystagmus
  - Calorics, rotary
- Otoliths
  - SVV
  - VEMPS

Subjective Visual Vertical Testing

- Test protocol
  - Align bar, vision and somatosensory cues min/eliminated
  - Cannot see or feel alignment
  - Vision blocked between trials
  - Within 2 degrees normal (even as young as 4.5 yo)

L. Farrell & RM Rine, CSM 2005
VEMP Testing (vestibular evoked myogenic potential)

- Response of SCM to stimulus
  - Air: 95 dB nHL
  - Bone: 55-66 Hz
  - Latency (P13 N23), amplitude (corrected to baseline)
- Adults and children 3-9 yrs
- Rep. Fx integrity of saccule or inf. vestibular nerve

Differential Diagnosis: (what if motor or vision?)

<table>
<thead>
<tr>
<th>Tests</th>
<th>Peripheral V</th>
<th>Central V</th>
<th>motor</th>
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</thead>
<tbody>
<tr>
<td>Sensory</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Motor synergy</td>
<td>- (+ for acute B Ves)</td>
<td>+ or -</td>
<td>+ (weak, absent)</td>
</tr>
<tr>
<td>SOT</td>
<td>+ selective</td>
<td>+ 4-6</td>
<td>ALL</td>
</tr>
<tr>
<td>Vestib-nystagmus</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Subjective
- Spinning
  - Dizzy; cannot walk
- Not dizzy; off balance
- Not dizzy; cannot stay up, not off balance

Evidence of reading acuity deficit: 10 year old - Bilateral hypofunction

- Typical development to 1.5 yrs
  - Diabetic coma w/reresultant hearing loss, VeD, no other functional loss.
  - Severe/profound SNHI (implant @ 3 yrs)
  - No referral, struggle in school, parent fighting for mainstreaming
- Exam & Evaluation:
  - CN (not VIII), DTR, motor development negative
  - HT and HS positive bilaterally
  - DVA - 6.5 line difference
  - Reading acuity - below norm
- Intervention:
  - 18 sessions - 3X/wk for 6 wks
  - focus: improve visual system & substitution - visual focus w/head and/or target mov't
Intervention to Improve Gaze Stability

- Targets: letters & numbers - 20, 16 & 12 point
- Backgrounds: simple to complex
- Change size, speed, background complexity @ 80% criterion

ABA design
- Improved CPS, RA, & DVA
- DVA to 3.5 lines difference: reading signs while riding in car
- Similar to adults, improved gaze stability with intervention
- ? Intensity vs duration

Plan and Results - Improved Gaze Stability

- Male (AG) episodic right lean (w/falls) over 7 mos
- Developmental: Prematurity w/ complications: mild L sided hemiparesis @ 6 mos, PT & OT T2W x past 4 years; PT D/C S - no gait deficits
- Corrective sx for strabismus (5 surgeries)
- Neurology referral:
  - MRI's (head, neck & spine) - negative
  - Ruled out seizure, vision & other CNS factors
- Otolaryngology referral:
  - Severe bilateral middle ear infection. Rx: bilateral tube insertion; Post-op lean lessened, but full w/in 4 mos
  - Rotary & caloric tests deferred 2° to tube insertion;
  - PT referral - comprehensive vestibular assessment and Rx

5 yo Child with VeD following severe MEF (? Neuritis)

5 yo – Examination (cont’d)

• Ambulation:
  - Symmetrical no deviations; steps/steady walking around/over object

Oculomotor:
  - OKN negative
  - Sm Pursuit negative R, corrective saccades L
  - Convergence intact.

Vestibular:
  - HS negative
  - HT positive L, negative R
  - DVA positive (3.5 difference)
  - During test, progressive lean to R and experienced LOB

  - VEMP testing: normal R, reduced/absent L, AR 56%

Examination (cont’d)

• Posturography:
  - LOB conditions 5 & 6; stepping on 3 & 4
  - Within age norms on conditions 1 & 2
  - Delayed TA on dynamic test (step)

• Neuromuscular & Musculoskeletal:
  - Symmetrical gait, no evident hemiparesis.
  - ROM, DTR’s strength negative.
  - Associated movements w/effort.
  - Proprioception: intact UE & LE’s (identified & mirrored)

• Motor development: PDMS Gross Motor Scale: Reflex
  - SLS < 5 sec ea leg, hop only 1x on either leg).

5 yo Evaluation Summary

• Diminished GM & oculomotor function consequent to, or exacerbated by UP-VeD involving left horiz. canal and saccule.
• Possible central involvement due to prematurity; visual–motor/strabismus.
• Impairments include aberrant:
  - sensory organization for balance
  - use of vision & somatosensation for balance
  - verticality
  - oculomotor ability.
5 yo UP –VeD Intervention

- Home exercises: oculomotor, vision, somatosensory training; 4x/week.
- Direct PT: balance & oculomotor training provided 2x/wk for 3 months.

5 yo Rx Results

- Improved alignment w/self correction,
- Improved postural control (SOT)
- Improved DVA
- Improved SM skills
- Head thrust negative bilaterally

Vestibular Related Impairments in Children with OME

- Plan:
  - Recruited children with OME
    - Exclusion criteria: any known or identified musculoskeletal abnormalities of the legs or spine, neuromuscular disease/condition, diminished sensation of the legs, significantly impaired vision, or developmental delay
  - Test vestibular function (pre & post sx)
    - Head thrust for canal, VEMP for otolith
  - Test Fx: motor development, postural control, dynamic visual acuity (pre and post-sx)
Central Hypothesis

- Children with chronic MEE or SNHI have concurrent vestibular dysfunction (VeD), which is reduced with tube insertion
- VeD in this group results in impairments of gaze stabilization, balance, and postural control

Results – Pre-test

- Vestibular tests
  - Positive HT tests, bilaterally
  - Positive air VEMP bilaterally
- Posturography
  - All above the 75th percentile conditions 1-3
  - All below the 50th percentile conditions 4-6
- PDMS II
  - All below the 50th percentile & scored significantly below the norm (p ≤ 0.05) on the stationary and object manipulation subtests.
- DVA – 1 child refused, all others had positive tests

Post-testing

- Vestibular tests
  - All negative head thrusts post sx
  - All negative air VEMP post sx

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Head Thrust Pre</th>
<th>Head Thrust Post</th>
<th>VEMP air Pre</th>
<th>VEMP air Post</th>
<th>VEMP bone pre</th>
<th>VEMP bone post</th>
</tr>
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<tbody>
<tr>
<td>NOMEJ001</td>
<td>NT</td>
<td>NT</td>
<td>NT</td>
<td>NT</td>
<td>NT</td>
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<tr>
<td>NOMEJ002</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>NT</td>
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<tr>
<td>NOMEJ003</td>
<td>NT</td>
<td>NT</td>
<td>+</td>
<td>NT</td>
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<tr>
<td>NOMEJ004</td>
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<td>NOMEJ005</td>
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<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>NT</td>
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</tbody>
</table>

- + = Positive test result
- - = Negative test result
- NT = Not tested
- * = Although the VEMP response is present, the child scores were significantly lower than their aged norm peers.
Post Tests – PDMS-II

- Two improved to above the 60th percentile
- T-test results support that improvement was significant: stationary and object manipulation $p = .05$; locomotion $p = .12$.
- Due to small sample size, power limitations affect these results.

Gross Motor Percentiles

<table>
<thead>
<tr>
<th>Subjects</th>
<th>DVA Pre</th>
<th>DVA Post</th>
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<tr>
<td>NUMEO01</td>
<td>N/A</td>
<td>NT-LPF</td>
</tr>
<tr>
<td>NUMEO02</td>
<td>+</td>
<td>NT-LPF</td>
</tr>
<tr>
<td>NUMEO03</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>NUMEG04</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>NUMEO05</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

Post-test DVA

- Two of three children had improved gaze stability scores to within normal limits.
- The lack of improvement in score for one child may be attributed to this being his third set of tubes.

Conclusion: In children w/OME

- Significant deficits of motor development, dynamic visual acuity and postural control
- Sx intervention improves status, but to norm
- Suggests need to examine efficacy of physical therapy intervention
- Additional study is needed to
  - Increase # tested
  - Compare to control group of OM recurrent

Study supported by UNF Brooks Professorship & Nemours Children’s Clinic
Effect of Exercise Intervention on Motor & Postural Control of Children with vestibular hypofunction

- Subjects:
  - 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

Impairments related to bilateral vestibular hypofunction

- 2.5-8.5 yoa w/SNHI
- delays on gross motor abilities (p < .03); less w/age
- Longitudinal testing: z scores lower (p < .05)
- Sensitivity of PRNT for identification of progressive deficit = excellent (91%)

Postural Control Deficits

- Lower on SCT-3, -4 (p < .04), vision and somatosensory ratios (p < .05)
- Increased latency & amplitude of TA (p = .04)
- Altered relative latency of soleus and TA (p = .05)

Study 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

**Testers - blinded to group placement
**Test 1 – intervention – Test 2 -- intervention – Test 3

Intervention
• Under direction of PT, by aide
  - 3 x weekly, small groups (2-3)
  - PT – weekly review, advance activities prn
• Activities to facilitate:
  - Vision and somatosensory function
  - Substitution
  - Learning

Balance Training:
• Proprioceptive training, and balance
  - Different postures
  - Different surface compliance
• Ex: scooter board, thick mat, tandem walk on busy surface
Visual -motor training

- Adaptation & habituation: 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

Results: Test 2 (post-intervention)

- Improvement of motor development (EP not PE group)
  - Raw scores (p < .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

![Somatosensory Effectiveness Ratios](image)

**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 versus post-test

![Age Equivalent Scores at Each Test Interval](image)

**Results: Test 3 (cont’d)**

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

![Vision Ratio Scores Pre- and Post-exercise](image)
Results:

- Before and after DPT
- Vestibular function
  - No relationship

Discussion

- Exercise intervention:
  - Improved function, 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 - omitted otolith test (related to acquisition of walking in norms)

Rine RM Braswell J Pediatric Otorhinolaryngology 2004
**Known and Unknown?**

- **Know:**
  - Children have vestibular & balance deficits w/consequent impairments in vision and motor abilities
  - Need intervention
  - DVA and posturography testing good tests to identify deficits
  - Assist in directing intervention
  - Intervention improves vision and motor abilities
  - **FOCUS INTERVENTION on appropriate mechanism!!**

- **Unknown:**
  - Incidence of vestibular or balance impairments in children with CNS deficits; babies in NICU
  - Simple testing of vestibular & posturography in children less than 3 yrs.
  - Normative data on posturography: EMG, ankle vs hip strategy, dynamic limits of stability
  - Relationship of posturography scores and functional testing in children

Thank you, the children and parents!