Vestibular and Balance Problems After mTBI: A Closer Look

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PRESENTEED BY: Natalie Pettigrew, PT, DPT
Jennifer L Wilhelm, PT, DPT, NCS
Disclosures

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Opinions, interpretations, conclusions and recommendations are those of the author and are not necessarily endorsed by the Department of Defense.

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This study uses commercial wearable sensor technology from APDM, Inc, a commercial entity that that may benefit from this work. Dr. Fino and Dr. King’s research have been partially supported in the past by federally funded awards to APDM, Inc., through sub-award contracts OHSU. OHSU and APDM, Inc. actively collaborate on several federally funded awards. Direct conflicts of interest between the two parties are managed by OHSU.
Objectives

• Evaluate the possible mechanism of vestibular function post mTBI
• Discuss a vestibular rehab protocol to improve balance
• Review results from ongoing trial and future directions
Balance related complaints are common in people suffering chronic effects of mild traumatic brain injury (mTBI) (Vanderploeg et al., 2007).

Patients with chronic dizziness after concussion are far less likely to return to work (Marzo, S.J. et al. Laryngoscope 2004).
Balance involves a complex integration of multi-sensory inputs

Brain injury disrupts one or more aspects of postural control \(^1\text{-}^{10}\)

Abnormal use of vestibular and visual systems may be linked to postural instability people with mTBI \(^10\)

Problem: Where is the dysfunction in mTBI?

Vestibular system
Vestibular Connection to CNS
Vestibular system: Inner ear
Use of sensory systems will change depending on the availability of sensory information

(Derived from sway responses evoked by low amplitude surface motion stimuli, Peterka 2002)
Problem: Where is the dysfunction in mTBI?

Importance

• Implications for access to care: ENT, Neurology, Rehab, Trauma?

Purpose

• To measure vestibular function and explore its relationship with measures of balance in people with chronic mTBI.
Canal testing

**Calorics** (traditional assessment of vestibular canal function and asymmetry)

**vHIT**-video head impulse test- VOR analysis of high frequency vestibular function

Otolith testing

**Vestibular Evoked Myogenic potential**

**cVEMP**- assesses saccular function

**oVEMP**- assesses utricular function
Static Balance Testing
Central sensorimotor integration test (CSMI)

Different from Gold standard SOT:
- Model provides weighting scores and output parameters
- Pseudo-random programmed surface and visual perturbations

**Sensory weight**
Measure of the relative contribution of one or more sensory systems

**Stiffness (Kp)**
Corrective ankle torque \( T \) generated in proportion to the body sway angle \( \theta \)

**Damping (Kd)**
Corrective ankle torque \( T \) generated in proportion to the body sway angular velocity \( \omega \)
Dynamic Balance Testing
Canal assessment; calorics and vHIT

Unpublished data, King lab 2018
Otolith assessment

Unpublished data, King lab 2018
Balance assessment

Unpublished data, King lab 2018
Correlations

<table>
<thead>
<tr>
<th>Vestibular</th>
<th>Sensory Organization (SOT)</th>
<th>Dynamic Balance (Gait)</th>
<th>Dynamic Balance (Turning Gait)</th>
<th>Clinical Symptoms (DHI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5MP Combined Amplitude</td>
<td>C5MP Combined Amplitude</td>
<td>RMS Sway</td>
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</tbody>
</table>

Effect size interpretation:
- Small: 0.10
- Medium: 0.25
- Large: 0.40

Correlation is significant at the 0.05 level (2-tailed).
Correlation is significant at the 0.01 level (2-tailed).
Sensory weighting with mTBI

CMSI Sensory Weight

CMSI Stiffness (Kp)

CMSI Damping (Kd)
Summary of sensory weighting in mTBI

- Chronic mTBI with balance deficits:
  - No peripheral otolith or canal dysfunction vs age matched healthy controls
  - Peripheral vestibular tests are not correlated with static and dynamic balance/gait deficits
  - Deficits likely due to central vs peripheral dysfunction of vestibular system
  - Non-blast subjects may **not benefit** from audiology assessment for dizziness/balance...
Role of rehab in central sensory reweighting?
Vestibular Rehabilitation

• Started in the 1940s
• Exercises are individually prescribed
• Cochrane review: moderate-strong evidence with unilateral peripheral disorders
• Includes:
  – Canalith repositioning
  – Habituation and adaptation
  – Substitution
  – Balance
  – Aerobic

McDonnell MN and Hillier SL 2015
Vestibular Rehabilitation in mTBI

• VOR x 1
  – Pitch (up/down) and yaw (L/R) with progressions in postures, base of support and visual input
• VOR Cancellation: pitch and yaw
• Sensory organization training
  – Feet together, tandem and semi-tandem on firm surface; eyes closed
  – Progressions: foam, head turns in yaw
• Ambulation with head turns
• Dual task/divided attention

Gottshall KR et al, J Neurol Phys Ther. 2010
Alsalaheen BA et al; Physiother Res Int 2012
Vestibular Rehabilitation with Concussion is effective

- Recommended by 5th Consensus statement on concussion in sport

Vestibular therapy + cervical PT vs sham

Proportion of patients medically cleared over time

Schneider KJ et al; Br J Sports Med 2014
Alsalaheen BA et al; J Neurol Phys Ther. 2010
Vestibular rehab protocol

- 24 subjects with complaints of imbalance > 3 months post mTBI
  - 70.1% female
  - 40.8 (11.6) years old
  - 2.1 (2.2) years post injury
- Vestibular rehab 2x/wk x 6 weeks
- Progressed exercises based on symptoms/stability
- Home program given to all subjects
### Vestibular rehabilitation program – progressing in difficulty over 6 weeks

<table>
<thead>
<tr>
<th>Static</th>
<th>Eyes Open</th>
<th>Eyes Closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feet Together (DS), Firm</td>
<td>Standing Still</td>
<td>Tossing Ball</td>
</tr>
<tr>
<td><strong>Footwork</strong></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Dynamic</th>
<th>Eyes Open</th>
<th>Eyes Closed</th>
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</thead>
<tbody>
<tr>
<td>Tandem Gait, Firm</td>
<td>Standing Still</td>
<td>Tossing Ball</td>
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<tr>
<td><strong>Footwork</strong></td>
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<thead>
<tr>
<th><strong>Activities</strong></th>
<th>Eyes Open</th>
<th>Eyes Closed</th>
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</thead>
<tbody>
<tr>
<td>Bending</td>
<td>Chair</td>
<td>Side of Treadmill</td>
</tr>
<tr>
<td><strong>Footwork</strong></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Squatting</th>
<th>Eyes Open</th>
<th>Eyes Closed</th>
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<tbody>
<tr>
<td><strong>Footwork</strong></td>
<td></td>
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<tr>
<td>Squat Firm</td>
<td>Sit to stand (mini squat)</td>
<td>Lunge</td>
</tr>
<tr>
<td>Squat Foam</td>
<td>Sit to stand (mini squat)</td>
<td>Lunge</td>
</tr>
</tbody>
</table>
Results

**SCAT**

- Pre: [Graph showing symptom score distribution]
- Post: [Graph showing symptom score distribution]

- *p*=0.001

**SOT**

- Pre: [Graph showing composite score distribution]
- Post: [Graph showing composite score distribution]

- *p*<0.001

**Dizziness Handicap Inventory**

- Pre: [Graph showing score as % Disability distribution]
- Post: [Graph showing score as % Disability distribution]

- *p*=0.15

**mBESS**

- Pre: [Graph showing number of errors distribution]
- Post: [Graph showing number of errors distribution]

- *p*=0.018
mTBI Baseline and Post-Intervention

SOT is Condition 5 – eyes closed, sway-referenced support
CSMI is Condition 1 – eyes closed, surface movement

<table>
<thead>
<tr>
<th></th>
<th>SOT Equilibrium Score</th>
<th>CSMI Sensory Weight</th>
<th>CSMI Stiffness (Kp)</th>
<th>CSMI Damping (Kd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t = -4.802, p &lt; 0.001$</td>
<td></td>
<td>$t = -1.745, p = 0.1116$</td>
<td>$t = -1.745, p = 0.1115$</td>
<td>$t = -3.183, p = 0.0098$</td>
</tr>
</tbody>
</table>
Targeted Intervention

Sample TEAM TBI Clinical Profile Prioritization

Kontos AP et al; Mil Med 2018
Take homes

• Chronic non-blast mTBI:
  • Central dysfunction of vestibular system
  • No peripheral dysfunction

• People with chronic mTBI improved!
  • Repetition in research protocol

• Outcome measures:
  • SCAT symptom checklist
  • SOT/CSMI
Take homes

• People with chronic mTBI have deficits in sensory weighting and motor output

• Largest change was increased ‘damping’
  • May be changing motor strategy rather than weighting
  • Focus on external perturbations and minimizing sway
Questions/Next Steps

- When is it best to intervene?
- Potential rehab components not previously addressed:
  - More in depth vision assessment
  - Cervical spine
  - Cardiovascular
- How can we optimize HEP?
START Study

• Sensor
• Technology
• And
• Rehabilitation
• Timing
Vestibular Rehabilitation is safe early post concussion

- **PT**: 10 days post injury
  - Safe
  - Shortened recovery time

VOMS Scoring Sheet

Symptoms on a 0-10 point scale

<table>
<thead>
<tr>
<th>Vestibular/ Oculomotor</th>
<th>Type</th>
<th>Not Tested</th>
<th>Headache</th>
<th>Dizziness</th>
<th>Nausea</th>
<th>Fogginess</th>
<th>Comments</th>
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<tbody>
<tr>
<td>Baseline Symptoms</td>
<td></td>
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<td>Smooth Pursuit</td>
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<td>Saccades (Horizontal)</td>
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<td>Saccades (Vertical)</td>
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<tr>
<td>Convergence (Near Point)</td>
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<td>Score#1____cm</td>
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<td>Score#2____cm</td>
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<td>Score#3____cm</td>
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<td>VOR Horizontal</td>
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<tr>
<td>VOR Vertical</td>
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<td>Visual Motion Sensitivity</td>
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Anzalone AJ et al.; 2017; Sufrinko AM et al; 2017
Eye Tracking

FIG. 1. Turning course marked with arrows including four 45-degree turns, four 90-degree turns, and two 135-degree turns. Two 45-degree turns (x) were excluded, leaving eight total turns per lap.
Aerobic Exercise: Buffalo Concussion Treadmill Test (BCTT) (Modified Balke protocol)

Provocative exercise test: help to determine if ready for RTP

- Protocol: Measure BP, HR and RPE
  - Treadmill: 3.6 mph, 0.0% incline
  - Minute 2: 3.6 mph, 1.0% incline
  - Minute 3: 3.6 mph, 2.0% incline
  - Minute 4: 3.6 mph, 3.0% incline
  - Keep going: ↑ 1.0% incline every min until:
    - Symptomatic (≥ 3 points)
    - Exhaustion (Borg 19/20 or 85% of age-predicted max HR)
- High inter-rater reliability (95%) and sensitivity (99%)

Leddy JJ et al 2013
Baker JG et al 2012
Intervention Protocol

**Cervical**
- Manual
- Stretching
- Strengthening
- Joint Position Sense

**Cardio**
- 80% of HR from Buffalo treadmill protocol

**Static balance**
- EO/EC
- Firm/Foam
- Head turns
- VOR gaze stabilization/visual motion sensitivity

**Dynamic balance**
- Walking
- Bending
- Squatting

**BPPV**
- Epley maneuver

**Vestibular Rehabilitation**
Contact Info

concussionresearch@ohsu.edu
Phone: 503-418-2602
Robert Peterka, Ph.D., National Center for Rehabilitative Auditory Research, VA Portland Health Care System, Portland

Tim Hullar, M.D., Department of Otolaryngology, Oregon Health & Science University, Portland

Lucy Parrington, Ph.D., Balance Disorders Laboratory, Department of Neurology, Oregon Health & Science University, Portland; VA Portland Health Care System, Portland

James Chesnutt, M.D., Orthopedics and Rehabilitation, Oregon Health & Science University, Portland

Peter Fino, Ph.D., Department of Health Kinesiology and Recreation; University of Utah, Salt Lake City, UT.

Deborah Jehu, PhD., Balance Disorders Laboratory, Department of Neurology, Oregon Health & Science University, Portland; VA Portland Health Care System, Portland

Sean Kampel, Audiologist, National Center for Rehabilitative Auditory Research, Veterans Affairs Portland Health Care System, Portland

Jenny Wilhelm, PT, Balance Disorders Laboratory, Department of Neurology, Oregon Health & Science University, Portland

Natalie Pettigrew, PT, Balance Disorders Laboratory, Department of Neurology, Oregon Health & Science University, Portland

Kate Scanlan, PT, Balance Disorders Laboratory, Department of Neurology, Oregon Health & Science University, Portland

Samuel Stuart, Ph.D., Balance Disorders Laboratory, Department of Neurology, Oregon Health & Science University, Portland; VA Portland Health Care System, Portland

Fay Horak, Ph.D., P.T., Balance Disorders Laboratory, Department of Neurology, Oregon Health & Science University, Portland; VA Portland Health Care System, Portland