Vestibular and Oculomotor Assessment: How to Balance it in the Concussion Assessment Battery

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*Portions of this presentation have been presented previously

Dizziness & Head Injury

- Common symptom report:
  - Headaches
  - Dizziness
  - Irritability
  - Visual issues
  - Memory problems
  - Photophobia
  - Phonophobia
  - Difficulty concentrating
  - Fatigue
  - Depression
  - Anxiety

Aligne & Lin, 2013; Harmon et al., 2013; Lovell, 2009; Ryan & Warden, 2003
Dizziness & Head Injury

- Dizziness & headache most common consequences of head injury (Davey, 1965; Barber, 1965; Berman and Fredrickson, 1978; Griffiths, 1979)
  - (25-90% incidence)
- Vestibular and oculomotor impairments occur in ~60% of athletes diagnosed with concussion (Mucha et al., 2014)
- On-field symptoms of dizziness was the only significant predictor of a prolonged recover (> 21 days) (Lau et al., 2011)

Visual Dysfunction

- Blurred vision
- Diplopia
- Headaches
- Vertigo
- Asthenopia
- Inability to focus
- Movement of print when reading
- Difficulty with tracking and fixations
- Photophobia

Collins et al., 2013
## Pathophysiology

<table>
<thead>
<tr>
<th>Peripheral System</th>
<th>Central System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semicircular canals</td>
<td>Cerebellum</td>
</tr>
<tr>
<td>Otolith Organs</td>
<td>Brainstem</td>
</tr>
<tr>
<td>BPPV</td>
<td>Vestibular migraines</td>
</tr>
<tr>
<td>Labyrinthine concussion</td>
<td></td>
</tr>
<tr>
<td>Endolymphatic Hydrops</td>
<td></td>
</tr>
<tr>
<td>Perilymphatic Fistula</td>
<td></td>
</tr>
<tr>
<td>Vestibulo-ocular Reflex (VOR)</td>
<td></td>
</tr>
</tbody>
</table>

Ernst et al., 2005; Fife & Giza 2013; Gottshall et al., 2003; Gottshall & Hoffer, 2010; Honaker et al., 2015; Mucha et al., 2014; Valovich McLeod & Hale, 2015; Zhou & Brodsky, 2015

## The Balance System

**Perception & orientation of movement**

**Static & dynamic postural control**

Gaze stability for clear visual imaging
Vestibular Vision Proprioception Somatosensory

Sensory Integration

Vision Vestibular Somatosensory

Motor output

Mismatch in perception = Dizziness/Instability
**VOR Function**

**Active head movement**
- Gain 1:1
- Phase 180 deg.

**Normal function**
- Gain 1:1
- Phase 180 deg.

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**Horizontal SCC**
**Anterior SCC**
**Posterior SCC**
**Utricle**
**Saccule**

**Vestibulo-Ocular Pathways**

- Saccadic System
- Optokinetic System
- Tracking System
- Neck Receptors

**Eye Muscles**

**Eye Movements**
Vestibulo-spinal reflex

- VSR purpose = to stabilize the body
- Signals from receptor in the inner ear generate this compensatory postural response
  - Limbs ipsi to the direction of acceleration are extended, while those contra are contracted

Postural Control

- Balance impairments have been reported subjectively by nearly 40% of athletes in the first few days following concussion (Broglio et al., 2007)
- Postural control is currently the most widely used assessment for the vestibular system
  - Most commonly assessed with BESS and SOT
Sensory Organization Test (SOT)

Firm Support Surface

Sway-Referenced Surface

Balance Error Scoring System

Guskiewicz, 2011; McCrea et al., 2003; Riemann & Guskiewicz, 2000; Valovich et al., 2003
Balance Error Scoring System

**Errors:**
- Hands lifted off iliac crest
- Opening eyes
- Step, stumble, or fall
- Moving hip into more than 30 deg flexion or abduction
- Lifting forefoot or heel
- Remaining out of testing position for more than 5 seconds

**Maximum Score** = 60 (10 per condition)
**Total score:** 12.03 ± 7.34

Guskiewicz, 2011; McCrea et al., 2003; Riemann & Guskiewicz, 2000; Valovich et al., 2003

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**Clinical Performance**

- ICC values of BESS and SOT in athletes who sustained a concussion ranged between 0.78 – 0.96 (Riemann & Guskiewicz, 2000)

- BESS score increases (poorer performance) by an average of 5.7 points in concussed players immediately after the injury
  - Average BESS score increases by only 2.7 points one day following injury (McCrea et al., 2003)
### Balance Assessment RCIs

<table>
<thead>
<tr>
<th>Author</th>
<th>Athletes</th>
<th>Measure</th>
<th>Test-Retest</th>
<th>CI 70%</th>
<th>CI 80%</th>
<th>CI 90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broglio et al. 2008</td>
<td>66</td>
<td>SOT</td>
<td>.56, 49 days</td>
<td>6.02</td>
<td>7.01</td>
<td></td>
</tr>
<tr>
<td>Registe et al. Mihalik et al. 2013</td>
<td>38</td>
<td>SOT</td>
<td>.45, 20.02 days</td>
<td>--</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>McLeod et al. 2006</td>
<td>50</td>
<td>BESS</td>
<td>.7, 4.15</td>
<td>3</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

### Clinical Performance BESS

<table>
<thead>
<tr>
<th>Time Point</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of Injury</td>
<td>34%</td>
<td>91%</td>
</tr>
<tr>
<td>Post-game</td>
<td>31%</td>
<td>96%</td>
</tr>
<tr>
<td>Day 1</td>
<td>16%</td>
<td>93%</td>
</tr>
<tr>
<td>Day 2</td>
<td>24%</td>
<td>91%</td>
</tr>
<tr>
<td>Day 3</td>
<td>16%</td>
<td>91%</td>
</tr>
<tr>
<td>Day 4</td>
<td>10%</td>
<td>93%</td>
</tr>
</tbody>
</table>

McCrea et al., 2003
Clinical Performance of Postural Control

- Combination of BESS, GSC, and SAC
  - 2 days post-injury
    - Sensitivity 23%
    - Specificity 93%
  - 1 week post-injury
    - Sensitivity 19%
    - Specificity 91%

McCrea et al., 2005

Current Concussion Assessment

- Return to baseline levels observed within 7-10 days
  - BESS & SOT (< 3 - 5 days)
- Poor sensitivity > 7 days

Riemann et al., 2000; McCrea et al., 2003; McCrea et al., 2005
Stability Evaluation Test (SET)

Average sway velocity of all six conditions = SET composite score (3.6 degs/s)

Body sway measured in degs/s

Concussion Center Balance Test (COBALT)

- Functional balance assessment to measure body sway while also stimulating the vestibular system (inner ear)
  - Portable system
  - Age-norms 10-25 years
- Eliminate the ceiling and floor effects observed with BESS

Bertec Balance Advantage (2016)
COBALT

- Condition 1: Eyes open firm surface
- Condition 2: Eyes closed firm surface
- Condition 3: Eyes closed firm surface headshake
- Condition 4: Visual motion sensitivity firm surface
- Condition 5: Eyes open foam surface
- Condition 6: Eyes closed foam surface
- Condition 7: Eyes closed foam surface headshake
- Condition 8: Visual motion sensitivity foam surface

Bertec Balance Advantage (2016)
COBALT

- Headshake
- Visual Motion

Errors:
- Lifting hands off iliac crest
- Opening eyes during closed trials
- Stepping off force plate or moving feet from placement markers while on plate/foam
- Unable to keep beat with the metronome for greater than 2 beats in a row

** Provides percentile ranking for conditions 7 and 8 based on age - norms**
**Should be able to complete conditions 7 and 8 with < 1 error**
### Advanced Postural Control

- **Nonlinear measures**
  - Approximate entropy (ApEn)
    - Orderliness in temporal output of complex system

<table>
<thead>
<tr>
<th>More Random</th>
<th>Less Random</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controls</td>
<td>Athletes with Concussion</td>
</tr>
</tbody>
</table>

**ApEn = 2**

**ApEn = 0**

- **Dual task postural control**
  - Cognitive task while performing standing balance
  - Performing VOR task while standing still

Cavanaugh et al., 2006; Cavanaugh et al., 2007
OM Abnormalities in Blast Patients

**Lew et al. (2007) (n=62)**
- Oculomotor problems 70%
  - Convergence
  - Accommodation
  - Saccadic pursuit

**Brahm et al. (2009)**
- Reading Problems
- Accomodative Pursuit/Saccades
- Subjective visual Convergence Fixation/Stabismus

- Abnormalities only observed in symptomatic group
OM Abnormalities in Athletes

<table>
<thead>
<tr>
<th>Bedside Test</th>
<th>Previous Concussion n = 15</th>
<th>No Concussion n = 25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth Pursuit</td>
<td>13% (2)</td>
<td>16% (4)</td>
</tr>
<tr>
<td>Saccades</td>
<td>20% (3)</td>
<td>28% (7)</td>
</tr>
<tr>
<td>Gaze Stability with Fixation</td>
<td>7% (1)</td>
<td>4% (1)</td>
</tr>
<tr>
<td>Gaze Stability without Fixation</td>
<td>33% (5)</td>
<td>28% (7)</td>
</tr>
<tr>
<td>Horizontal Head Thrust</td>
<td>13% (2)</td>
<td>8% (2)</td>
</tr>
<tr>
<td>Horizontal Head Shake</td>
<td>20% (3)</td>
<td>12% (3)</td>
</tr>
</tbody>
</table>

Honaker, Lester, Patterson, & Jones, 2014

OM Abnormalities in Athletes

- Significantly decreased performance on horizontal anti-saccades, self-paced saccades, and memory guided saccades
- No significant difference on reflexive saccades, fixation, and smooth pursuit
  - Significant increase in BOLD signal during fMRI

Johnson et al. 2014
Vestibular Oculomotor Screening (VOMS)

- 5 domains:
  - smooth pursuit
  - horizontal and vertical saccades
  - convergence
  - horizontal vestibular ocular reflex
  - visual motion sensitivity (VMS)

**Concussion Predictors** = VMS, VOR & Convergence

AUC = 0.89

Objective OM Assessment

- Smooth pursuit
- Saccades
- Gaze stability
- Headshake
- Positional testing

**Limited information on clinical performance in the concussion battery**
Vestibular abnormalities

- Head injury may disrupt:
  - vestibular system via direct damage to the vestibular end organs or vestibular nerve
  - brainstem pathways
  - visual, motor and ocular motor pathways
  - cerebellum

Visual-Vestibular Dysfunction

- Spatial disorientation rather than classic vertigo
- Symptoms provoked when:
  - viewing moving objects
  - viewing patterns
  - moving through a visually complex environment
  - “over reliant on vision for postural control”
- Functional dysfunction of VOR

Ernst et al., 2005; Fife & Giza 2013; Gottshall et al., 2003; Gottshall & Hoffer, 2010; Honaker et al., 2015; Mucha et al., 2014; Valovich McLeod & Hale, 2015; Zhou & Brodsky, 2015

Bronstein, 2010; Longridge et al., 2002
Visual-vestibular tests

Dynamic Visual Acuity
- Fixed Head Velocity
- Various Head Velocities

Gaze Stabilization Test

Visual-Vestibular Dysfunction

**Zhou & Brodsky (2015):**
- > 50% abnormal DVA in young athletes (13.9 ± 2.9 yrs)
- 26 ± 20 weeks post-concussion

Dynamic Visual Acuity Results Post- TBI
(Gottshall et al. 2003)
Gaze Stability Test

Athletes Without Previous Concussion

Athletes With Previous Concussion

GST Asymmetry %

30.00
25.00
20.00
15.00
10.00
5.00
0.00

100- Specificity

Gaze Stabilization Test

Stability Evaluation Test

Sensitivity

100
80
60
40
20
0

Reliable Change Indices

<table>
<thead>
<tr>
<th></th>
<th>70% CI</th>
<th>80% CI</th>
<th>90% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>GST (degs/s)</td>
<td>22</td>
<td>27.07</td>
<td>34.69</td>
</tr>
<tr>
<td>DVA (logMAR)</td>
<td>0.1</td>
<td>0.13</td>
<td>0.16</td>
</tr>
</tbody>
</table>

75% - 90% neurocognitive testing (Barr & McCrea, 2001)
70% - 80% balance testing (McLeod et al. 2006; Broglio et al. 2008; Register-Mihalik et al. 2013)

More false positives, but safer return to play

Honaker & Patterson, 2015
Dynamic Visual Acuity

- Functional VOR assessment
- Good to excellent test-retest reliability for DVA in collegiate and high school athletes (Kaufman et. al., 2013)
- Good to excellent sensitivity (94.5%) and specificity (95.2%) in vestibular disorder patients (Herdman et al., 1998)

Limited information regarding clinical performance in concussion assessment

Clinical Performance DVA

<table>
<thead>
<tr>
<th>Group</th>
<th>Sensitivity/Specificity (%)</th>
<th>AUC (95%: Confidence Interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptomatic concussed athletes (&lt; three days of head injury)</td>
<td>50%/29%</td>
<td>.64 (95% CI: .42 - .86), p = .21</td>
</tr>
<tr>
<td>Symptomatic concussed athletes (&lt; seven days of head injury)</td>
<td>57%/27%</td>
<td>.66 (95% CI: .50 - .83), p = .06</td>
</tr>
<tr>
<td>Asymptomatic concussed athletes (&lt; three days of head injury)</td>
<td>47%/33%</td>
<td>.53 (95% CI: .32 - .75), p = .76</td>
</tr>
<tr>
<td>Asymptomatic concussed athletes (&lt; seven days of head injury)</td>
<td>50%/36%</td>
<td>.52 (95% CI: .36 - .67), p = .81</td>
</tr>
</tbody>
</table>

Patterson (2016)
### Clinical Performance of DVA

<table>
<thead>
<tr>
<th>Group</th>
<th>BESS &amp; ImPACT</th>
<th>BESS, ImPACT, &amp; DVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptomatic concussed athletes (&lt; three days of head injury)</td>
<td>AUC = .95 (95% CI: .87 – 1.00), p &lt; .001</td>
<td>AUC = .95 (95% CI: .87 – 1.00), p &lt; .001</td>
</tr>
<tr>
<td>Symptomatic concussed athletes (&lt; seven days of head injury)</td>
<td>AUC = .85 (95% CI: .74 – .97), p &lt; .001</td>
<td>AUC = .86 (95% CI: .74 – .97), p &lt; .001</td>
</tr>
<tr>
<td>Asymptomatic concussed athletes (&lt; three days of head injury)</td>
<td>AUC = .75 (95% CI: .57 – .94), p = .02</td>
<td>AUC = .78 (95% CI: .61 – .95), p = .01</td>
</tr>
<tr>
<td>Asymptomatic concussed athletes (&lt; seven days of head injury)</td>
<td>AUC = .71 (95% CI: .58 – .85), p = .007</td>
<td>AUC = .72 (95% CI: .58 – .85), p = .006</td>
</tr>
</tbody>
</table>

Patterson (2016)

### Video Head Impulse Test

- **Normal vHIT**
- **Abnormal vHIT**
- **Abnormal vHIT**

- Head
- Eye

GAIN

- 1.0
- 0.5
- 0.0

Overt

Covert
Case Example

- 21 y.o. football player
- Sustained concussion during practice
- Sx at time of assessment:
  - Poor balance (veers to the right when walking)
  - Dizziness – lightheadedness & disorientation
  - Difficulty concentrating

- ImPACT
  - Deficits with visual memory, visual motor speed and reaction time

Case Example

- VOMS
  - Total sx score for each subtest was between 10-15
  - Horizontal VOR and VMS provoked highest symptoms at 15 each
  - Average convergence was 17 cm

- Video head impulse test (vHIT)
  - Normal horizontal canal function in both ears
Case Example

• Oculomotor test battery
  ○ Spontaneous nystagmus/gaze stability

[Graphs of eye movement data]

Case Example

• Oculomotor test battery
  ○ Spontaneous nystagmus/gaze stability
  ○ Saccades

[Graphs of saccade data]
Case Example

- Oculomotor test battery
  - Spontaneous nystagmus/gaze stability
  - Saccades
  - Antisaccades

Case Example

- Oculomotor test battery
  - Spontaneous nystagmus/gaze stability
  - Saccades
  - Antisaccades
  - Smooth pursuit
Case Example

- **DVA**
  - Dynamic Visual Acuity Loss
    - LogMAR Loss
    - Left: 0.4
    - Right: 0.32

- **BESS/SET**
  - Total BESS score = 30
  - SET Composite = 4.7 deg/s

ImPACT Clinical Trajectories

- Concussion
- Vestibular
- Ocular
- Anxiety/Mood
- Cervical
- Cognitive/Fatigue
- Post-Traumatic Migraine

Collins, et al. (2014)
Components of Therapy

Vestibular

- Sx: dizziness, fogginess, nausea, feeling of being detached, anxiety and overstimulation
- Increase in sx: busier, more stimulating environments, rapid head movements, riding in car, running, rolling over in bed
- ImPACT: processing speed and reaction time

Collins, et al. (2014)

Components of Therapy

Vestibular

- Treatment: VBRT
  - Coordination of head/eye motion to improve vision stability
  - Static and dynamic postural control
  - Static and dynamic stance control
  - Graded exposure to moving visual environments

Collins, et al. (2014)
Components of Therapy

Oculomotor coordination training

- Headache, fatigue, distractibility, difficulty with visually based classes, pressure behind eyes, difficulty focusing
- Increase in sx: extended time in front of computer or reading, full day of work/school
- ImPACT: visual memory, reaction time

Collins, et al. (2014)

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Components of Therapy

Oculomotor coordination training

- Treatment: vision therapy

Marsden ball

Vergence drills

Collins, et al. (2014)
Bioness Integrated Therapy System (BITS)
Bioness Integrated Therapy System (BITS)

QUESTIONS?

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