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Vestibular and Balance Assessment of Athletes with Concussion

Julie A. Honaker, Ph.D., CCC-A

Disclosure

- Julie Honaker received funding by the Big Ten/Committee on Institutional Cooperation and Ivy League Traumatic Brain Injury Research Collaboration to support this work
- Some portions of this presentation were previously presented at Association for Research in Otolaryngology, 2013, Audiology Now! 2015, and the American Balance Society Meeting, 2015.
- It is the policy of the University of Nebraska-Lincoln not to discriminate based upon age, race, ethnicity, color, national origin, gender, sex, pregnancy, disability, sexual orientation, genetic information, veteran's status, marital status, religion or political affiliation.

Learning Objectives

After this course learners will be able to:

- Explain the impact of concussion on balance function and list associated symptoms and clinical signs that would indicate need for balance evaluation.
- Describe how to complete standard concussion balance measures including the balance error scoring system and the sensory organization test.
- Describe the importance of reliable change indices to estimate measurement error for test-retest comparison of changes in balance function post-concussion.
Agenda

- Overview of the balance system
- Consequences of concussion
- Concussion assessment: Current best practice
- Concussion assessment: Future Best Practice Considerations
  - Vestibular and balance concussion protocol for collegiate athletes
  - Discussion of research findings
- Summary and conclusions

University of Nebraska – Lincoln
Dizziness and Balance Disorders Lab

The balance system
The Balance System

Gaze stability for clear visual imaging
Perception & orientation of movement
Static & dynamic postural control

Vestibular
Vision
Proprioception Somatosensory

Sensory Integration

Mismatch in perception = Dizziness Instability

Motor output

CNS

Vision
Vestibular
Somatosensory

Sensory integration & weighting
Concussion Overview

- Traumatic brain injury growing medical concern
- 1.6 - 3.8 million concussions annually
  - 50-80% go unreported!
- Annually ~ 300,000 hospitalizations & $60 billion in medical expenses
  - Mild traumatic brain injury ~ $22 billion

Langlois et al., 2006; McCrea et al., 2004; Liewellyn et al., 2014; Gerberding et al., 2003; Finkelstein et al., 2006.

Concussion Overview

Mild TBI vs. Concussion

- Mild TBI and concussion often used interchangeably
- Concussion is historical term:
  - Low-velocity injuries that cause "brain shaking"
  - Result in clinical symptoms not necessarily related to pathological injury
  - Subset of TBI

McCroy et al., 2013 – Zurich Guidelines

Concussion Overview

- "Clinical syndrome of biomechanically induced alteration of brain function, typically involving memory and orientation, which may or may not involve loss of consciousness"
- "Spreading depression"
- Full recovery ~ 7-10 days from onset

Giza & Hovda, 2001; McCrory et al., 2013; Giza, 2013; Giza & Hovda, 2014

continued
### Factors increasing/ decreasing concussion risk:

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Analysis of Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age/Level of Competition</td>
<td>Although more males studied, risk may be higher for women</td>
</tr>
<tr>
<td>Gender</td>
<td>Insufficient evidence</td>
</tr>
<tr>
<td>Type of Sport</td>
<td>American football, Australian rugby, soccer</td>
</tr>
<tr>
<td>Equipment</td>
<td>rugby headgear reduces risk</td>
</tr>
<tr>
<td>Position</td>
<td>Insufficient evidence for mouth guards, or one type of</td>
</tr>
<tr>
<td>Athlete-related factors</td>
<td>football helmet</td>
</tr>
<tr>
<td>Body mass index &gt; 27kg/m² &amp; training &lt; 3 hours weekly</td>
<td>Football only – linebackers, offensive linemen, and defensive backs</td>
</tr>
</tbody>
</table>

Giza et al., 2013

### Factors associated with protracted recovery:

- Post-traumatic:
  - headache,
  - fatigue/fogginess
  - early amnesia
  - alteration in mental status or disorientation
- Younger age/level of play
- Position in football (quarterback)
- Playing on artificial turf

### Concussion Assessment

Current Best Practice

[continued]
Current Concussion Assessment

Acute evaluation – need to monitor change over time

• Test-retest reliability = test stability over time

• Reliable indices of change (RCI)
  – Adjusts for practice effects
  – Assesses intraindividual differences & measurement error over time (z-score)

McLeod et al., 2006

Current Concussion Assessment

• Athlete reported symptoms

  Immediate Post-Concussion Assessment and Cognitive Testing (ImpACT)

• Neurocognitive functioning tests

  Sport Concussion Assessment Tool (SCAT)

McCrory et al., 2013

Current Concussion Assessment

<table>
<thead>
<tr>
<th>Post Concussion Symptom Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Headache</td>
</tr>
<tr>
<td>“Pressure in head”</td>
</tr>
<tr>
<td>Neck Pain</td>
</tr>
<tr>
<td>Balance problems or dizziness</td>
</tr>
<tr>
<td>Nausea or vomiting</td>
</tr>
<tr>
<td>Vision problems</td>
</tr>
<tr>
<td>Hearing problems / ringing</td>
</tr>
<tr>
<td>“Don’t feel right”</td>
</tr>
<tr>
<td>Feeling “dinged” or “dazed”</td>
</tr>
<tr>
<td>Confusion</td>
</tr>
<tr>
<td>Feeling slowed down</td>
</tr>
</tbody>
</table>
Dizziness & Concussion

- Dizziness/Imbalance common symptom complaints post-concussion
  - Headache most common symptom
- Symptoms may be the result when multiple systems contributing to overall balance fail
- Dizziness is also common following cervical disorders (e.g., whiplash)
  - Possible abnormal cervical proprioceptors

Binder, Ingebrigsten et al., van der Naalt, 2001; Maskell et al., 2006; Alsalahieen et al., 2010

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Dizziness & Concussion

What symptom predictors contribute to reports of dizziness and imbalance, and combined dizziness/imbalance?

1-3 Days Post-Concussion

- Headache
- Photophobia, & phonophobia
- Cognitive symptoms

Dizziness
F(5, 44), 15.35, R² = .64

Imbalance
F(4,46) = 13.23, R² = .54

Dizziness/Imbalance
F(5, 44) = 21.55, R² = .71

Honaker, Lester & Patterson, in preparation

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Dizziness & Concussion

Dizziness/imbalance correlated with functional measures, but no effect on neurocognitive performance

Honaker, Lester, Patterson, Jones, 2014
Dizziness & Concussion

- Symptoms of dizziness and imbalance predict protracted recovery from concussion
- Lau et al. (2011) – dizziness symptom indicated 6.42 OR of protracted recovery
  - Unreported how many athletes with dizziness also had headache
  - Headache may be the true predicting factor

Current Concussion Assessment

- Athlete reported symptoms
- Neurocognitive functioning tests
- Postural control measures (linear)

Balance Error Scoring System (BESS)

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
**Stability Evaluation Test (SET)**

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

<table>
<thead>
<tr>
<th>Condition</th>
<th>Average Sway Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firm Support Surface</td>
<td>0.63 ± 0.17 degs/s</td>
</tr>
<tr>
<td>Eyes Open</td>
<td>3.09 ± 1.78 degs/s</td>
</tr>
<tr>
<td>Eyes Closed</td>
<td>1.41 ± 0.67 degs/s</td>
</tr>
<tr>
<td>Sway-Referenced Surround</td>
<td>2.42 ± 0.94 degs/s</td>
</tr>
<tr>
<td>Eyes Open</td>
<td>5.46 ± 1.62 degs/s</td>
</tr>
<tr>
<td>Eyes Closed</td>
<td>4.92 ± 3.02 degs/s</td>
</tr>
</tbody>
</table>

Body sway measured in degs/s

**Sensory Organization Test (SOT)**

**Firm Support Surface**

Eyes Open

Eyes Closed

**Sway-Referenced Surround**

Sway-Referenced Surface

**Concussion 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 (20.11 ± 1.96 yrs)</td>
<td>SOT</td>
<td>56, 49 days</td>
<td>6.02</td>
<td>7.01</td>
<td></td>
</tr>
<tr>
<td>Register-Mihalik et al. 2013</td>
<td>38 (20.64 ± 1.62 yrs)</td>
<td>SOT</td>
<td>45, 46.72 ± 20.02 days</td>
<td>--</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>McLeod et al. 2006</td>
<td>50 (9-14 yrs)</td>
<td>BESS</td>
<td>7, 57.94 ± 4.15 days</td>
<td>3</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>
Current Concussion Assessment

Current multifaceted protocols highly sensitive but...

- Only in acute concussion
- 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

Concussion Assessment

Future Best Practice Considerations

Oculomotor & Vestibular Function
Advanced Postural Control

Oculomotor & Vestibular Assessment

19 YO football player
Sustained concussion during practice
Sx Dizziness & Poor balance (veers to right when walking)
DHI 28/100

Dynamic Visual Acuity Loss

LogMAR LOSS

0.5
0.4
0.3
0.2
0.1
0

0.4
0.32
0

Left
Right
Visual Dysfunction Resulting From TBI

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

OM Abnormalities

- VNG testing on 12 symptomatic and 12 asymptomatic
  - Smooth pursuit
  - Saccades
  - Optokinetic testing
- Abnormalities only observed in symptomatic group

Scherer et al., 2011

OM Abnormalities

<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

- 40% (n = 22/55) had abnormal smooth pursuit tracking.
  - Average gain values from 0.2-0.7 for rightward smooth pursuit tracking was 0.86 ± 0.13 and average leftward was 0.86 ± 0.10.

### Smooth Pursuit Test Results

<table>
<thead>
<tr>
<th>Smooth Pursuit Test Results</th>
<th>Football</th>
<th>Soccer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>58.3% (n=28)</td>
<td>71.4% (n=5)</td>
</tr>
<tr>
<td>Abnormal</td>
<td>41.7% (n=20)</td>
<td>28.6% (n=2)</td>
</tr>
</tbody>
</table>

Patterson & Honaker, 2015

OM Abnormalities

- Significant association found between position (offense vs defense) & smooth pursuit
  - $\chi^2 (1, n = 48) = 4.48, p = 0.034$,
    - 61% (n = 11/18) of defensive players with abnormal findings.
    - 29% (n = 9/30) of offensive players with abnormal findings.
OM Abnormalities

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

Concussion Predictors = VMS, VOR & Convergence

OM Abnormalities

Vestibular Oculomotor Screening

Concussion Predictors = VMS, VOR & Convergence

OM Abnormalities

Vestibular Oculomotor Screening

19 YO football player
Sustained concussion during practice
Sx Dizziness & Poor balance (veers to right when walking)
DHI 28/100

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 Interaction Dysfunction

OM Abnormalities

Concussion Predictors = VMS, VOR & Convergence
Visual-Vestibular Interaction Problems

- 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"

Longridge et al., 2002

Visual-Vestibular Interaction Problems

- Convergence between visual and vestibular inputs occurs at multiple levels (medulla to cortex)
  - Sx. could originate at any level
  - Secondary vestibular neurons unable to distinguish b/t sources of afferent activity
    • Migraine may be a predisposing factor

Bronstein, 2010

What are visual-vestibular tests?

- Dynamic Visual Acuity
- Gaze Stabilization Test
- Fixed Head Velocity
- Various Head Velocities

Kaufman et al., 2013; Gottshall & Hoffer, 2010; Gottshall et al., 2007; Gottshall et al., 2003
LogMAR Loss

Visual-Vestibular Interaction Problems

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

Visual-Vestibular Interaction Tests

<table>
<thead>
<tr>
<th>Measure</th>
<th>Baseline</th>
<th>End of Season</th>
<th>Test-Retest</th>
</tr>
</thead>
<tbody>
<tr>
<td>GST (degs/s)</td>
<td>148.87 ± 25.53</td>
<td>157.69 ± 25.29</td>
<td>t(35) = -1.82, p = .07</td>
</tr>
<tr>
<td>DVA (logMAR)</td>
<td>13 ± 0.08</td>
<td>13 ± 0.08</td>
<td>t(33) = -0.75, p = .94</td>
</tr>
</tbody>
</table>

No significant practice effects observed

Patterson & Honaker, 2015
Visual-Vestibular Interaction Tests

<table>
<thead>
<tr>
<th>Reliable Change Indices</th>
</tr>
</thead>
<tbody>
<tr>
<td>70% CI 80% CI 90% CI</td>
</tr>
<tr>
<td>GST (degs/s)</td>
</tr>
<tr>
<td>22 27.07 34.69</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

Discussion

- DVA and GST were positively correlated
  - May not be necessary to perform both measures on the athletes

**GST**

<table>
<thead>
<tr>
<th>Patterson &amp; Honaker (n = 37)</th>
<th>ICC (95% CI) = .50 (.05-.74)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Collegiate only</td>
<td></td>
</tr>
<tr>
<td>- ~ 120 -180 day interval</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Kaufman et al. 2013 (n = 50)</th>
<th>ICC (95% CI) = .63 (.36-.80)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- High school/collegiate</td>
<td></td>
</tr>
<tr>
<td>- 1-14 day interval</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ward et al. 2010 (n =20)</th>
<th>ICC (95% CI) = .59 (.21-.81)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- non-athletes (young &amp; old)</td>
<td></td>
</tr>
<tr>
<td>- 7-10 day interval</td>
<td></td>
</tr>
</tbody>
</table>

Discussion

- DVA and GST were positively correlated
  - May not be necessary to perform both measures on the athletes

**DVA**

<table>
<thead>
<tr>
<th>Patterson &amp; Honaker (n = 37)</th>
<th>ICC(95% CI) = .01(-1.04-.51)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Collegiate only</td>
<td></td>
</tr>
<tr>
<td>- 120 -180 day interval</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Kaufman et al. 2013 (n = 50)</th>
<th>ICC(95% CI) = .77 (.59-.86)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- High school/collegiate</td>
<td></td>
</tr>
<tr>
<td>- 1-14 day interval</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ward et al. 2010 (n =20)</th>
<th>ICC(95% CI) = .49 (.08-.76)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- non-athletes (young &amp; old)</td>
<td></td>
</tr>
<tr>
<td>- 7-10 day interval</td>
<td></td>
</tr>
</tbody>
</table>
Oculomotor & Vestibular Assessment

19 YO football player sustained concussion during practice. Symptoms include dizziness and poor balance (veers to right when walking). DHI 28/100.

LogMAR Loss

What is Video Head Impulse Test (vHIT)?

Leftward Eye Movements

Rightward Head Movement

Normal vHIT

Abnormal vHIT

GAIN

CONTINUED
Advanced Postural Control

• Linear measures (e.g., BESS, SOT)
  – Based on stimulus-response paradigm
  • Monitor changes in center of pressure (COP) over time
  • Return to baseline (< 5 days)
  • Limited to sensory system input
    – Difficulties with visual/vestibular
    – Visual field motion balance deficit observed up to 30 days
    – Impaired motor (gait) termination

Cavanaugh et al., 2006; Slobounov et al., 2006; Buckley et al., 2013

Advanced Postural Control

• Nonlinear measures
  – Approximate entropy (ApEn)
    • Orderliness in temporal output of complex system

Advanced Postural Control

• Nonlinear models
  – Greatest change in medial/lateral ApEn
    • Protracted recovery compared to BESS/SOT

• Dual Task postural control
  – Standing still and digit recall (SOT)
  – Anterior/posterior ApEn in healthy athletes

Cavanaugh et al., 2006; Cavanaugh et al., 2007
Advanced Postural Control

Dual Task is feasible & reliable

Advanced Postural Control

No floor effects observed

NCAA Return-To-Play (RTP) Stepwise Progression:
1. Light aerobic exercise (e.g., riding stationary bike, walking)
2. Sport-specific exercises
3. Sport-specific activity with no head impact
4. Non-contact sport-specific drills and resistance training
5. Full-contact practice
6. Return-to-play

Athlete must be asymptomatic during each activity to progress to the next step

NCAA Concussion Guidelines
NCAA Return-to-Learn Stepwise Progression:

1. Remain at place of residence if cannot tolerate mild cognitive activities
2. Return to classroom if able to tolerate mild cognitive activities without onset of symptoms
   • Graduated increments

Academic adjustments should be decided by a multi-disciplinary team.

NCAA Concussion Guidelines

Summary

• Symptoms of dizziness/imbalance common after concussion
• Current best practice tests return to baseline < 7-10 days
• Advanced postural control/oculomotor and vestibular measures may better monitor change over time
  – Improve return to play decisions

Acknowledgements

My Lab Team (current and former students)
– Jessie Patterson, Au.D. (Ph.D. student)
– Alaina Bassett, B.S. (Au.D./Ph.D. student)
– Diana Weissbeck, B.S. (Au.D. student)
– Chelsea Hull, B.S. (Au.D. student)
– Max Twedt, B.S. (BioMed student)
– Claire Mollak (undergraduate student)
– Robin Criter, Au.D., Ph.D. (Assistant Professor, Western Michigan University)

A special thank you to the UNL Athletics department and the UNL student athletes
Thank you!

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Thank you!