Post-Concussion Balance Deficits – Are Athletic Trainers Missing Lingering Impairments?

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  – NATA Research & Education Foundation
  – State of Delaware Economic Development Office
Balance

• Impaired balance is a cardinal post-concussion symptom.

• What is Balance?
  – Coordination of multiple neurological systems
    • Motor System
    • Sensory System
      – Visual, Vestibular, Somatosensory
    • Cognitive Processing
Table 2. Concussion-Assessment Practice Patterns, % (No./Total)\textsuperscript{a}

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall use, % (n/total)</td>
<td></td>
</tr>
<tr>
<td>Division II</td>
<td>79.7 (228/286)</td>
</tr>
<tr>
<td>Division III</td>
<td>81.3 (351/432)</td>
</tr>
<tr>
<td>Baseline testing, % (n/total)</td>
<td></td>
</tr>
<tr>
<td>Division II</td>
<td>79.0 (168/213)</td>
</tr>
<tr>
<td>Division III</td>
<td>76.7 (254/331)</td>
</tr>
<tr>
<td>When is baseline testing performed?, % (n/total)</td>
<td></td>
</tr>
<tr>
<td>One time only as student-athlete enters the program:</td>
<td></td>
</tr>
<tr>
<td>69.3 (248/358)</td>
<td></td>
</tr>
<tr>
<td>Annually:</td>
<td>24.0 (86/358)</td>
</tr>
<tr>
<td>Who performs the baseline test?, % (n/total)</td>
<td></td>
</tr>
<tr>
<td>Any available athletic trainer</td>
<td>43.1 (156/362)</td>
</tr>
<tr>
<td>Team-specific athletic trainer</td>
<td>22.7 (82/362)</td>
</tr>
<tr>
<td>Where are the test results stored?, % (n/total)</td>
<td></td>
</tr>
<tr>
<td>Student file</td>
<td>71.1 (261/367)</td>
</tr>
<tr>
<td>Online</td>
<td>18.8 (69/367)</td>
</tr>
<tr>
<td>Where is the test performed postinjury?, % (n/total)</td>
<td></td>
</tr>
<tr>
<td>Athletic training room</td>
<td>63.8 (241/378)</td>
</tr>
<tr>
<td>Sidelines</td>
<td>57.7 (218/378)</td>
</tr>
</tbody>
</table>

\textsuperscript{a}National Collegiate Athletic Association Division I Athletic Trainers’ Concussion-Management Practice Patterns

Kassandra C. Kelly, MS, ATC\textsuperscript{*}; Erin M. Jordan, MS, ATC\textsuperscript{*}; A. Barry Joyner, PhD\textsuperscript{*}; G. Trey Burdette, EdD\textsuperscript{*}; Thomas A. Buckley, EdD, ATC\textsuperscript{†}

Concussion-Management Practice Patterns of National Collegiate Athletic Association Division II and III Athletic Trainers: How the Other Half Lives
Balance Assessment by ATCs

- Limitations.....
  - Fatigue
  - Functional Ankle Instability
    - Docherty et al, 2006
  - Practice Effect
  - Scoring (MDC’s)
    - Finoff et al, 2009
  - Dehydration
    - Weber et al, 2013
  - Environment
    - Onate et al, 2007; Rahn et al 2014
  - Known Unknowns
    - LAS, ACL, Strains & Sprains, Attentional Focus, Compensatory Strategies, mat physical properties, & others
## Standard Clinical Recovery

Table 6. Sensitivity (Sn) and specificity (Sp) for detecting impairment at postinjury time points

<table>
<thead>
<tr>
<th></th>
<th>Time of injury</th>
<th>Postgame</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 5</th>
<th>Day 7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Se</td>
<td>Sp</td>
<td>Se</td>
<td>Sp</td>
<td>Se</td>
<td>Sp</td>
<td>Se</td>
</tr>
<tr>
<td>GSC</td>
<td>.89</td>
<td>1.00</td>
<td>.74</td>
<td>1.00</td>
<td>.53</td>
<td>1.00</td>
<td>.27</td>
</tr>
<tr>
<td>BESS</td>
<td>.34</td>
<td>.91</td>
<td>.31</td>
<td>.96</td>
<td>.16</td>
<td>.93</td>
<td>.24</td>
</tr>
<tr>
<td>SAC</td>
<td>.80</td>
<td>.91</td>
<td>.65</td>
<td>.93</td>
<td>.31</td>
<td>.95</td>
<td>.22</td>
</tr>
<tr>
<td>Brief battery without NP testing</td>
<td>.94</td>
<td>.89</td>
<td>.86</td>
<td>.89</td>
<td>.69</td>
<td>.89</td>
<td>.51</td>
</tr>
<tr>
<td>NP testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.23</td>
</tr>
<tr>
<td>Full battery with NP testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.56</td>
</tr>
</tbody>
</table>

Notes. Sensitivity values indicate the probability that a player originally injured continued to be correctly classified as "abnormal". Specificity (Sp) refers to the probability that a control participant will be correctly classified as "normal" using the same method. Brief battery refers to GSC, BESS, and SAC. Full battery refers to brief battery plus neuropsychological testing. GSC = Graded Symptom Checklist (Lovell & Collins, 1998); BESS = Balance Error Scoring System (Guskiewicz et al., 2001); SAC = Standardized Assessment of Concussion (McCrea et al., 2000); NP testing = neuropsychological test battery.

Standard regression-based methods for measuring recovery after sport-related concussion

*Journal of the International Neuropsychological Society (2005), 11, 58-69*
BESS Results

Figure. Symptom, Cognitive, and Postural Stability Recovery in Concussion and Control Participants

Acute Effects and Recovery Time Following Concussion in Collegiate Football Players
The NCAA Concussion Study
Michael McCrea, PhD
JAMA, November 19, 2003—Vol 290, No. 19
Figure 4. Composite Score means (±SD) on the NeuroCom Smart Balance Master for 36 injured and 36 control subjects across test sessions (preseason through day 5 postinjury). Higher scores represent better performance.

Figure 5. Vestibular ratio means (±SD) on the NeuroCom Smart Balance Master System for 36 injured and 36 control subjects across test sessions (preseason through day 5 postinjury). Higher scores represent better performance.

Figure 6. Visual ratio means (±SD) on the NeuroCom Smart Balance Master for 36 injured and 36 control subjects across test sessions (preseason through day 5 postinjury). Higher scores represent better performance.

Figure 7. Balance Error Scoring System means (±SD) (combined errors on all 6 trials) for 36 injured and 36 control subjects across test sessions (preseason through day 5 postinjury). Lower scores represent better performance.
Experimental Evidence of Lingering Impairments
Figure 5. Temporal variations of Renyi entropies for 2 subjects. The 2nd subject (right) had two concussions: day 7 was the 1st day of the 2nd concussion. doi:10.1371/journal.pone.0024446.g005

• Gait Initiation Videos
S1 A/P
HYA: 4.7cm
HOA: 3.54cm
PD: 2.94cm
S1 A/P
HYA: 5.42cm
mTBI: 2.29cm
GI COP Displacement

Cohen’s $d$ vs Baseline

- Baseline: $d = 1.99$
- Day 1: $d = 1.48$
- BESS: $d = 0.78$

Displacement (cm)

S1 A/P

S1 M/L

* $d = 0.78$
• Gait Termination Video
# Gait Termination

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Day-1 post-concussion</th>
<th>Control to Day-1 post hoc <em>p</em>-values (effect size)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gait velocity (m/s)</td>
<td>$1.32 \pm 0.14$ ($1.26$ to $1.38$), $n=26$</td>
<td>$1.16 \pm 0.14^{*1}$ ($1.08$ to $1.23$), $n=15$</td>
<td>0.01 (1.14)</td>
</tr>
<tr>
<td>Propulsive %</td>
<td>$-0.25 \pm 0.53$ ($-0.41$ to $-0.10$), $n=26$</td>
<td>$0.44 \pm 0.17^{*}$ ($0.24$ to $0.64$), $n=15$</td>
<td>$&lt;0.01$ (0.85)</td>
</tr>
<tr>
<td>Braking %</td>
<td>$-0.30 \pm 0.20$ ($-0.39$ to $-0.21$), $n=26$</td>
<td>$-0.05 \pm 0.27^{*1}$ ($-0.17$ to $0.07$), $n=15$</td>
<td>$&lt;0.01$ (0.54)</td>
</tr>
</tbody>
</table>

* Significant difference from the control group.

† Significant difference from the Day-10 time point.

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**Altered gait termination strategies following a concussion.**  
Buckley TA, Munkasy BA, Tapia-Lovler TG, Wikstrom EA.
Post-Concussion Balance Deficits – Are Athletic Trainers Missing Lingering Impairments?

The Role of Dual-Tasks

David R. Howell, PhD, ATC
The Micheli Center for Sports Injury Prevention
Division of Sports Medicine, Boston Children’s Hospital

68th Annual EATA Meeting and Clinical Symposium
10 January 2016
Post-Concussion Balance Deficits – Are Athletic Trainers Missing Lingering Impairments?

The Role of Dual-Tasks

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Conflict of Interest

No disclosures or conflicts of interest to report related to the topic of this presentation
Concussion

Cortex
- Frontal Lobe
- Temporal Lobe
- Parietal Lobe

Cognition

Memory

Complex functioning

Sub-Cortical Structures
- Hypothalamus
- Trigeminal System
- Basal Ganglia
- Cerebellum

Thermoregulation
- BP Control
- Sleep Patterns
- Sexual Function
- Diabetes Insipidus

Sensory-Motor
- Balance/Posture

Headache
- Facial Pain

Adapted from E. Toledo et al., Neurosci Biobehav Rev (2012)
Topics

1) How long do deficits last after concussion?

2) How can we accurately monitor recovery to determine appropriate RTP timing?

3) What factors (+/-) affect recovery?
Initial Evaluation

Video
Evaluation of Recovery

Varied levels of subjectivity/objectivity for each tool:
Symptom Resolution

Worse

Self-Reported Symptom Severity Score

SYMPTOM SEVERITY

Group x time interaction

\[ p < .001, \eta_p^2 = .344 \]

Howell et al., *Arch Phys Med Rehab*, 2013; Data from 40 adolescents (20 with concussion)
Cognitive Deficits

Video
ImPACT

Plate
ImPACT

Verbal Memory

Visual Memory

Visual Motor Speed

Reaction Time

* Concussion  
Control

Testing Day

Composite Score

Testing Day

Composite Score

Testing Day

Composite Score

Testing Day
Motor Deficits

Isolated motor deficits (BESS) resolve within a week of injury

Broglio et al., *JAT*, 2009; Murray et al., *JAT*, 2014
A weak relationship exists between mBESS performance (static stability) and average gait speed (dynamic stability).

Howell et al., 2016, *In Prep*
Cognitive-Motor Interaction

Stroop tasks (congruent/incongruent stimuli)
Conflict Resolution

Frontal Lobe
Anterior cingulate gyrus, prefrontal cortex

Motor Cortex \(\rightarrow\) Internal Capsule \(\rightarrow\) Spinal Cord \(\rightarrow\) Muscle Control

Temporal/Parietal/ Frontal Lobes
Fusiform gyrus, lingual gyrus, thalamus

Mental Status Examination (spelling backwards, arithmetic)
Dual-Task

Video
Poor Gait Balance Control

Video
Total COM M-L Displacement

Group x Task ($p = .006$, $\eta_p^2 = .189$)

Dual-task: Concussion group > control group ($p = .014$)

Concussion group: dual-task > single-task ($p < .001$)

Howell et al., Arch Phys Med Rehabil, 2013; Data from 40 adolescents (20 with concussion)
# Stroop Accuracy Rates

<table>
<thead>
<tr>
<th>Testing Day</th>
<th>Concussion*</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>72 hour</td>
<td>96.6% (±5.0)</td>
<td>99.4% (± 1.3)</td>
</tr>
<tr>
<td>1 week</td>
<td>96.8% (± 4.6)</td>
<td>98.9% (± 2.2)</td>
</tr>
<tr>
<td>2 week</td>
<td>97.6% (± 4.8)</td>
<td>99.6% (± 1.1)</td>
</tr>
<tr>
<td>1 month</td>
<td>97.7% (± 3.9)</td>
<td>99.6% (± 1.0)</td>
</tr>
<tr>
<td>2 month</td>
<td>97.5% (± 3.2)</td>
<td>99.4% (± 1.5)</td>
</tr>
</tbody>
</table>

* = Main effect of group, *p* = .004

Howell et al., *Arch Phys Med Rehabil*, 2013; Data from 40 adolescents (20 with concussion)
Topics

1) How long do deficits last for after concussion?

2) How can we accurately monitor recovery to determine appropriate RTP timing?

3) What factors (+/-) affect recovery?
Concussion Occurs

72 hrs 1 week 2 weeks 1 month 2 months

Return-to-activity day:
# of subjects for each RTA day:
1 2 1 2 1 1 1 1 1 1 56 57

n = 4 n = 9 n = 6

RTA day: 1st day participation was allowed by attending physician
Pre RTA Post RTA

Clinical decisions made using conventional methods
Pre RTA Post RTA

Independent from study-related data
Pre RTA Post RTA
Total COM Medial/Lateral Displacement

A  Dual-task Walking

B  Single-task Walking

Time x group: \( p = .009, \eta_p^2 = .175 \)

Howell et al., Med Sci Sport Exer, 2015; Data from 38 adolescents (mean age = 15.5 years)
**Computerized Tests of Attention**

**Conflict Effect:**
*Attentional Network Test*

![Graph showing improvement and worsening in mean % change from Pre RTA to Post RTA.]

**Switch Cost:**
*Task Switching Test*

![Graph showing improvement and worsening in mean % change from Pre RTA to Post RTA.]

- **Main effect of time:** \( p = .028, \eta^2 = .127 \)
- \(^*\) = difference between time points (both groups)

Howell et al., *Med Sci Sport Exer*, 2015; Data from 38 adolescents (mean age = 15.5 years)
Self-Reported Symptom Severity

Group x time interaction: $p = .009$

Howell et al., *Med Sci Sport Exer*, 2015; Data from 38 adolescents (mean age = 15.5 years)
Topics

1) How long do deficits last for after concussion?

2) How can we accurately monitor recovery to determine appropriate RTP timing?

3) What factors (+/-) affect recovery?
The role of physical activity

Return to unrestricted PA may negatively affect dual-task balance control

**But**, too much inactivity for athletes may lead to concussive symptoms

Physical activity level and symptom resolution time are not associated (Howell et al., *AJSM*, 2015, In Press)
Some physical activity may not be harmful during recovery

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hazard Ratio</th>
<th>SE</th>
<th>95% C.I.</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>1.0013</td>
<td>0.0351</td>
<td>0.9463 - 1.0841</td>
<td>.712</td>
</tr>
<tr>
<td>Sex*</td>
<td>1.3695</td>
<td>0.2003</td>
<td>1.0282 - 1.8242</td>
<td>.032</td>
</tr>
<tr>
<td>Total score: initial PCSS*</td>
<td>0.9830</td>
<td>0.0046</td>
<td>0.9740 - 0.9920</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Number of previous concussions</td>
<td>0.8748</td>
<td>0.0669</td>
<td>0.7530 - 1.0163</td>
<td>.081</td>
</tr>
<tr>
<td>LOC at time of injury</td>
<td>0.9160</td>
<td>0.1882</td>
<td>0.6124 - 1.3702</td>
<td>.669</td>
</tr>
<tr>
<td>Amnesia at time of injury</td>
<td>0.7890</td>
<td>0.2054</td>
<td>0.4737 - 1.3140</td>
<td>.362</td>
</tr>
<tr>
<td>Prior treatment for headaches</td>
<td>0.7064</td>
<td>0.1875</td>
<td>0.4199 - 1.1884</td>
<td>.190</td>
</tr>
<tr>
<td>Initial period of physical rest</td>
<td>0.7935</td>
<td>0.1345</td>
<td>0.5692 - 1.1062</td>
<td>.172</td>
</tr>
<tr>
<td>Physical activity level</td>
<td>1.0008</td>
<td>0.0007</td>
<td>0.9994 - 1.0021</td>
<td>.261</td>
</tr>
</tbody>
</table>

*Multivariate Cox Regression Model: Outcome variable = Symptom Duration (days)*

Howell et al., *AJSM In Press*, 2015; Data from 364 adolescents/young adults with concussion (mean age = 15.0 years)
Long-term effects of early RTP

When is the optimal timing to return to sport and academic activities?

   Easy answer: it is multifaceted

The appropriate timing and dosage of physical activity during each recovery stage remains unknown

   Likely based on many factors
2 months post-injury: Dual-Task M-L Displacement

Dual-task gait stability was significantly and strongly associated with the time from injury until resumption of pre-injury levels of physical activity.

Howell et al., *J Head Trauma Rehab*, 2015
Clinical Implications

Some physical activity is not harmful to time required for symptom resolution

However, balance deficits undetectable through current assessment paradigms may exist after RTP

Lingering balance control deficits may lead to increased risk of subsequent injury

Lynall et al., MSSE, 2015; Cross et al., BJSM, 2015
Conclusions

1) Deficits after concussion persist from days-months, depending on the testing battery employed

2) Dynamic dual-task assessments provide functional information about concussion recovery

3) Physical activity may not be detrimental to recovery of symptoms

   • But, unrestricted RTA may provoke balance altered balance problems undetectable through other exams
THANK YOU!
Consequences of Prolonged Postural Control Deficits
Subsequent Injuries

• So What?
  – Well established concussion dose response (↑3 – 6x)
  – Other Injuries?
  – Long Term?
Complications of Prolonged Deficits Subsequent Injuries?

- **Professional Soccer (UEFA) Champions League**
  - Soccer players who suffer concussions are more likely to suffer another injury both in the year following (2.2x) and year prior (2.0x) a concussion.


- **Rugby**
  - ↑ 60% elevated risk of subsequent injury in the same season as compared to players without a concussion.

Complications of Prolonged Deficits Subsequent Injuries?

• Retired NFL Football Players
  – ↑ risk of serious LE injury (up to 3.5x) in football players with concussion history
  – Dose Response

• NCAA Student Athletes
  – ↑ risk of acute LE injury (1.97X) in the year post-concussion
  – Positive Association (↑1.6 – 2.9x) between concussion history and LAS, ACL, and Muscle Strain
    • Gilbert & Llewellyn in review.
Complications of Prolonged Deficits Subsequent Injuries

• So What?
Clinically Feasible Balance Tests

- Tandem ST & DT Gait Videos
Clinically Feasible Balance Tests

- BESS & SAC DT Video
Clinically Feasible Balance Tests

Healthy Participants

- Emergence of a “Posture-First” Strategy
Clinically Feasible Balance Tests

"Recovery Day"

- SAC
- BESS

Options for ST and DT
Clinically Feasible Balance Tests

Return to Play Day

SAC

BESS

DECISION MAKING
Concluding Thoughts

• Instrumented measures of postural control can identify lingering and persistent balance deficits often missed with clinical examination.

• Dual-tasks can assess concussion recovery on functions potentially associated with risk of subsequent injury.

• Challenges
  – Clinically feasible, yet sensitive, measures of post-concussion postural control need to be developed
  – Cause and Effect relationship between lingering balance deficit and subsequent injury