Preventing Concussion in Sport: From the Lab to the Law

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“Sport as a Concussion Laboratory”
Peer-reviewed publications on “Sports Concussion”

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Concussion Epidemiology - Current Trends

Football, ice hockey, soccer and lacrosse have the highest concussion incidence rates when calculated by athlete exposure (HS & College combined).

Competition concussion incidence rates are consistently higher than practice rates.

In sports with the same rules (basketball & soccer), recent research suggests the reported concussion incidence rate is higher in females.

Reported differences between the incidence of concussion between adolescent and adult athletes is inconclusive.

(Lincoln et al., 2011; Hootman et al., 2009; Gessel et al., 2007)
Concussion = Brain Injury

- Traumatically induced alteration in mental status that may or may not involve a loss of consciousness (LOC)
- Should not be dismissed as “ding” or “bell-ringer”
  - “Ding”/Grade 1 injuries resulted in neurocognitive deficits 36 hours after injury (Lovell et al. 2004)
  - 33% of players w/ concussion returned on same day experienced delayed onset of sx at 3 hrs, compared w/ only 12.6% of those who didn’t RTP same day (Guskiewicz, et al., JAMA 2003)

- Grading of concussions? **NO!**
What are the risks of not reporting?

Short Term Risks of Mismanagement

- Worsening of post-concussive signs and symptoms
- Repeat concussion with post concussion syndrome
- School-related issues in student athletes
- Second Impact Syndrome (younger athletes)

What are the risks of ignoring recurrent concussions?

Long Term Risks of Mismanagement

- Prolonged concussion symptoms (daily basis)
- Depression, cognitive impairment, dementia, CTE
- Long-term academic issues in student athletes
- Decreased Quality of Life
The Concussion Solution

Impact Biomechanics
- Linear acceleration
- Frequency
- Angular acceleration
- Location

Quantify exposure
- Player positions
- Helmet types and helmet fit
- Open-field vs. interior line plays
- Special teams vs. off/def plays

Acute Dx
- Biomarkers?

Acute Tx
- Omega 3-FA?
- Hyperbarics?
- Progesterone?

Symptoms

Neurocognitive function

Balance

Chronic effects
(PCS, depression, MCI)
Clinical Recovery

Amnesia
LOC
Concussion Hx

Symptoms
Sex
Balance
Brief Mental Status
Incidence, Clinical Course, and Predictors of Prolonged Recovery Time Following Sport-Related Concussion in High School and College Athletes

Michael McCrea,1 Kevin Guskiewicz,2,3,4 Christopher Randolph,5 William B. Barr,6 Thomas A. Hammeke,7 Stephen W. Marshall,3,4,8 Matthew R. Powell,9 Kwang Woo Ahn,10 Yanzhi Wang,10 AND James P. Kelly11

JINS (2012), 18, 1–12.
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570 Concussed HS & College Athletes
166 Control (uninjured) Athletes

Prolonged Recovery (s/s >7 days)
Typical Recovery (s/s <7 days)
Controls (uninjured)

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570 Concussed HS & College Athletes
166 Control (uninjured) Athletes

Controls (uninjured)

Typical Recovery (s/s <7 days)

Prolonged Recovery (s/s >7 days)
**Purpose**: Examine the proportion of concussed athletes with impairment disagreements across various clinical concussion assessment measures.

**Methods**: N= 100 concussed collegiate-aged athletes assessed at BL & <72 hrs post-injury on GSC, computerized NP, and balance
- Significant disagreements (~52% of cases) between symptom severity scores and all other clinical measures (NP & Balance Tests).

- Symptom severity scores identified more impairments than all other measures.

- Emphasizes multifaceted approach to concussion assessment.
Purpose: Examine the proportion of concussed athletes with impairment disagreements across various clinical concussion assessment measures.

Methods: N= 100 concussed collegiate athletes assessed at BL & <72 hrs post-injury on GSC, computerized NP, and balance.
Disagreements between symptom severity total scores and all other clinical measures (NP & Balance Testing). Disagreement proportions ranged from 22-52%.

Symptom severity total scores identified more impairments than all other measures.

Emphasizes need for multifaceted approach to concussion assessment.
Balance Error Scoring System (BESS)

Clinical Test Battery
Six 20 sec trials using 3 different stances (double, single, tandem) on 2 different surfaces (firm, foam)

Recorded Errors
- Hands lifted off iliac crests
- Opening eyes
- Step, stumble, or fall
- Moving into >30 deg. of hip flexion or abduction
- Remaining out of testing position for >5 secs.
Serial Evaluations

**TOI:** clinical eval & symptom checklist

1-3 hrs: symptom checklist

24 hrs: follow-up clinical eval & symptom checklist

**Symptomatic**

1. Continued rest
2. Monitoring of s/s
3. If deteriorating – consider imaging

**Asymptomatic**

1. Neuropsychological testing
2. Balance testing
3. Monitoring of s/s
Serial Evaluations (con’t)

Once athlete has been asymptomatic for 24 hrs:

- Reassess on clinical measures and compare to baseline scores.

- Continue to monitor symptoms for 24 hrs after assessment.

- If remain asymptomatic, reassess on clinical measures to see where they are relative to baseline and to previous day.

- Start **Graduated RTP Progression** if:
  
  * 95% baseline achieved
  * no deterioration from previous day
5 Step Graduated Return to Play

- **Exertion Step 1**: 20 minute stationary bike ride (10-14 MPH)
- **Exertion Step 2**: Interval bike ride: 30 sec sprint (18-20 MPH/10-14 MPH)/30 sec recovery x 10; and BW circuit: Squats/Push Ups/Situps x 20 sec x 3
- **Exertion Step 3**: 60 yard shuttle run x 10 (40 sec rest); and plyometric workout: 10 yard bounding/10 medicine ball throws/10 vertical jumps x 3; and non-contact, sports-specific drills for approximately 15 minutes
- **Exertion Step 4**: Limited, controlled return to non-contact practice
- **Exertion 5**: Full sport participation in a practice
Working through the RTP Progression

- The 5 steps do not necessarily require 5 days.

- No more than 2 steps should be performed on the same day, which allows for monitoring of both acute symptoms (during the activity) and delayed symptoms (within 24 hrs after the activity).
  - In general, If the exertional activities do not produce acute symptoms, the athlete may progress to the next step.

- The athlete may advance to Step 5 and return to full participation once they have remained asymptomatic for 24 hrs following Step 4 of the protocol.

- Always document the process, day by day, step by step!
Concussion-proof helmets? NO!

- Helmets do a great job of preventing catastrophic head injuries
  - Skull Fracture
  - More focal injuries

- Properly fitted, properly worn, and good condition!

☆ Managing energy inside the cranial cavity
Helmet Testing: Challenges

- Different methods used for head injury risk assessment
  - Peak linear acceleration ($a$)
  - Head Injury Criterion (HIC)
  - Severity Index (SI)
    - Predicts traumatic skull & brain injury risk
  - Peak angular acceleration ($\alpha$)
    - Best predictor of loss of consciousness

- NOCSAE standard
  - Severe head injury prevention (skull fx, hematomas, etc.)
  - Drop to rigid surfaces over 5 m/s
  - Severity Index <1,200 to pass; one size fits all
Helmet Testing: Challenges

Injury Risk Curves – which one is correct?
- Self-reported “cognitive impairment” was reported by nearly half of the concussed athletes, yet NP testing did not identify many as impaired. **30% of the athletes who were impaired on the GSC would have cleared if only NP testing were utilized.**

- Nearly 1/3 of the concussed athletes reported either a “balance problem” or “dizziness” but balance testing did not identify as impaired. **>30% of the athletes who were impaired on the GSC would have cleared if only balance testing was utilized.**

- GSC should be administered by a trained health care provider, and NOT simply placed in front of an athlete for them to complete. **It will not ascertain the same information as a clinician administered GSC.**

- Unless needed for academic or other outside performance based decisions, using computerized NP testing while an athlete is still symptomatic is not clinically beneficial.
Aftermarket Helmet Inserts/ Force Reduction Materials?

**Riddell** - “Riddell views the use of third party aftermarket accessories or products that alter the fit, form and function of the helmet as unauthorized alterations to our football helmets. Such accessories may affect NOCSAE certification, and we do not recommend their use.”

**Schutt** - “Adding (product) to anything from Schutt would add weight, compromise fit and could compromise the protection of your athletes. Using these (products) in any Schutt helmet would be considered altering the helmet. Adding this (product or material) will void the helmet warranty and release Schutt from all liability associated with the altered helmet.”

**Rawlings** - “Rawlings does not recommend the use of third party aftermarket accessories or products that alter the fit, form, function, or performance characteristics of the helmet. In addition, Rawlings’ warranty may be voided by ‘any alterations of, additions to, or component omissions or removals to’ the helmet.”
Head Impact Telemetry (HIT) System
On-Field Biomechanics

- Following 6 NCAA fall football seasons:
  - 255,432 head impacts recorded in 107 players

- Players’ ave. impact = 23.7g linear acceleration

- The brain can withstand a large number of impacts without clinically distinguishable injury; Ave 950 impacts per season; BUT what are the long-term effects?

- Impacts sustained during helmets-only (“light”) practices were higher than those in full contact practices and games/scrimmages
Impact accelerations and corresponding changes for clinical measures after concussion in 19 collegiate football players: BIG hits ≠ biggest deficits!

<table>
<thead>
<tr>
<th>Case #</th>
<th>Player Position*</th>
<th>Linear Magnitude (g)</th>
<th>Rotational acceleration (rad/s²)</th>
<th>Impact Location</th>
<th>ΔSymptom Scores†</th>
<th>ΔSOT Composite‡</th>
<th>ΔANAM Composite‡</th>
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<tr>
<td>1</td>
<td>OL</td>
<td>60.31</td>
<td>5419.18</td>
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<td>WR</td>
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<td>5573.42</td>
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<td>-1.49</td>
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<td>Front</td>
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<td>4762.74</td>
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<td>32</td>
<td>8.08</td>
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</table>
Injury Results:

- 17x more likely to sustain a concussion if linear acceleration $\geq 100\text{g}$, compared to $<100\text{g}$.
- 14x more likely to sustain a concussion if rotational acceleration $>5000 \text{ rad/sec}^2$, compared to $<5000 \text{ rad/sec}^2$.

Red = Lower FA in concussed vs. control group

Two sample t-test
p<0.05 FDR corrected
Cluster size > 100
Diffusion Tensor Imaging – FA (white matter integrity)

**Red** = Lower FA value at post-season vs. pre-season

Paired t-test

p<0.05 FDR corrected

Cluster size > 100
Leading with the head: Is it still a problem?

- Yes

- 15% of all impacts occurred to top of head; down from 19% (ave. seasons 1, 2, 3)

- Players were 3x more likely to sustain an impact of >80 g to top of the head any other helmet location:

Are special teams (punts & kickoffs) a problem?
The Play

The Data

157.5 g
1020.0 rad/s²
Front
## Impact magnitude by play type position

<table>
<thead>
<tr>
<th>Play Type</th>
<th>Closing Distance</th>
<th>Ave Linear Acc.</th>
<th>lower_cl</th>
<th>upper_cl</th>
<th>DF</th>
<th>Prob.t</th>
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<tbody>
<tr>
<td>Defense</td>
<td>&gt;10 yards</td>
<td>25.36</td>
<td>23.14</td>
<td>27.79</td>
<td>9</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Defense</td>
<td>&lt;10 yards</td>
<td>23.47</td>
<td>21.99</td>
<td>25.05</td>
<td>9</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Offense</td>
<td>&gt;10 yards</td>
<td>24.66</td>
<td>22.48</td>
<td>27.04</td>
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<td>&lt;.0001</td>
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<td>&lt;10 yards</td>
<td>23.94</td>
<td>22.59</td>
<td>25.36</td>
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<td>&lt;.0001</td>
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<tr>
<td>Special teams</td>
<td>&gt;10 yards</td>
<td>26.82</td>
<td>24.93</td>
<td>28.84</td>
<td>9</td>
<td>&lt;.0001</td>
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<tr>
<td>Special teams</td>
<td>&lt;10 yards</td>
<td>20.93</td>
<td>18.13</td>
<td>24.15</td>
<td>9</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

*Ocwieja, Mihalik, Marshall, Schmidt, Trulock, Guskiewicz– ABME, 2011*
# NFL’s 2011 Kick-off Rule Change

Table 2. Regular Season Game Kickoff Statistics in 2011; 3-year Comparison

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Returns</th>
<th>Touchbacks</th>
<th>Fair Catches</th>
<th>Kick Out of Bounds</th>
<th>Short Free or Onside Kicks</th>
<th>Opponent Received</th>
<th>Total Kickoffs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>2114</td>
<td>371</td>
<td>7</td>
<td>36</td>
<td>47</td>
<td>1</td>
<td>2576</td>
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<tr>
<td>2009</td>
<td>2004</td>
<td>401</td>
<td>12</td>
<td>30</td>
<td>36</td>
<td>1</td>
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<tr>
<td>2010</td>
<td>2034</td>
<td>416</td>
<td>7</td>
<td>39</td>
<td>43</td>
<td>0</td>
<td>2539</td>
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<tr>
<td>2011</td>
<td>1375</td>
<td>1120</td>
<td>1</td>
<td>26</td>
<td>50</td>
<td>0</td>
<td>2572</td>
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<tr>
<td>Average 2008-2010</td>
<td>2050.7</td>
<td>396</td>
<td>8.7</td>
<td>35</td>
<td>42</td>
<td>0.7</td>
<td>2533</td>
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</tbody>
</table>
## NFL’s 2011 Kick-off Rule Change

### Table 3. Significant Injuries As a Function of Kickoff Plays 2011 Regular Season; 3-year Comparison

<table>
<thead>
<tr>
<th>Year</th>
<th>Concussions</th>
<th>Neck/Spine (year)</th>
<th>Fractures (year)</th>
<th>ACL Sprain (year)</th>
<th>All Injuries (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>26 (1.0%)</td>
<td>12 (0.5%)</td>
<td>10 (0.4%)</td>
<td>3 (0.1%)</td>
<td>152 (5.9%)</td>
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<td>(N=2576)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>25 (1.0%)</td>
<td>7 (0.3%)</td>
<td>6 (0.2%)</td>
<td>2 (0.1%)</td>
<td>147 (5.9%)</td>
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<tr>
<td>(N=2484)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>28 (1.1%)</td>
<td>7 (0.3%)</td>
<td>11 (0.4%)</td>
<td>8 (0.3%)</td>
<td>135 (5.3%)</td>
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<tr>
<td>(N=2539)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>15 (0.6%)</td>
<td>8 (0.3%)</td>
<td>8 (0.3%)</td>
<td>7 (0.3%)</td>
<td>136 (5.3%)</td>
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<td>(N=2572)</td>
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<td></td>
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</tr>
<tr>
<td>Average</td>
<td>26.3 (1.0%)</td>
<td>8.7 (0.3%)</td>
<td>9.0 (0.4%)</td>
<td>4.3 (0.2%)</td>
<td>144.7 (5.7%)</td>
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<tr>
<td>(N=2533)</td>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>
Role of the cervical muscles?

67% ↑ in effective mass

Vianno, 2007
Athletes must be able to accurately:

- Identify static and dynamic features
- Scan and interpret visual information
- Alternate between looking between varying distances
- Perform efficient eye movements
- Respond quickly to visual stimuli
Level of Anticipation
**Vision: Eye-Hand Coordination**

- 8x6 grid of equally spaced circle
- Turquoise dot will appear within one circle of the grid

**Go/No Go**

- Dot stimulus could be either turquoise or red (64 turquoise, 32 red)
- Touch the turquoise dots and avoid the red dots
Safer Football, Taught From Inside the Helmet

UNC athletic trainer Scott Trulock and Dr. Kevin Guskiewicz talking with Offensive Linemen Alan Pelc.

By ALAN SCHWARZ  Published: November 5, 2010  New York Times

CHAPEL HILL, N.C. — Alan Pelc has been taught how to block since his Houston boyhood, how to push and pulverize and punish oncoming defenders on the football field. This was different. He was learning how not to punish himself.

“Right there,” Dr. Kevin Guskiewicz said, pointing at a presentation screen showing more than a dozen arrows pointed straight into the top of a mannequin head. “These are all your recorded hits to the top of your helmet against L.S.U. Every time you drop your head. These are the ones we’re concerned about.”
4 weeks later
The Center conducts clinical and epidemiological research with the purpose of improving quality of life for retired athletes. Through these endeavors, the Center provides medical screenings to educate retired athletes about their potential health risks and needs.
Risk For Late Life Cognitive Impairment?

**CLINICAL STUDIES**

**ASSOCIATION BETWEEN RECURRENT CONCUSSION AND LATE-LIFE COGNITIVE IMPAIRMENT IN RETIRED PROFESSIONAL FOOTBALL PLAYERS**

OBJECTIVE: Cerebral concussion is common in collision sports such as football, yet the chronic neurological effects of recurrent concussion are not well understood. The purpose of our study was to investigate the association between previous head injury and the likelihood of developing mild cognitive impairment (MCI) and Alzheimer’s disease in a unique group of retired professional football players with previous head injury exposure.

METHODS: A general health questionnaire was completed by 2552 retired professional football players with an average age of 53.8 (±13.4) years and an average professional football playing career of 6.6 (±2.3) years. A second questionnaire focusing on memory and issues related to MCI was then completed by a subset of 736 retired professional football players (≥50 yr of age). Results on MCI were then cross-tabulated with results from the original health questionnaire for this subset of older retirees.

RESULTS: Of the former players, 61% sustained at least one concussion during their professional football career, and 24% sustained three or more concussions. Statistical analysis of the data identified an association between recurrent concussion and clinically diagnosed MCI ($\chi^2 = 7.82, df = 2, P = 0.02$) and self-reported significant memory impairments ($\chi^2 = 19.75, df = 2, P = 0.001$). Retired players with three or more reported concussions had a fivefold prevalence of MCI diagnosis and a threshold prevalence of reported significant memory problems compared with retirees without a history of concussion. Although there was not an association between recurrent concussion and Alzheimer’s disease, we observed an earlier onset of Alzheimer’s disease in the retirees than in the general American male population.

CONCLUSION: Our findings suggest that the onset of dementia-related syndromes may be initiated by repetitive cerebral concussions in professional football players.

**KEYWORDS:** Alzheimer, Concussion, Mild cognitive impairment, Retired professional football players

Guskiewicz et al., Neurosurgery, 2005
Risk for Clinical Depression?

- 11% of all respondents dx with a bout with depression.
  - 0 concussions: 6.4%
  - 1-2 concussions: 9.8%
  - 3+ concussions: 21.2%
  \( \chi^2 = 71.51, df=2, p<.001 \)

- 87% still suffering from depression & 46% currently being tx with anti-depressants.

Risk for Clinical Depression?

Depression Incidence

Percentage of Respondents

NFL Retirees

Risk for Clinical Depression?
Grey Matter Volume: Control vs. NFL Retirees

Atrophy in NFL Retirees

P < 0.01 FDR-corrected, cluster size > 100, no significant NFL > control found
White Matter FA: Control vs. NFL Retirees

Red = decrease FA in NFL retirees

Inferior frontal-occipital fasciculus       Genu

P < 0.01 FDR-corrected, cluster size > 100
Longitudinal Perspective on MTBI: Influence of Multiple Trauma

- Risk of concussion
- Influence on recovery
- Chronic Symptoms
- Cognitive Impairment
  - Influence on post-injury recovery
  - Persistent neurocognitive effects
- Neuropsychiatric Disorders
  - Mood disorders
  - Neurobehavioral changes
- Neurodegenerative Disease
  - MCI
  - Dementia
States with Legislation on Management of Youth Sports-Concussions

March 2009

NONE!
States with Legislation on Management of Youth Sports-Concussions

December 2012

42 State Laws Passed 8 State Laws Pending

Source: National Conference of State Legislatures (www.ncsl.org)
State Concussion Laws

• Require that secondary school athletes:
  – removed from play if concussed
  – MD clearance required before return
  – concussion education for coaches, parents & athletes

• Evidence-based

• Effectiveness unknown
Conclusion: Research Drives Change

• Forcing clinicians to re-think how concussion is managed
  – defining the recovery curves
  – guiding policy change: NFL, NCAA, NFHS, Youth Sports

• Providing a better understanding of injury biomechanics
  – determining the concussion threshold & influence of repetitive sub-concussive impacts? Behavior modification!
  – Helmet design, rules change, player/coaching education

• Providing an understanding of long-term effects of TBI
  – Slowed recovery and influence on academic performance & quality of life
  – Early detection of neurodegenerative processes (neuropsych, balance tests and advanced neuroimaging)
  – Introducing interventions (concussion education, hyperbarics, Omega-3 FA)
Thank You
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