Concussion and Helmet Technology: Clinical and Practical Implications

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Disclosure

Neither I, Stefan Duma, Steven Rowson, nor any family member(s) or co-author(s), have any relevant financial relationships to be discussed, directly or indirectly, referred to or illustrated with or without recognition within this presentation.
Brief History of Helmet Safety Standards
American National Standards Institute (ANSI)

- ANSI accredits standards that are developed by representatives of other standards organizations, government agencies, consumer groups, companies, and others. These standards ensure that the characteristics and performance of products are consistent, that people use the same definitions and terms, and that products are tested the same way. ANSI also accredits organizations that carry out product or personnel certification in accordance with requirements defined in international standards.

National Operating Committee on Standards for Sports Equipment

- The National Operating Committee on Standards for Athletic Equipment (NOCSAE) is a non-profit organization whose mission is to reduce athletic injuries and death through standards and certification for athletic equipment. Schools and universities look to NOCSAE certification of equipment, particularly helmets, to protect players and reduce liability. NOCSAE data indicate a significant reduction in athlete fatalities and brain injuries when using NOCSAE certified equipment. NOCSAE has been criticized for stifling innovation, holding a conflict of interest, and not furthering true player safety.

- NOCSAE’s commissioning came in the wake of the death of 32 players in organized football in 1968 and subsequent concerns over safety of athletic equipment. Based on its limited funding, NOCSAE has narrowed its efforts from protective athletic equipment in all sports toward helmets’ effectiveness in reducing injury, particularly in football, lacrosse, and baseball.

The Snell Memorial Foundation (SMF) is a not-for-profit organization created to provide a high quality standard of safety for helmets. Founded in 1957, SMF is named after William "Pete" Snell, a popular sports car racer who died in 1956 of head injuries he received when the racing helmet he wore failed to protect his head. A group of friends, scientists, physicians, and others joined together to create a group that would promote research and education as well as test and develop standards to improve the effectiveness of helmets.

Snell Standards significantly surpass those set by the U.S. Department of Transportation (DOT), the American National Standards Institute (ANSI), ASTM International (ASTM) and the U.S. Consumer Products Safety Commission's 16 CFR Part 1203.

Snell Standards are updated about every five years. These updates are based on new scientific research and improved, available manufacturing technologies. As such, and in addition to other factors such as typical use wear and tear, Snell recommends that helmets be replaced approximately every five years to ensure good safety.

Acceleration-Based Brain Injury

• Inertial Loading (everyday case)
  – From direct head loading
  – From whole body loading
  – Motion of the brain relative to the skull

Acceleration is a metric for characterizing injury risk

• Skull acceleration is indicative of the inertial response of the brain to impact loading

• Skull acceleration doesn’t cause injury, but the pressure and strain response within the brain tissue does
In Situ Brain Biomechanics

• High Speed X-Ray Cadaver Experiments
  – Head impacts at concussive severities
  – Brain response
  – Skull kinematics

• Brain is not “flopping” around
  – 5 to 7 mm of movement
  – Looping pattern

• Acceleration correlated to brain injury mechanisms
  – Strain Response
  – Pressure Response

Hardy et al. (2007)
Basic Helmet Function

- There are two primary components of a helmet to protect from injury
  - Helmet Shell
    - Deflects to distribute force over a larger area
  - Helmet Liner
    - Modulates the energy transferred to the head
    - Impact response can be tuned to meet design requirements

**Helmets can be designed to reduce concussion risk**

Football helmets used as an example, but applicable to all sports
Brain Injuries in Football

- 1.6 to 3.8 million sports-related concussions each year in the US

- Increased Occurrence in Collegiate Sports
  - Football has largest total of any sport
  - “Human volunteers” for onset of MTBI

- Instrument and observe a high risk population

- 9 years of head acceleration data collected
HIT System Hardware

- 6 accelerometer configuration
- Measures resultant linear acceleration
- Estimates peak rotational acceleration
- Spring-mounted accelerometers
  - Remain in contact with head
Head Acceleration Data Collection

- Up to 64 Virginia Tech players instrumented each season
- Data collected for every game and practice

- instrumented helmet
Cumulative HITS Data Collection

Total Number of Impacts Recorded at Virginia Tech

- 165, 2,000
- 2,000,000+ impacts recorded at all institutions
Helmets modulate energy transferred to the head

Helmets can be designed to reduce head acceleration

Concussion risk is lowered
Football Helmet Evaluations

All head impact data was used to create:

[Image]

Combines impact exposure with a risk analysis using real world biomechanical data to assess helmet performance for consumers.
Helmet Testing 101
STAR Rating System for Football Helmets

STAR: Summation of Tests for the Analysis of Risk

\[ \text{STAR} = \sum_{L=1}^{4} \left( \sum_{H=1}^{6} E(L, H) \cdot R(a) \right) \]

Through a series of drop tests, helmets are evaluated using 2 fundamental concepts:

1. Tests are weighted based on how often they occur
2. Helmets that lower head acceleration reduce risk

Exposure x Risk = Incidence
Helmet Testing Protocol

Test 4 impact locations:

Front  Rear  Side  Top

Test 5 impact energies: 12 in, 24 in, 36 in, 48 in, 60 in
Drop Tests Mapped to Impact Exposure

Front Impact – 36 in Drop
Exposure = 10 Impacts

Side Impact – 36 in Drop
Exposure = 1 Impact
Linear Acceleration Risk Curve

Exposure x Risk = Incidence

10 Impacts x 40% Concussion Risk = 4 Concussions

Probability of MTBI vs Linear Acceleration (g)
Star Football Helmet Ranking System

- STAR is first system to account for ALL impacts over the course of a season
  - 1000 impacts
  - Four directions
  - Six severity levels
- Weighted values based on exposure
  - Higher weights for lower severity given the higher number of lower impacts

STAR Testing Process

For each model, 3 new helmets are tested twice at the 20 STAR matrix (2x20x3 = 120)

The two peak accelerations for each testing configuration are averaged.

A STAR value for each helmet is determined from the average accelerations for that helmet.

The overall STAR value is determined by averaging the three individual STAR values.

Statistical significance between helmet models is determined using the average and variance in the three individual STAR values.
### STAR Ratings of Current Helmets

15 helmet models were evaluated with the STAR system.

<table>
<thead>
<tr>
<th>5 Stars: Best Available</th>
<th>3 Stars: Good</th>
<th>2 Stars: Adequate</th>
<th>1 Star: Marginal</th>
<th>NR: Not Recommended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riddell 360</td>
<td>Rawlings Quantum</td>
<td>Schutt Air XP</td>
<td>Riddell VSR4</td>
<td>Adams A2000 Pro Elite</td>
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<td>Rawlings Quantum Plus</td>
<td>Riddell Revolution IQ</td>
<td>Xenith X2</td>
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<td>Schutt DNA Pro +</td>
<td>Schutt Air Advantage</td>
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<td>Rawlings Impulse</td>
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<table>
<thead>
<tr>
<th>Helmet Model</th>
<th>STAR Value</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rawlings Quantum</td>
<td>0.239</td>
<td>$374.95</td>
</tr>
<tr>
<td>Riddell Revolution IQ</td>
<td>0.369</td>
<td>$222.99</td>
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<td>Schutt Air XP</td>
<td>0.434</td>
<td>$179.95</td>
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<tr>
<td>Xenith X2</td>
<td>0.477</td>
<td>$220.00</td>
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<tr>
<td>Schutt Air Advantage</td>
<td>0.678</td>
<td>$159.99</td>
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<tr>
<td>Riddell VSR4</td>
<td>0.791</td>
<td>Not Applicable</td>
</tr>
<tr>
<td>Adams A2000 Pro Elite</td>
<td>1.700</td>
<td>$199.95</td>
</tr>
</tbody>
</table>
# Helmet Distribution Comparison

Virginia Tech instrumented players 2009 + 2010  
Comparison of all players in VSR4 and Revolution helmets

<table>
<thead>
<tr>
<th>Acceleration Range</th>
<th>Revolution</th>
<th>VSR4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 20 g</td>
<td>53.14%</td>
<td>53.40%</td>
</tr>
<tr>
<td>20 – 40 g</td>
<td>32.22%</td>
<td>30.30%</td>
</tr>
<tr>
<td>40 – 60 g</td>
<td>9.22%</td>
<td>8.84%</td>
</tr>
<tr>
<td>60 – 80 g</td>
<td>3.13%</td>
<td>4.02%</td>
</tr>
<tr>
<td>80 -100 g</td>
<td>1.38%</td>
<td>1.89%</td>
</tr>
<tr>
<td>100+ g</td>
<td>0.91%</td>
<td>1.56%</td>
</tr>
</tbody>
</table>

**Revolution impacts were more likely to be < 60 g**  
**VSR4 impacts were more likely to be > 60 g**
Clinical Validation of STAR

• Collins et al. (2006)
  • Studied over 2000 high school players
  • Riddell Revolution reduced risk of concussion by 31% (p = 0.027)

• Virginia Tech Clinical Data (2005 - 2010)
  • Studied over 250 college football players
  • Riddell Revolution reduced risk of concussion by 85% compared to Riddell VSR4 (p = 0.03)

• STAR Evaluation System
  – Developed from data on over 100,000 head impacts
  – Predicts Riddell Revolution reduces risk of concussion by 54% compared to Riddell VSR4
Clinical Validation of STAR

3 different studies show differences between helmets in ability to reduce concussion risk with Revolution

<table>
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<tr>
<th></th>
<th>Riddell Revolution</th>
<th>Riddell VSR4</th>
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<tbody>
<tr>
<td>STAR Value</td>
<td>0.362</td>
<td>0.791</td>
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</table>

- Collins: 31% STAR, 54% VT
- Lab and clinical agreement on ability to reduce concussion risk
Consider Two Helmets

Which helmet would you choose?

For Identical Impacts:

- **Helmet A**
  - 90 g
  - 1% risk of concussion

- **Helmet B**
  - 200 g
  - 59% risk of concussion
NCAA Viewpoint: Concussion Prevention and Management

- Also, there are emerging sensor devices that may help us to better understand the biomechanics and clinical outcomes of head impact. We are working with member institutions and allied organizations to assess these potentially important technologies. At present, marketing claims are not in sync with science or the National Operating Committee on Standards for Athletic Equipment (NOCSAE). To date, there is no sensor device that accurately measures both linear and rotational forces to the head, but ongoing research is bringing us closer to such a reality. We will continue to support this important research.

- Protective equipment around helmets is another emerging technology in which market claims are not in sync with science or NOCSAE. Because of the singular importance of rotational forces in generating a concussion, the scientific literature to date has noted that helmets provide little, if any, protective effects in concussion. We hope to bridge market claims with science and NOCSAE.

Source: NCAA
What About Rotational Acceleration?

- Pure rotational impacts do not occur
  - Helmets are smooth, round
  - Helmets do not catch and rotate the head, like animal tests did

- Linear component of the impact drives the rotational component

- Rotational acceleration is highly correlated to linear acceleration

If linear acceleration is reduced by a helmet, rotational acceleration is also reduced

Gennarelli et al. (1982)
NOCSAE on the STAR rating system

July 3, 2013

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Statement from the National Operating Committee on Standards for Athletic Equipment Regarding 2013 Virginia Tech Star Rating System

"The National Operating Committee on Standards for Athletic Equipment (NOCSAE) supports and encourages the scientific research being done by Virginia Tech in the very important area of concussion protection for athletes in all sports, and particularly in football. There are, however, very important limitations in the STAR rating system as recognized by the experts at Virginia Tech. NOCSAE believes that many parents, players, coaches, and athletic directors are unaware of these limitations. Unless the limitations of the STAR rating system are considered, the potential exists for players, parents, coaches, and administrators to overemphasize the role of the helmet in protecting against concussions. This overemphasis increases the likelihood that less attention will be given to other steps that have a more immediate and much greater impact on concussion reduction.

*According to the The Virginia Tech Helmet Ratings™ STAR website FAQ which can be found at http://www.sbes.vt.edu/pdf/FrequentlyAskedQuestions2013.pdf:

- Only adult-size large helmets were evaluated. There are no data to support applying the same ratings to other sized helmets of the same model, including youth football helmets. No adult X-Large, Medium, Small, X-Small or any youth-size helmets were tested.
- The STAR value itself is a theoretical calculation that is based on a probabilistic analysis of impact exposure and injury risk at the collegiate level.
- There are a near infinite number of ways to test helmets (varying temperature, impact location, helmet size, drop height, etc.), and, therefore, generalizations were made so that the helmets could be tested in a practical manner. Helmets were not tested under game conditions. For example, air bladder fitting and protection systems were not inflated to achieve fit, even though the NOCSAE standards require that manufacturer fitting instructions be followed.

*According to an independent statistical review of the scores and categories upon which the STAR number is based, there is no significant statistical difference between helmets in the 5 STAR, 4 STAR, and 3 STAR categories.

- It is important to note that in the past two years, more people are listening to our work at Virginia Tech, then NOCSAE (been around 40+ years), that speaks very highly of our research.
- We have written to NOCSE and the NCAA correcting the inaccuracies in their press releases and they have chosen not to respond
NOCSAE position on “add ons”

• On 7/16/13, NOCSAE released a statement which concludes that "The addition of after-market items by anyone that changes or alters the protective system by adding or deleting protective padding to the inside or outside of the helmet, or which changes or alters the geometry of the shell or adds mass to the helmet, whether temporary or permanent, voids the certification of compliance with the NOCSAE standard."
Do Helmets Work?

• Yes!!! Helmets work and can reduce the risk of concussion
  • helmet design can be greatly improved
  • Data exists that can improve design criteria

• Helmets modulate the energy transferred to the head during impact

• Helmets that reduce the acceleration of the head, reduce the risk of concussion
  • Linear and rotational components linked

• Reduction in concussion risk has been experimentally and clinically quantified
Concussion Incidence Minimization

3 Strategies:

- Reduce exposure to head impact
  - Rule changes
  - Proper technique

- Reduce concussion risk for remaining head impacts
  - Improve helmet design

Fewest Concussions
STAR Clinical Caveats

• Any player in any sport can sustain a head injury with even the very best head protection.

• This analysis is based on data trends and probabilities, and therefore a specific person's risk may vary.

• This variation is likely dominated by genetic differences, health history, and impact factors such as muscle activation. Many variables...

• Education, coaching, and rules changes/enforcement are critical factors that must be included in any sport concussion program.
  – The helmet is the last line of defense

• Not perfect, but big step in right direction: lowering loads lowers risk
  – Future versions can include modifications based on new research and publications
All Data and Reports Online

http://www.vcom.vt.edu/sportsmed/
Publicly Available Data for Consumers

Virginia Tech Helmet Ratings™
Adult Football Helmet Ratings - May 2012

A total of 16 adult football helmet models that have been evaluated using the STAR evaluation system are included in the May 2012 Virginia Tech Helmet Ratings™. All 16 helmets included in the ratings have been made available to consumers at the time of publication. Helmets with lower STAR values provide a reduction in concussion risk compared to helmets with higher STAR values. Based on this, the best overall rating of 5 stars has the lowest STAR value. Group rankings are differentiated by pre-determined thresholds.

5 Stars: Best Available

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4 Stars: Very Good

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