DEFENSE CENTERS OF EXCELLENCE

For Psychological Health & Traumatic Brain Injury

Do Helmets Prevent Concussion?

July 10, 2014, 1-2:30 p.m. (EDT)

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DVBIC Defense and Veterans Brain Injury Center

DHCC Deployment Health Clinical Center

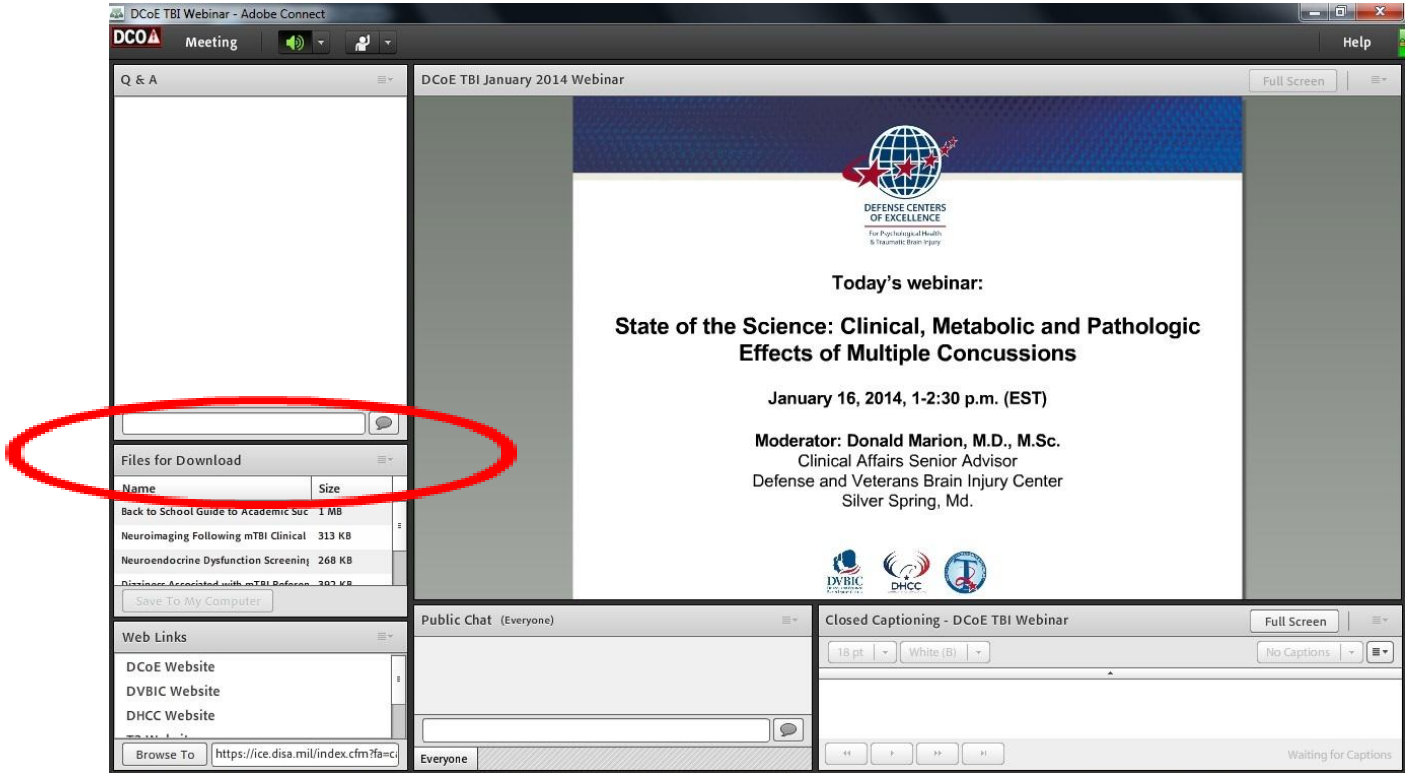
National Center for Telehealth & Technology

Webinar Details

- Live closed captioning is available through Federal Relay Conference Captioning (see the “Closed Captioning” box)
- Webinar audio is **not** provided through Adobe Connect or Defense Connect Online
  - Dial: CONUS **888-877-0398**; International **210-234-5878**
  - Use participant pass code: **3938468**
- Question-and-answer (Q&A) session
  - Submit questions via the Q&A box

Resources Available for Download

- Today's presentation and resources are available for download in the "Files" box on the screen, or visit **dvbic.dcoe.mil/online-education**



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- DCoE's awarding of continuing education (CE) credit is limited in scope to health care providers who actively provide psychological health and traumatic brain injury care to active-duty U.S. service members, reservists, National Guardsmen, military veterans and/or their families.

- The authority for training of contractors is at the discretion of the chief contracting official.
  - Currently, only those contractors with scope of work or with commensurate contract language are permitted in this training.

- All who registered **prior** to the deadline on **Thursday, July 10, 2014,** at 3 p.m. (EDT) and meet eligibility requirements stated above, are eligible to receive a certificate of attendance or CE credit.

Continuing Education Details (continued)

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Continuing Education Details (continued)

- Credit Designation – The Duke University School of Medicine designates this live webinar for:
  - 1.5 AMA PRA Category 1 Credit(s)
- Additional Credit Designation includes:
  - 1.5 ANCC nursing contact hours
  - 0.15 IACET continuing education credit
  - 1.5 NBCC contact hours credit commensurate to the length of the program
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  - 1.5 NASW contact hours commensurate to the length of the program for those who attend 100% of the program

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- NBCC: Southern Regional Area Health Education Center (AHEC) is a National Board for Certified Counselors and Affiliates, Inc.(NBCC)-Approved Continuing Education Provider (ACEP™) and a cosponsor of this event/program. Southern Regional AHEC may award NBCC-approved clock hours for events or programs that meet NBCC requirements. The ACEP maintains responsibility for the content of this event. Contact hours credit commensurate to the length of the program will be awarded to participants who attend 100% of the program.

- Psychology: This activity complies with all of the Continuing Education Criteria identified through the North Carolina Psychology Board's Continuing Education Requirements (21 NCAC 54.2104). Learners may take the certificate to their respective State Boards to determine credit eligibility for contact hours.

- NASW: National Association of Social Workers (NASW), North Carolina Chapter: Southern Regional AHEC will award contact hours commensurate to the length of the program to participants who attend 100% of the program.

NASW. NORTH CAROLINA CHAPTER
National Association of Social Workers
Approval Year
2014

Questions and Chat

- Throughout the webinar, you are welcome to submit technical or content-related questions via the Q&A pod located on the screen. **Please do not submit technical or content-related questions via the chat pod**.
- The Q&A pod is monitored during the webinar; questions will be forwarded to presenters for response during the Q&A session.
- Participants may chat with one another during the webinar using the chat pod.
- The chat function will remain open 10 minutes after the conclusion of the webinar.

Webinar Overview

- Reports of concussions during sporting events are increasing despite improvements in personal protective gear. Sports medicine experts recently published statements about the lack of effectiveness helmets and other equipment have on the incidence and severity of concussion. However, a recent study indicates that helmet design can reduce the transmission of impact forces to the brain and reduce concussion incidence.

- Biomechanical determinants of injury risk can be measured even though an objective marker of mild traumatic brain injury diagnosis is not available. Determining an acceptable level of risk, risk variation with age, directional variables and other factors is important. The effects of sub-concussive blows, multiple concussions and the interval between them are largely unknown. This webinar will address the biomechanical determinants of concussion risk and their relevance to real world sports injuries.

- At the conclusion of this webinar, participants will be able to:
  - Describe current sports medicine expert consensus statements about the effectiveness of football helmets on concussion prevention
  - Examine the biomechanical factors and pathophysiology of concussion
  - Discuss the use of acceleration information as a metric for characterizing brain injury risk
  - Relate the concussion risk in football in relationship to better equipment, rule changes and proper techniques

Presenter: Donald Marion, M.D., M.Sc.

Donald Marion, M.D., M.Sc.

- Academic neurosurgeon who has focused on the clinical pathophysiology and treatment of traumatic brain injury (TBI) for more than 30 years
- One of the charter authors of the Brain Trauma Foundation's "Guidelines for the Management of Severe Traumatic Brain Injury"
- Authored or co-authored more than 200 journal articles and book chapters, mostly related to TBI
- Former professor and chair of the Department of Neurosurgery, The Boston University School of Medicine; professor and vice chair, Department of Neurosurgery, The University of Pittsburgh School of Medicine; and director of the Brain Trauma Research Center, the University of Pittsburgh

Helmet Protection from Sports-related Concussion – An Overview

Donald Marion, M.D.

Disclosure

- The views expressed in this presentation are those of the presenter and do not reflect the official policy of the Defense Department (DoD) or the U.S. Government.

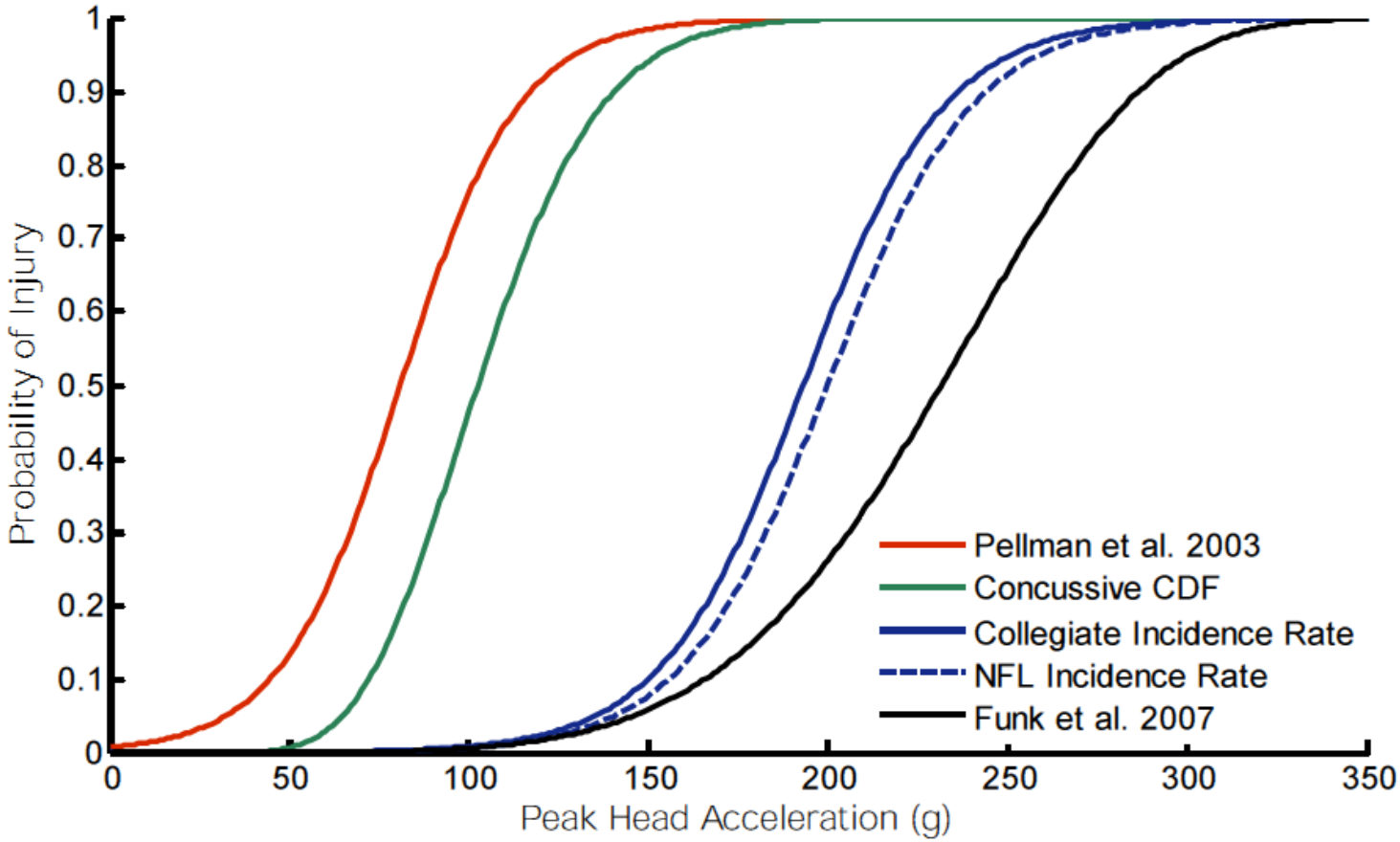
- The presenter does not intend to discuss the off-label/ investigative (unapproved) use of commercial products or devices.

Helmet Protection for Sports-related Concussion

- Is it possible to reduce the risk of concussion?
- What are current helmet design standards?
- What is the consensus of the experts?
- Can a better helmet design actually lower the risk of concussion?

Football Players Are at Risk for Concussion: 1,200-2,000 Hits to Head per Season

Concussion Risk R(a) = Collegiate Incidence Rate Curve



(Rowson & Duma, 2011)

Physical and Environmental Effects on Rate of Concussion

- Greater neck strength and anticipatory cervical muscle activation ("bracing for impact") can reduce the magnitude of the head's kinematic response (Eckner, Oh, Joshi, Richardson, & Ashton-Miller, 2014)

- In the National Football League (NFL) a multivariable generalized linear model controlling for season, week and clustering of team at home and away found that the odds of at least one concussion were reduced by 32% in games played at a higher elevation (Myer et al., 2014)

National Operating Committee on Standards for Athletic Equipment (NOCSAE)

- Severe head injuries were the leading cause of disability and death in football 50 years ago
- Immediately prior to the formation of NOCSAE and implementation of helmet standards (1964-1968), the incidence of serious head injuries was estimated to average 4.25/100,000 players
- During the 2002-2006 seasons the incidence of serious head injury has averaged only 0.51/100,000 players, an 88% drop

(National Operating Committee on Standards for Athletic Equipment, 2014)

Consumer Alert: New York Attorney General Eric Schneiderman

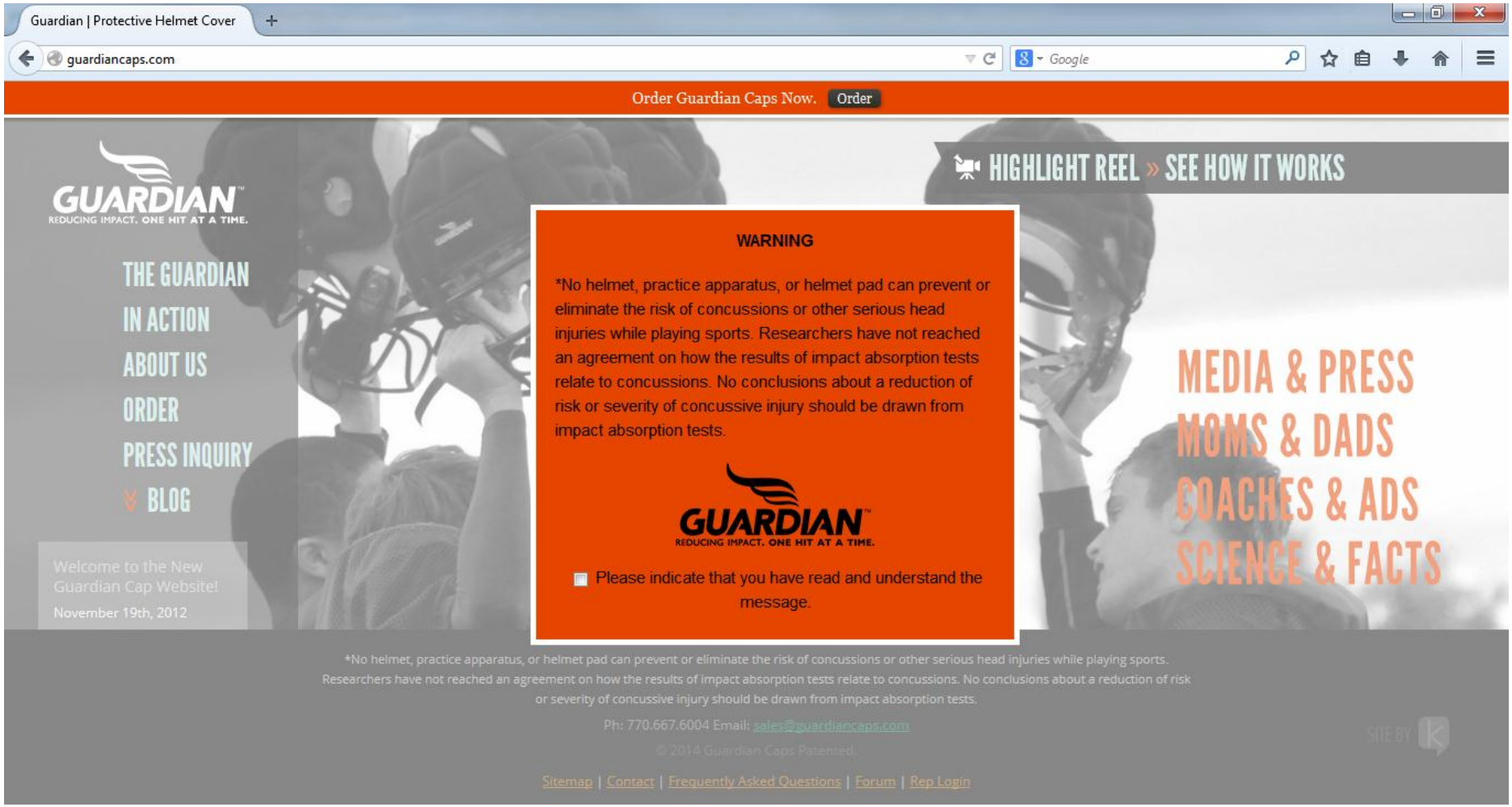
- Marketing boasts about “concussion-proof” or “anti-concussive” helmets are often misleading and can give young players and their parents a false sense of security when they step on to the gridiron. “It’s important to remember that no helmet can fully prevent a concussion,” he said.

- Schneiderman also sounded the alarm about helmet add-ons, such as extra liners and pads, noting there is little research to demonstrate the effectiveness of those products, especially for younger players.

(Bain, 2013)

Helmet manufacturers now post clear warnings on their products and on their websites

Guardian Caps



(Guardian, 2014)

Riddell: Small Insert on Side of Advertisement

Riddell 360 Helmet - Helmets ...

www.riddell.com/shop/on-field-equipment/helmets/riddell-360-helmet.html

WARNING & WARRANTY INFORMATION

NO HELMET CAN PREVENT SERIOUS HEAD OR NECK INJURIES A PLAYER MIGHT RECEIVE WHILE PARTICIPATING IN FOOTBALL.

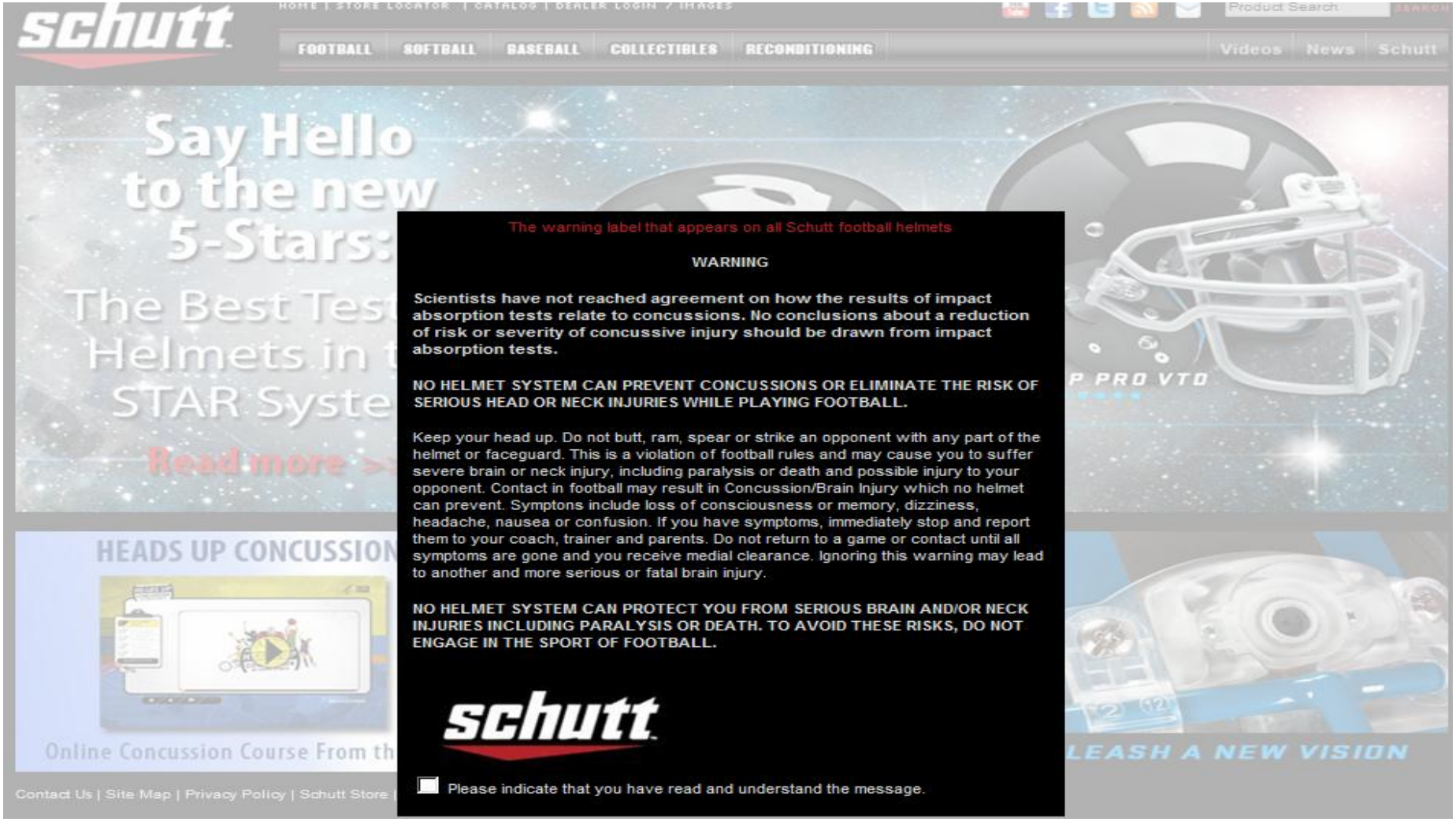
Do not use this helmet to butt, ram or spear an opposing player. This is in violation of the football rules and such use can result in severe head or neck injuries, paralysis or death to you and possible injury to your opponent. Contact in football may result in CONCUSSION-BRAIN INJURY which no helmet can prevent. Symptoms include: loss of consciousness or memory, dizziness, headache, nausea or confusion. If you have symptoms, immediately stop playing and report them to your coach, trainer and parents. Do not return to a game or practice until all symptoms are gone and you have received medical clearance. Ignoring this warning may lead to another and more serious or fatal brain injury.

The warranty on helmet shells is five (5) years for polycarbonate (Varsity) helmets and three (3) years for ABS (Youth) helmets, provided there has been normal use and proper maintenance. It is recommended that your helmet be reconditioned every year by a Riddell Factory Authorized Reconditioner. Proper maintenance requires reconditioning of your helmet at least every two (2) years by NOCSAE Licensed Reconditioner using only new factory replacement liners in the reconditioning process. Evidence of any of the following conditions will operate to void this warranty:

1) Failure to have the helmet reconditioned at least every two (2) years by a NOCSAE Licensed Reconditioner.
2) Installation of non-OEM parts whenever a liner replacement is necessary.
3) Where shells have been damaged by a chemical reaction from the use of incompatible materials such as:
a. Attachment of a guard, face mask or component of another manufacturer or mismated material.
b. Use of cleaners, waxes or paints of another manufacturer or failure to follow recommended cleaning an painting instructions.

(Riddell, 2014)

Schutt: Warning Appears When You Click on Web Page



(Schutt, 2014)

Consensus of Sports Medicine Experts

- Team Physicians' Consensus Statement on Concussion and the National Federation of State High School Associations. There is no football helmet, or mouth guard for that matter, that can prevent a concussion. Helmets have been designed to prevent skull fractures, cerebral bleeding, and other head trauma. Mouth guards have been developed to protect teeth and against oral injuries.

- American Medical Society for Sports Medicine Position Statement: Concussion in Sport. Helmets are best suited to prevent impact injuries such as fractures, bleeding and lacerations, but have not been shown to reduce the incidence and severity of concussions.

- American Academy of Neurology Summary of evidence-based guideline update: Evaluation and management of concussion in sports. Data are insufficient to support or refute the superiority of one type of football helmet in the prevention of concussions.

- Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. There is no good clinical evidence that currently available protective equipment will prevent concussion, although mouth guards have a definite role in preventing dental and orofacial injury. Biomechanical studies have shown a reduction in impact forces to the brain with the use of head gear and helmets, but these findings have not been translated to show a reduction in concussion incidence.

(West & Marion, 2014)

The STAR Rating System for Football Helmets

STAR = Summation of Tests for the Analysis of Risk

$$STAR = \sum_{L=1}^{4}\left(\sum_{H=1}^{6} E(L,H) \bullet R(a)\right)$$

Using NOCSAE style tests with the following nomenclature:

L = helmet location, four total: front, top, side (combined), and rear

H = drop height, six total: 60”, 48”, 36”, 24”, 12”, and lowest

E = exposure (function of drop height), number of impacts at that drop height for that location a player may experience in one year

R = Concussion injury risk (function of peak acceleration)

a = peak resultant acceleration

(Rowson & Duma, 2011)

Can Improved Helmet Design Reduce the Risk of Concussion?

- Retrospective analysis of head impact data collected from 1,833 collegiate football players who were instrumented with helmet-mounted accelerometer arrays for games and practices
  - Concussion rates were compared between players wearing Riddell VSR4 and Riddell Revolution helmets while controlling for the head impact exposure of each player
  - A total of 1,281,444 head impacts were recorded, from which 64 concussions were diagnosed
- Data collected at Virginia Tech, University of North Carolina, University of Oklahoma, Dartmouth College, Brown University, University of Minnesota, Indiana University and University of Illinois
- When controlling for each player's exposure to head impact, a significant difference was found between concussion rates for players in VSR4 and Revolution helmets ($\chi(2) = 4.68$, $p = 0.0305$), suggesting that concussion risk is reduced with the Riddell Revolution helmet

(Rowson et al., 2014)

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Presenter: Kristy Arbogast, Ph.D.

Kristy Arbogast, Ph.D.

- Director of engineering, Center for Injury Research and Prevention, The Children's Hospital of Philadelphia
- Research associate professor of pediatrics, University of Pennsylvania
- Holds a Ph.D. in bioengineering with a focus on brain injury mechanics
- Internationally recognized expert on pediatric injury biomechanics, injury causation and the effectiveness of safety products for children
- Served on the Institute of Medicine Committee on Sports Concussion in Youth
- Led Children's Hospital effort to standardize clinical care of concussion throughout the Hospital's health care network
- Co-directed the National Science Foundation-sponsored Center for Child Injury Prevention Studies, an Industry-University Cooperative Research Center focused on the advancement of safety for children, youth and young adults by facilitating scientific inquiry into childhood and young adult injuries and to translate these findings into commercial applications and public education programs for preventing future injuries

Head Injury Prevention: Scientific Foundation

Kristy Arbogast, Ph.D.

The Children's Hospital of Philadelphia®
RESEARCH INSTITUTE
CENTER FOR INJURY RESEARCH AND PREVENTION

Perelman School of Medicine
University of Pennsylvania

Disclosure

- The views expressed in this presentation are those of the presenter and do not reflect the official policy of The Children's Hospital of Philadelphia, University of Pennsylvania, the Defense Department (DoD) or the U.S. Government.
- The presenter does not intend to discuss the off-label/ investigative (unapproved) use of commercial products or devices.
- Dr. Arbogast discloses these relationships:
  - Advisory boards: National Youth Council on Sports Safety
  - Consultant: National Football League Players Association

Concussion

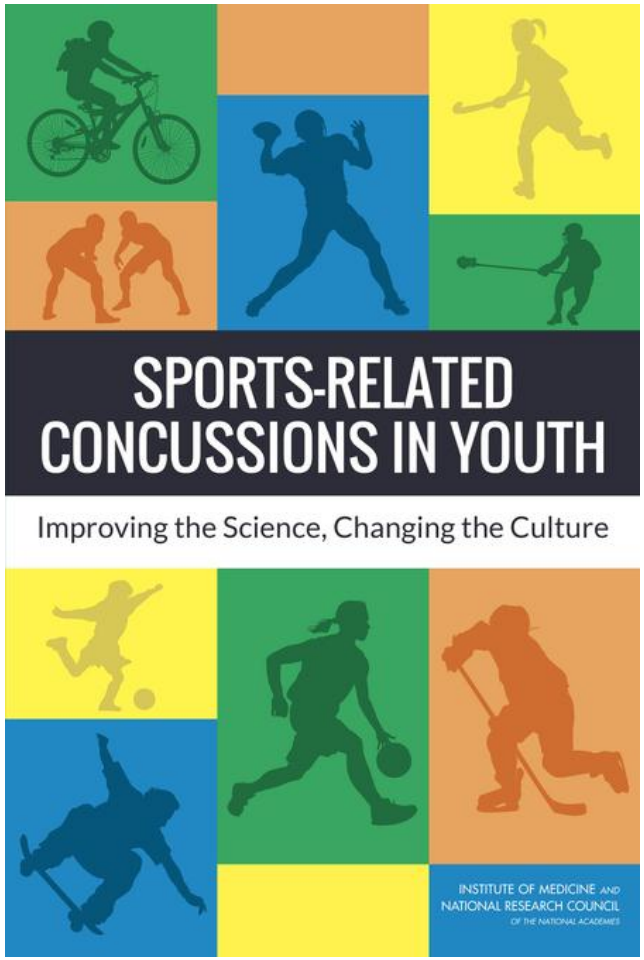
- A concussion occurs when the brain decelerates – rotational component of the acceleration is important
- Concussion is a functional injury not a structural injury

Concussion Myths

- Requires blow to head (brain deceleration is required)
- Always results in loss of consciousness (LOC) (only about 10% get LOC)
- Mild traumatic brain injury (mTBI) means mild consequences (mild describes acute threat to life)
- You can tell how bad a concussion is from the very beginning

National Attention to the Issue

- Institute of Medicine (IOM) Report released October 2013
- Review literature on concussions in youth related to:
  - The causes and consequences of concussions
  - The current state of the art on diagnosis and management
  - The effectiveness of protective equipment and sports regulations for prevention of injury
- Recommend actions
  - Schools, parents, medical providers, funding agencies, legislatures

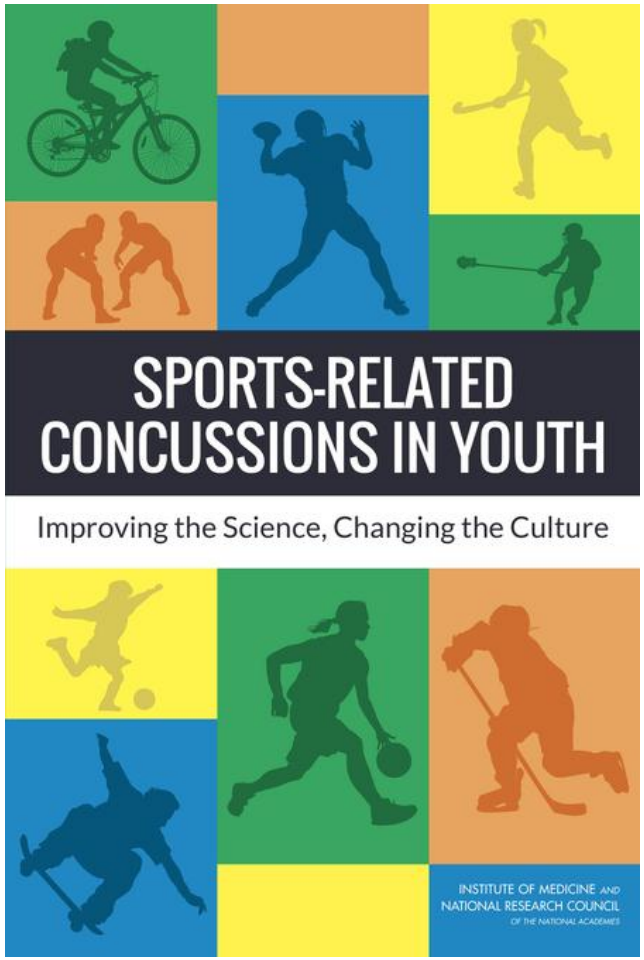


(Institute of Medicine and National Research Council, 2014)

INSTITUTE OF MEDICINE *AND* NATIONAL RESEARCH COUNCIL *OF THE NATIONAL ACADEMIES*

National Attention to the Issue

- Key recommendation with respect to prevention
  - National Institutes of Health and DoD should fund research on age- and sex-related biomechanical determinants of injury risk for concussion in youth, including how injury thresholds are modified by the number of and time interval between head impacts and concussions



(Institute of Medicine and National Research Council, 2014)

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Helmets and Protective Devices: Barrage of Conflicting Information in the Lay Press

Concussion Prevention: Pass on Pricey Football Helmets, Study Suggests

Can Headgear Halt Soccer Concussions?

Alex Ovechkin Advances Player Safety With New Concussion-Preventing Helmet

NFL Concussion Prevention: Could New Helmet Save Football?

Football Helmet Shells May Prevent Concussions

Girl soccer players turn to head gear to curb concussions, but does it work?

The Best Concussion-Proof Helmets

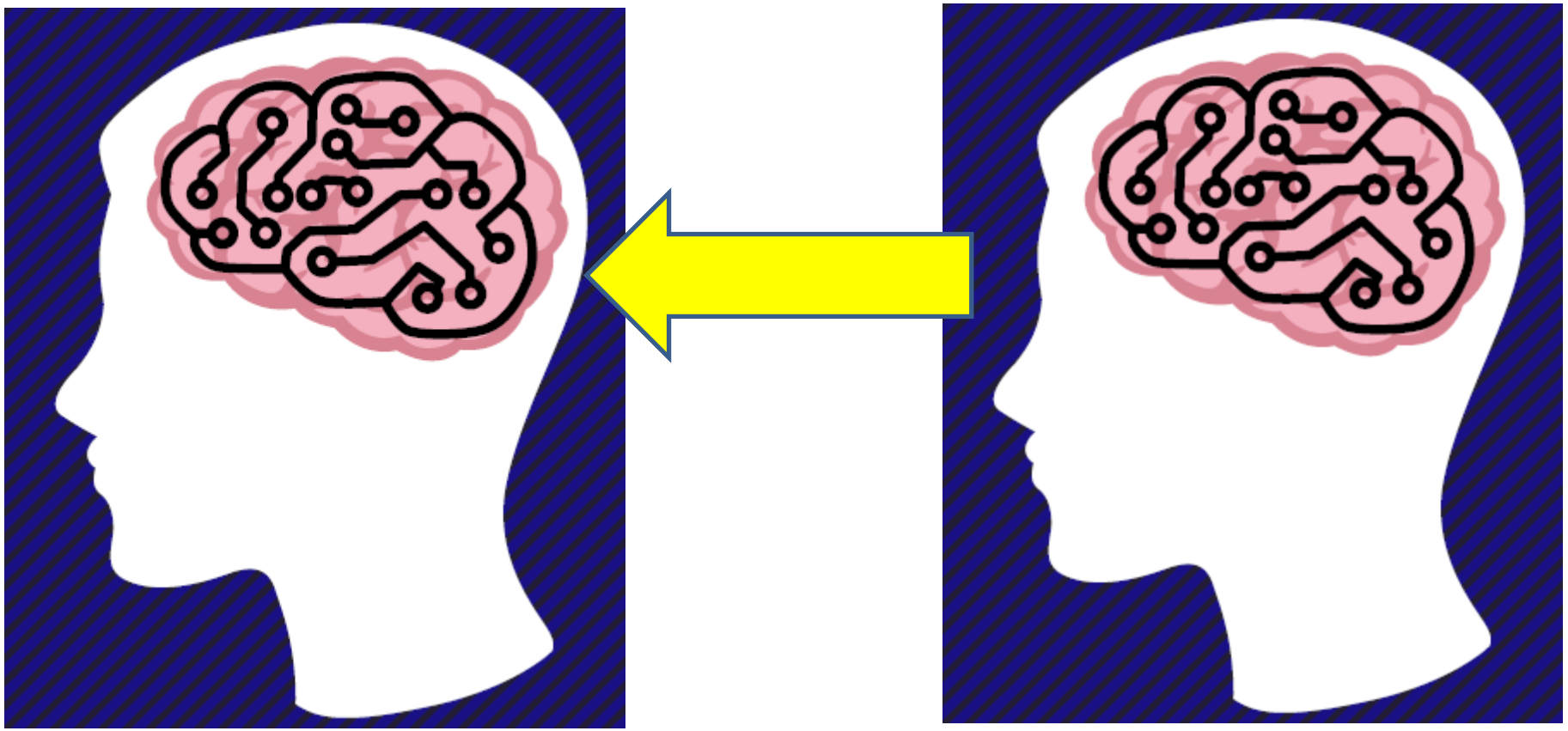
Football helmet design can lower concussion risk, study finds

Helmets, mouthguards: Is there 'concussion-proof' equipment for fall sports?

Fundamental Questions to Answer to Fuel Advances in Prevention

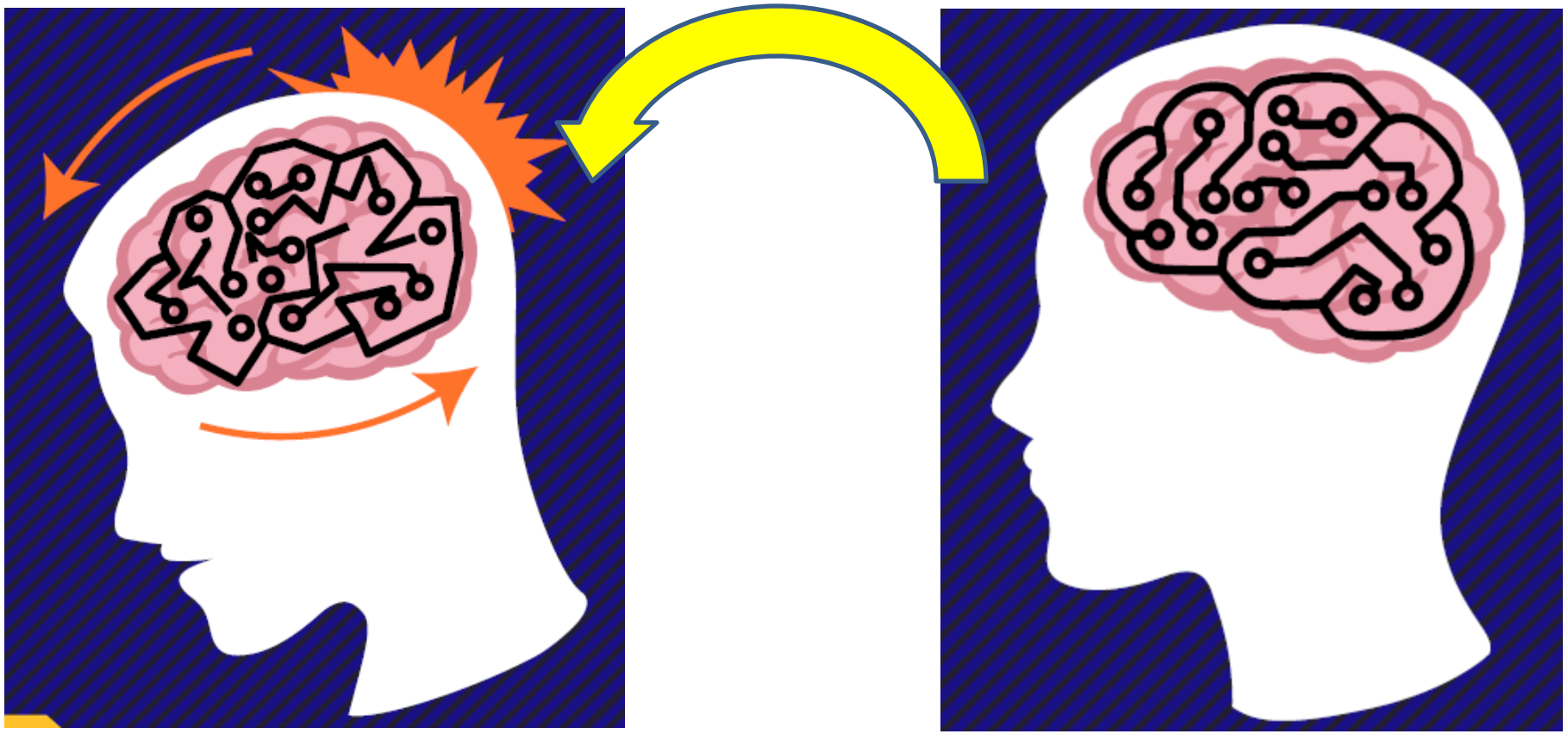
- What is the clinical entity that is a mTBI?
  - Objective, age-specific markers and metrics for diagnosis and monitoring of recovery
- What is the mechanical event that leads to mTBI?
  - Quantifying the biomechanics at a global head kinematic level and a brain tissue level

Linear Movement



(Adapted from The Children's Hospital of Philadelphia, 2014)

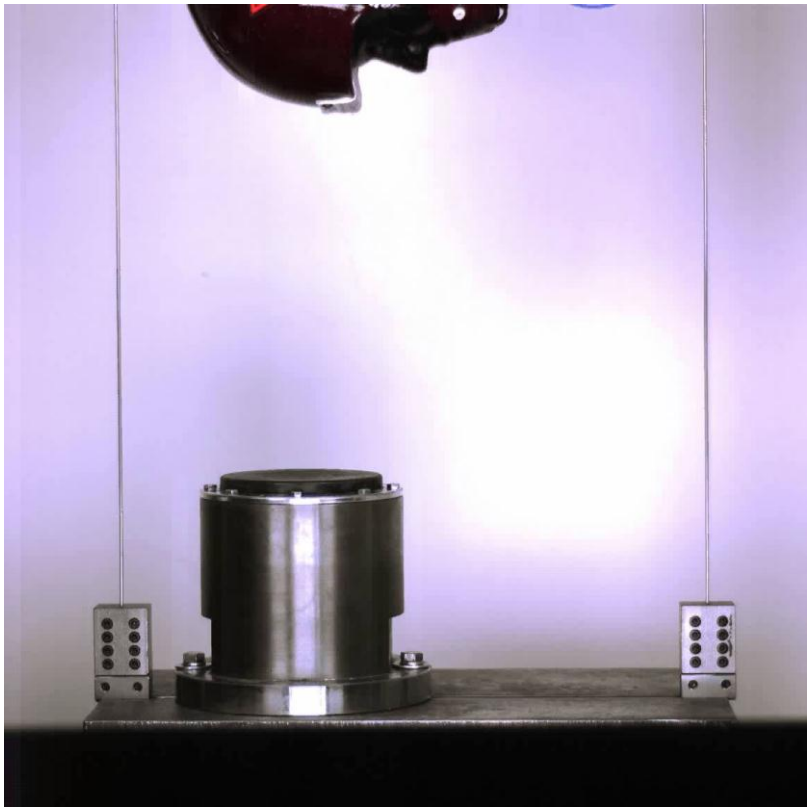
Rotational Movement



(Adapted from The Children's Hospital of Philadelphia, 2014)

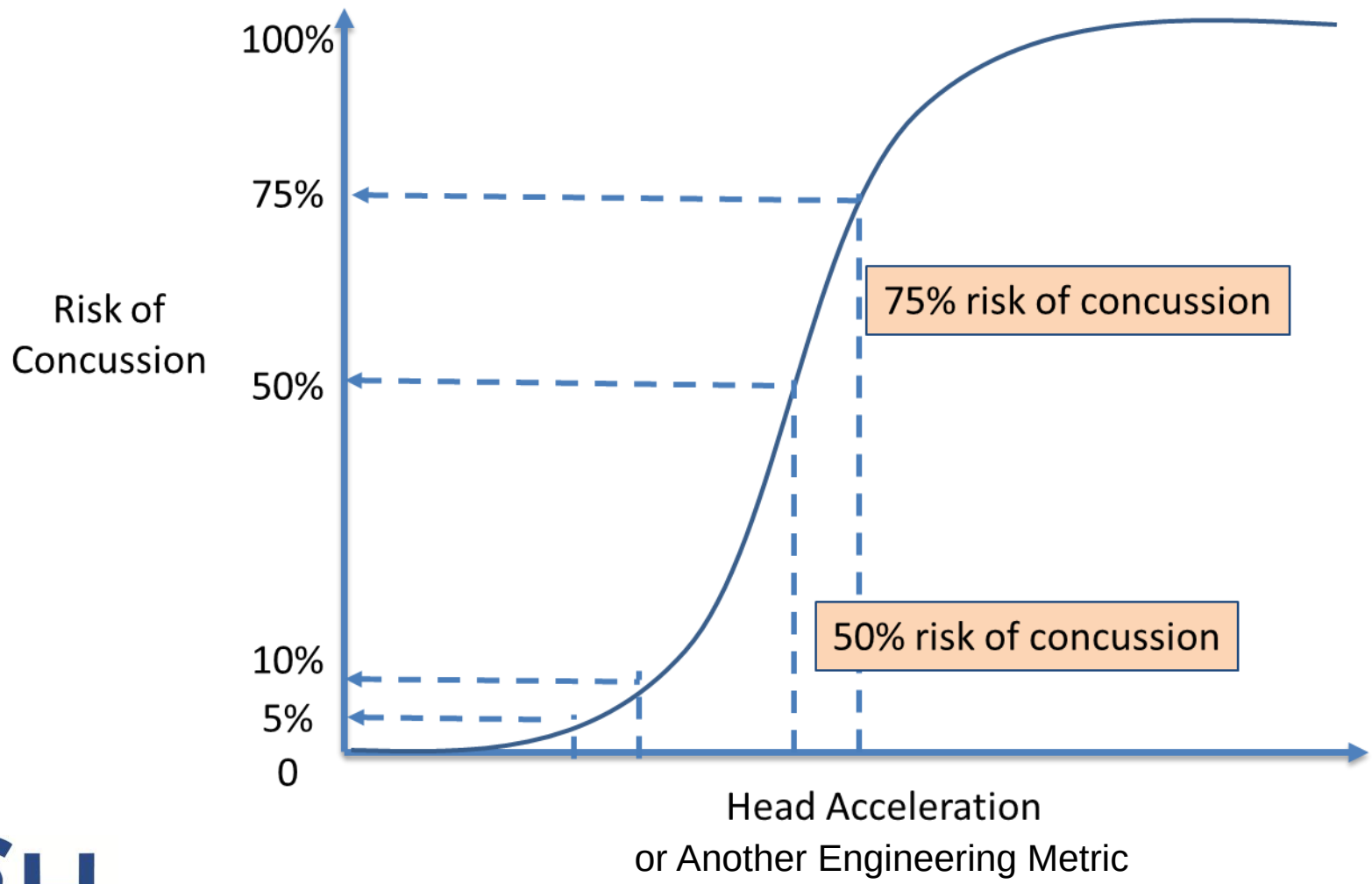
What Do We Know About Helmets?

- Originally designed to prevent skull fractures and more serious TBI
- Primarily designed and tested to reduce linear acceleration
- On-field impacts combine linear and rotational acceleration
- Current test standards do not incorporate both linear and rotational acceleration
  - Do not comprehensively evaluate a device's ability to mitigate concussion
- Some new designs are focusing on reducing rotational acceleration

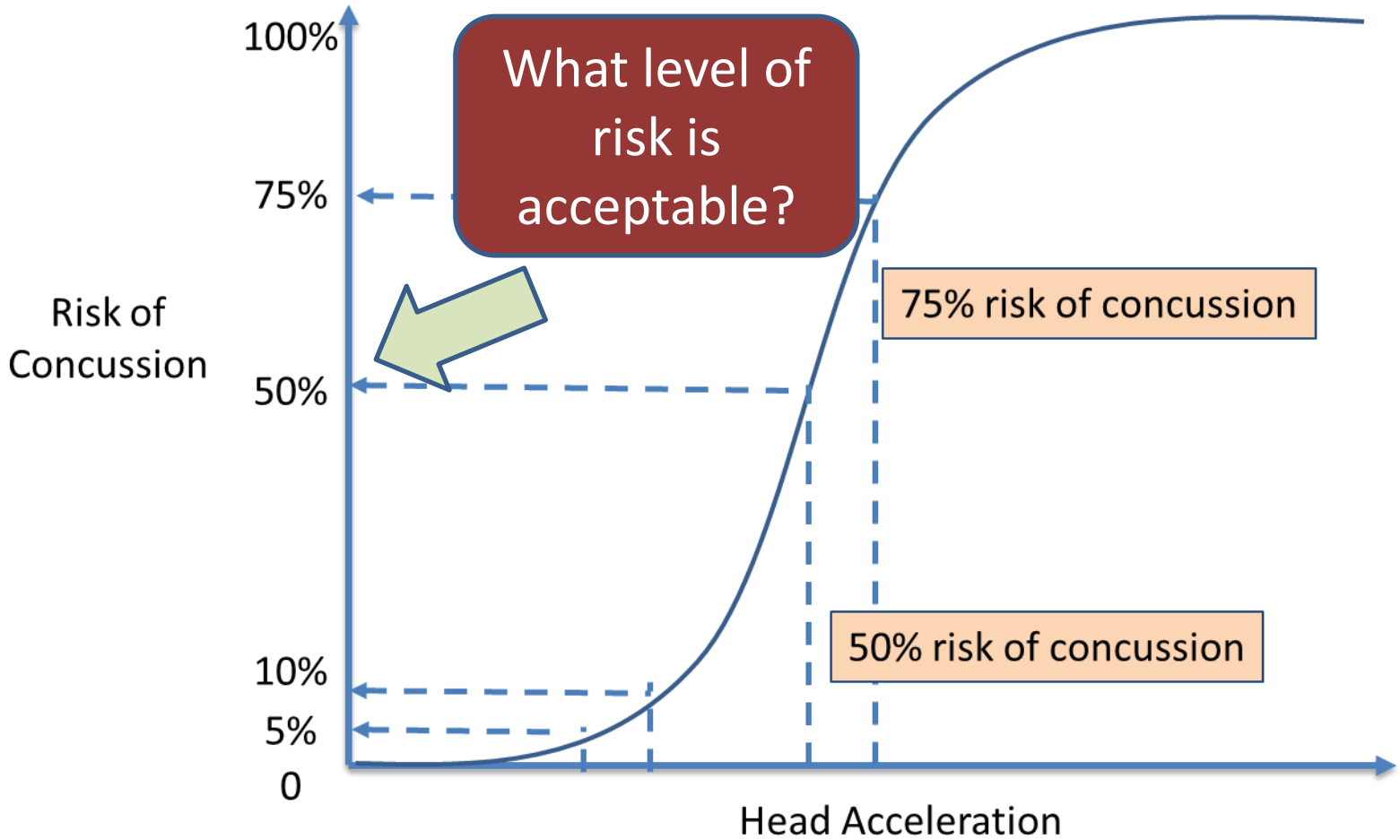


Video courtesy of S. Rowson, VT

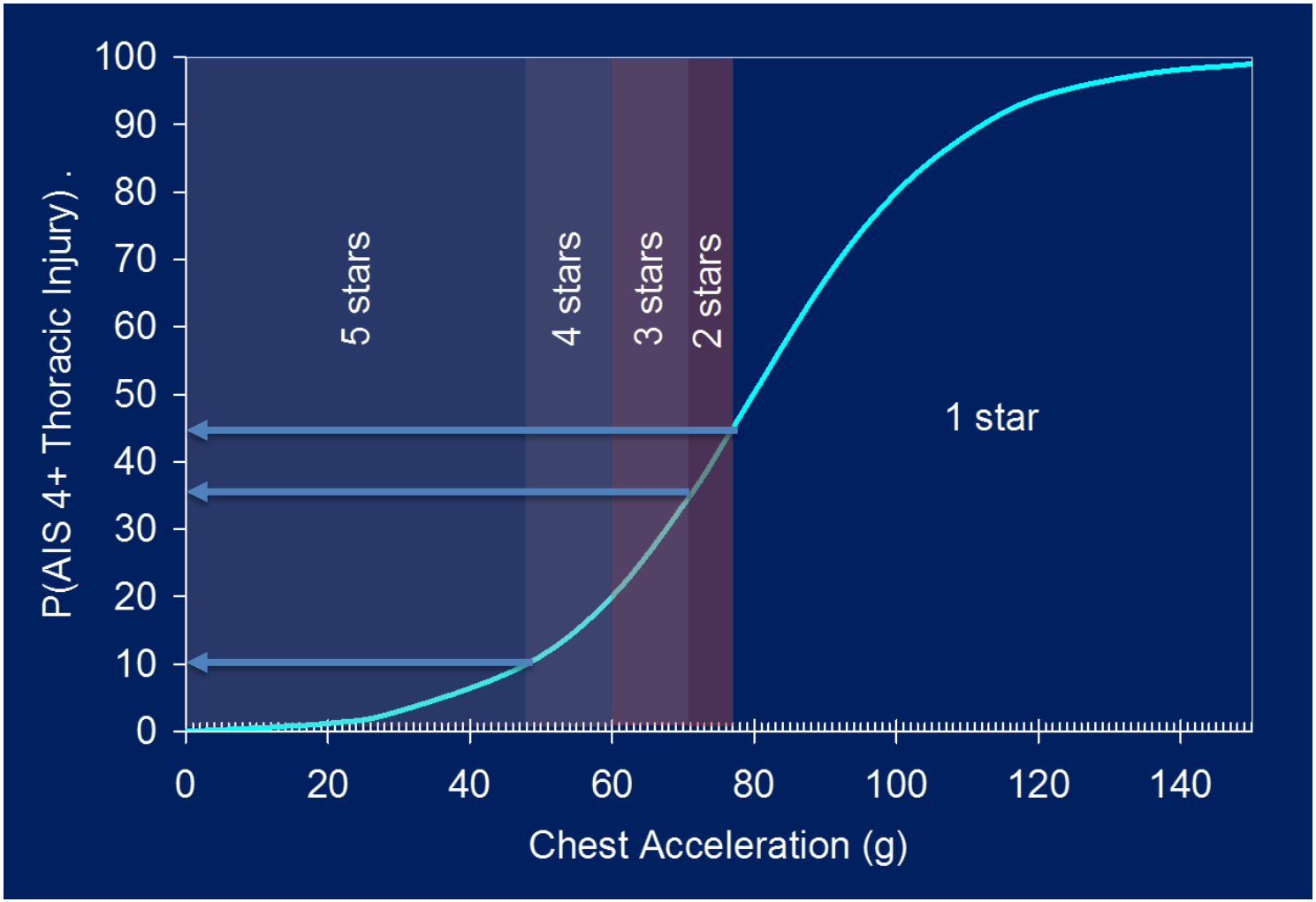
Injury Risk


100%
75%
50%
10%
5%
0
Risk of Concussion
75% risk of concussion
50% risk of concussion
Head Acceleration
or Another Engineering Metric

Injury Risk: Prevention versus Mitigation

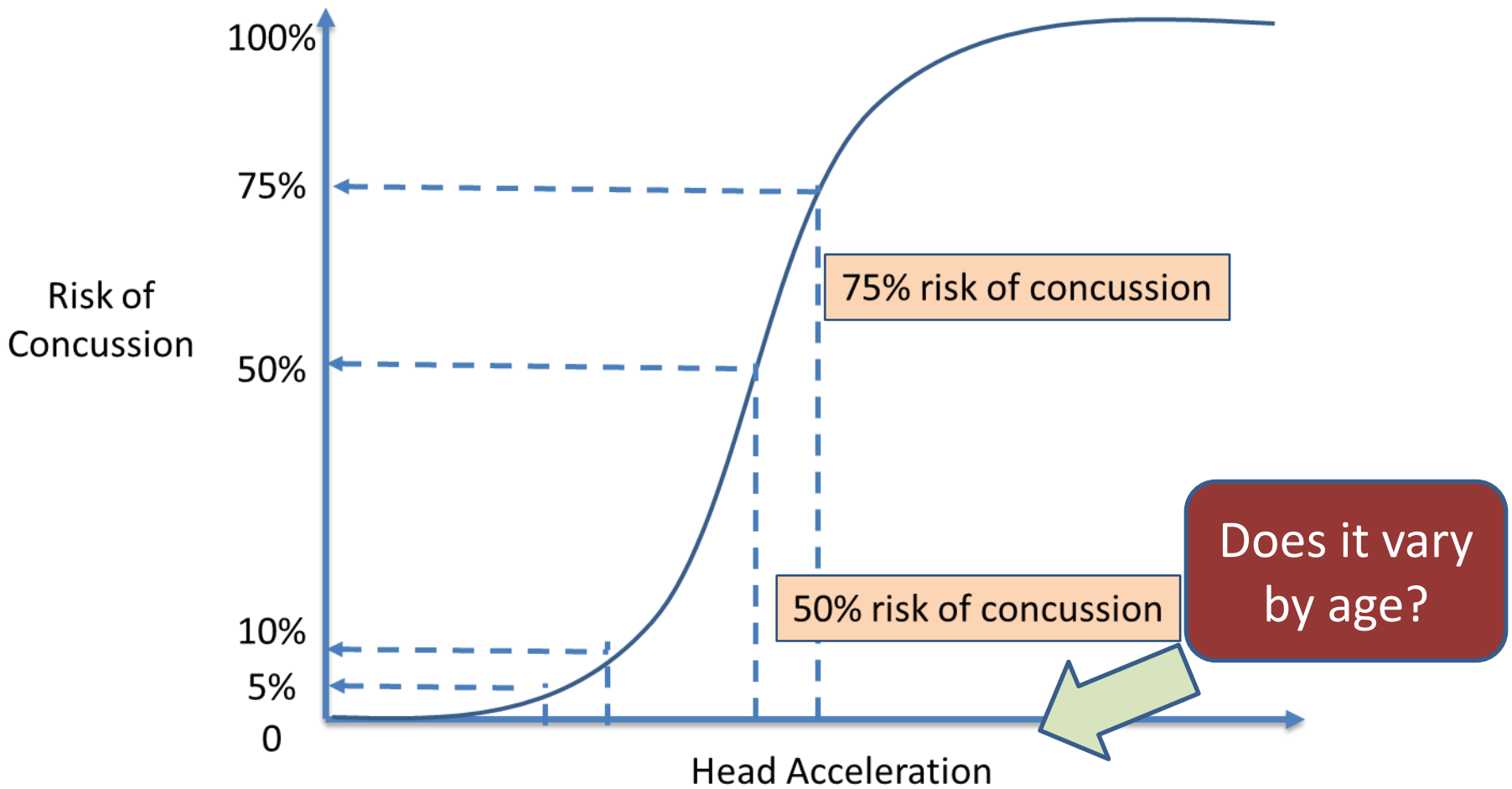


Injury Risk in Auto Safety Acceptable Risk?



(Kent & Patrie, 2003)

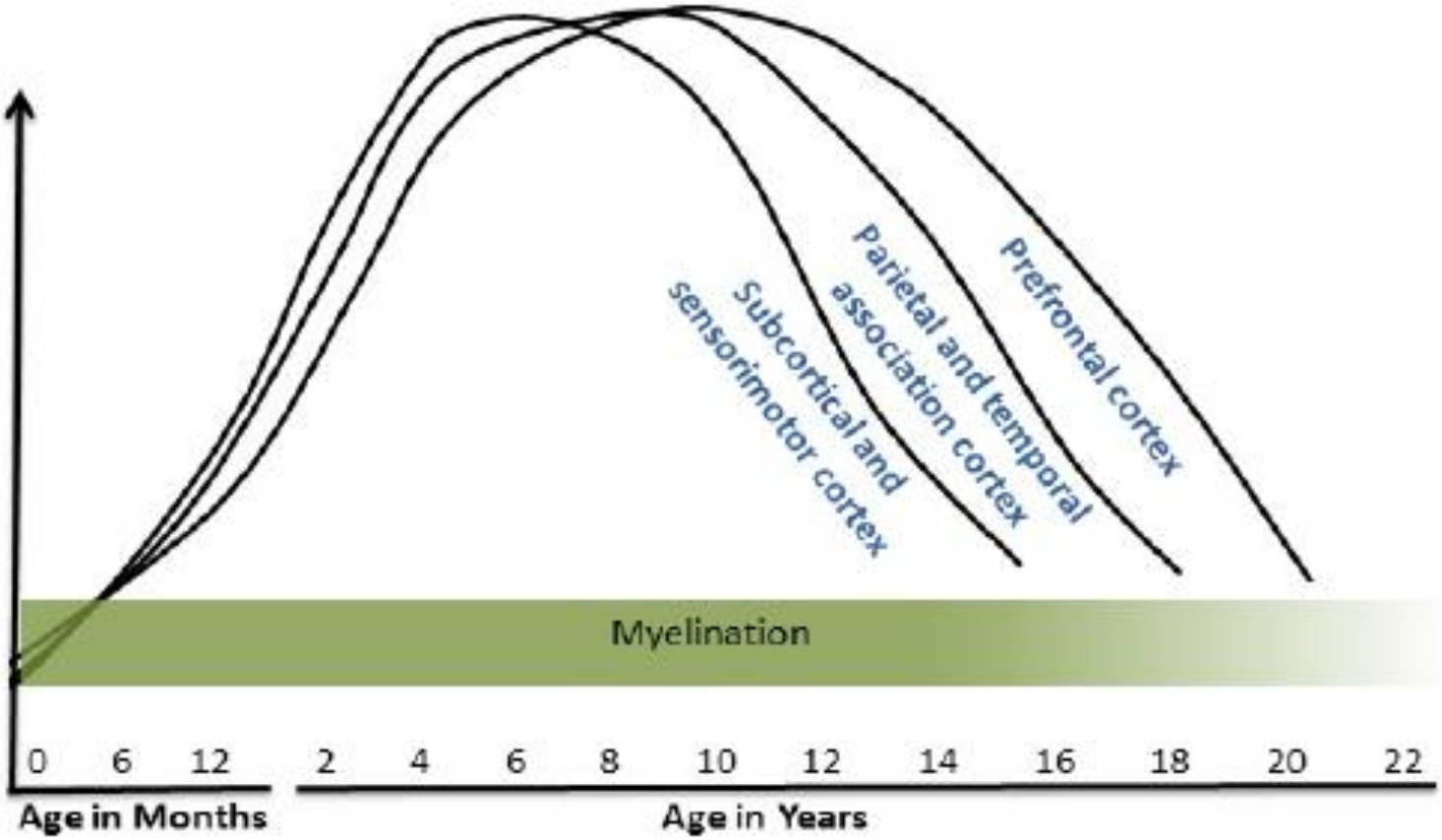
Injury Risk


100%
75%
50%
10%
5%
0
Risk of Concussion
75% risk of concussion
50% risk of concussion
Does it vary by age?
Head Acceleration

Pathophysiology of Concussion

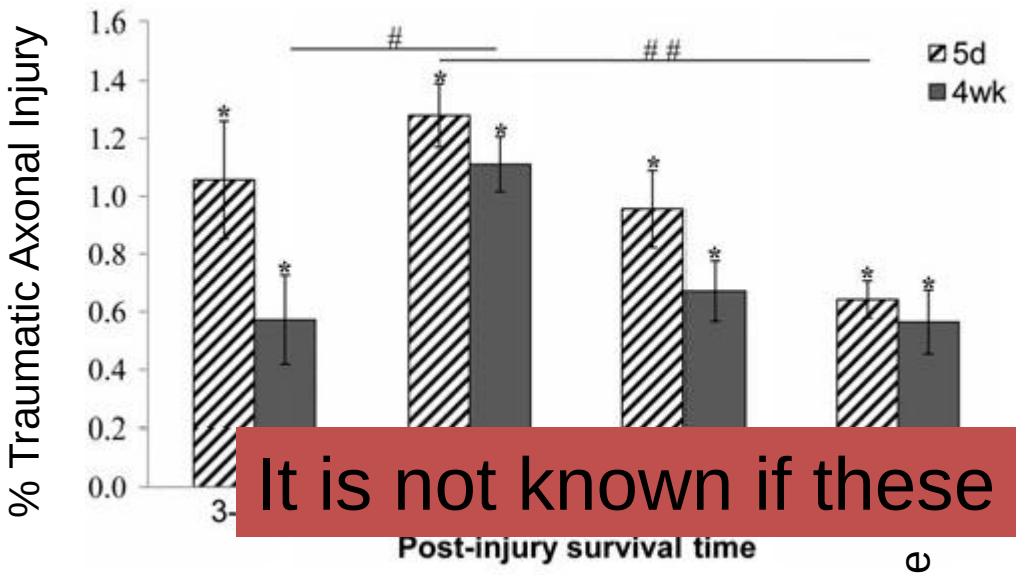
- After injury, metabolic needs of the cell, including glucose requirements, increase
  - Cerebral blood flow reduced
- Deficits in synaptic transmission, signaling pathways, membrane permeability
- Functional not structural changes

Brain Development
Regional Time Course of Synaptic Formation, Cerebral Blood Flow and Metabolic Changes



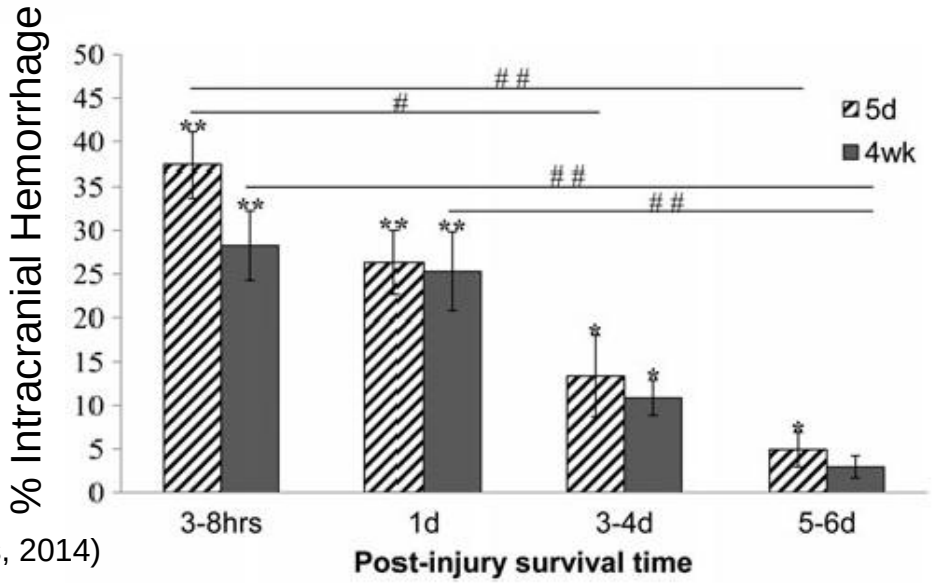
(Institute of Medicine and National Research Council, 2014)

Age Dependency in Brain Injury Tolerance (Moderate to Severe TBI)



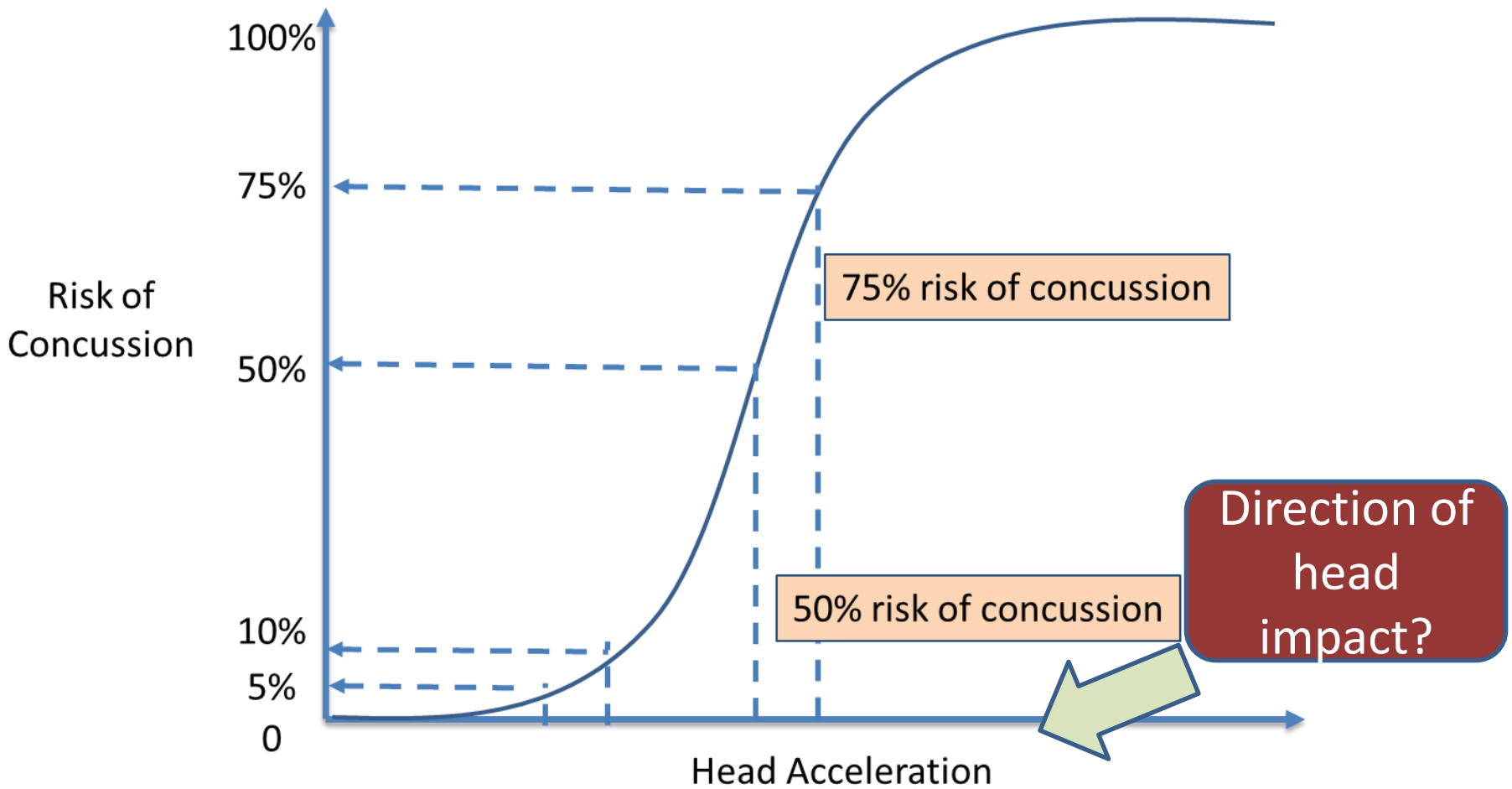
- Porcine model
- Single, rapid non-impact rotational injury

It is not known if these findings apply to mTBI

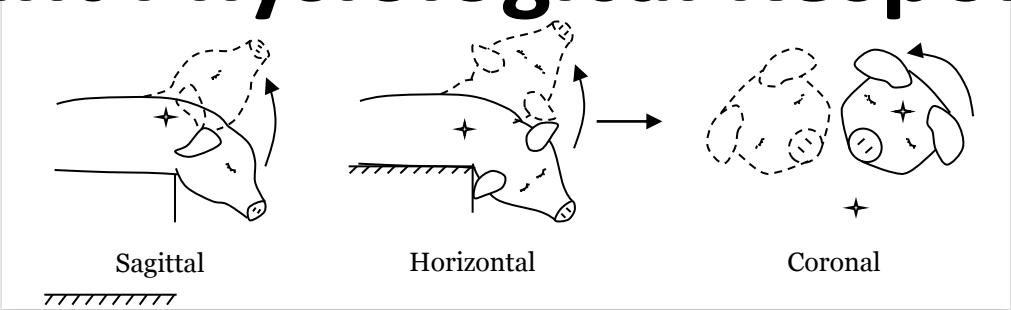


(Weeks, Sullivan, Kilbaugh, Smith, & Margulies, 2014)

Injury Risk


100%
75%
50%
10%
5%
0
Risk of Concussion
75% risk of concussion
50% risk of concussion
Direction of head impact?
Head Acceleration

Head Rotation Direction Matters Infant Physiological Response



Group	n	Unconsciousness time (min, ± SEM)	% Apneic
SHAM	4	1.7 ± 0.8	0
HORIZ-High	9	7.1 ± 1.8*	67*
CORONAL	7	3.7 ± 1.1	14
SAGITTAL	6	11.0 ± 1.9*	100*
HORIZ-Low	7	8.9 ± 1.3*	0

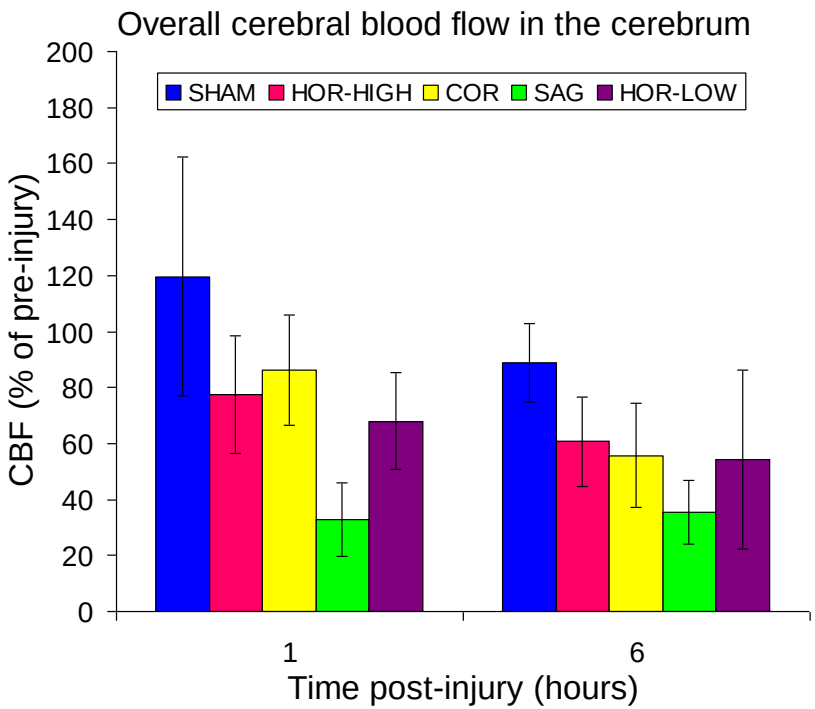
*significantly higher than SHAM

Sagittal rotation produced the worst incidence of apnea and longest unconsciousness time

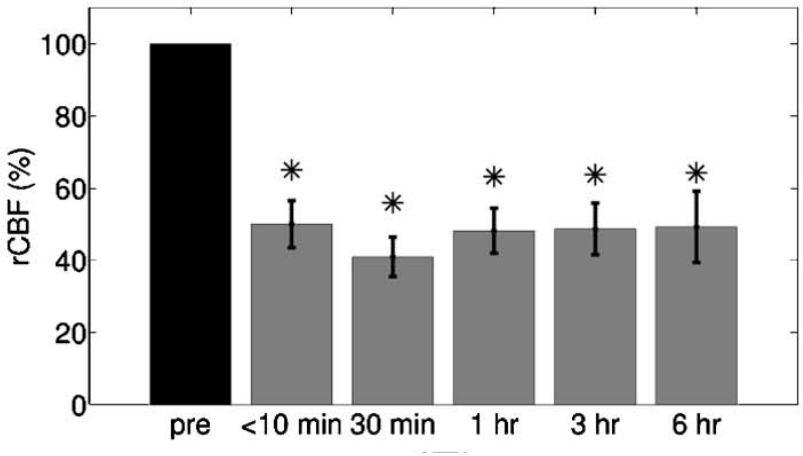
(Eucker, Smith, Ralston, Friess, & Margulies, 2011)

Sagittal Rotation – Cerebral Blood Flow is Reduced Rapidly and Sustained

- Sagittal rotation produced the greatest reductions in cerebral blood flow



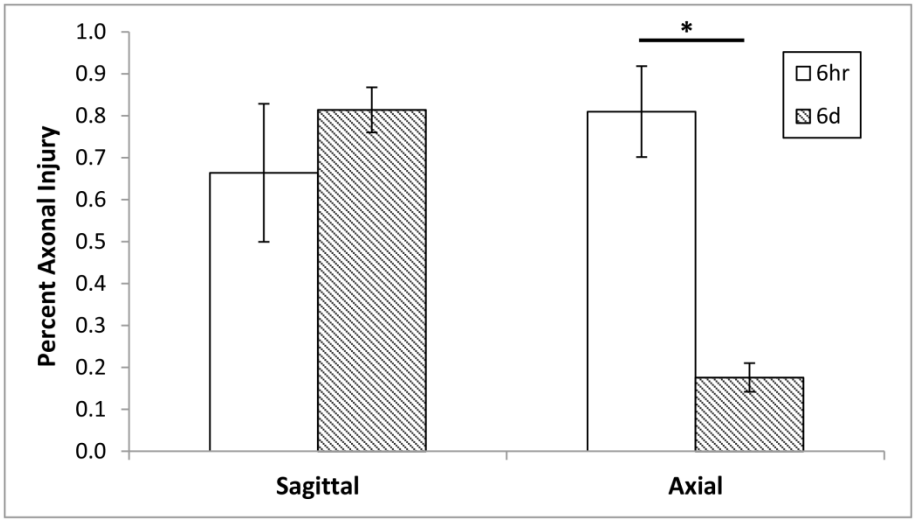
(Eucker, Smith, Ralston, Friess, & Margulies, 2011)



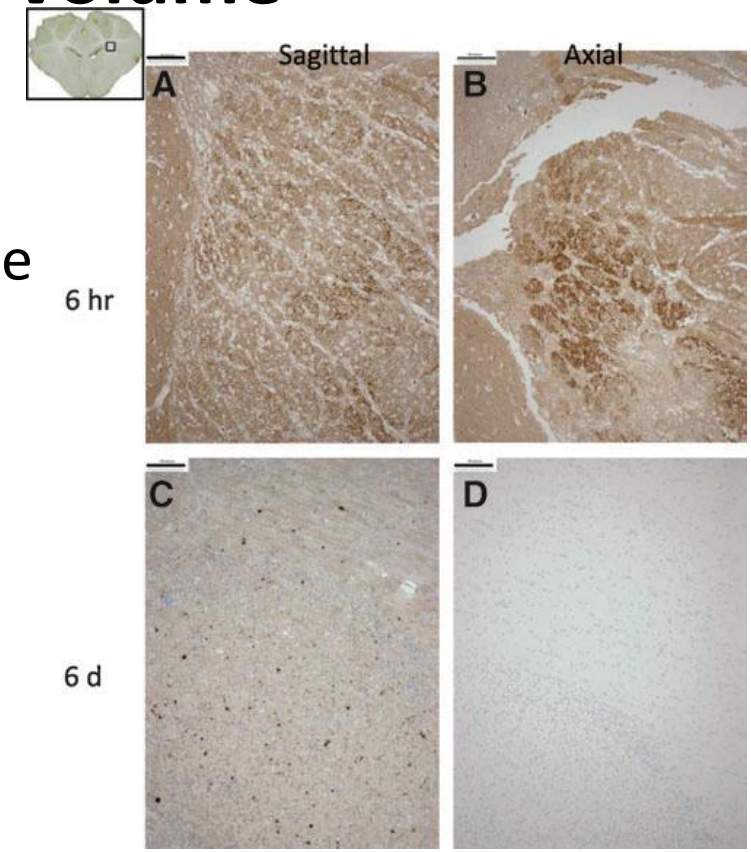
(Zhou et al., 2009)

Sagittal Rotations Produce Persistent Axonal Injury and Significant Functional Deficits With <1% Injury Volume

- 3-5 day old piglets
- Axonal injury is more persistent in sagittal plane injuries than axial plane injuries.



Percent axonal injury (AI) for each plane of rotation at different time points. Mean and standard error shown. Axial 6 h to 6 days $p < 0.001$.

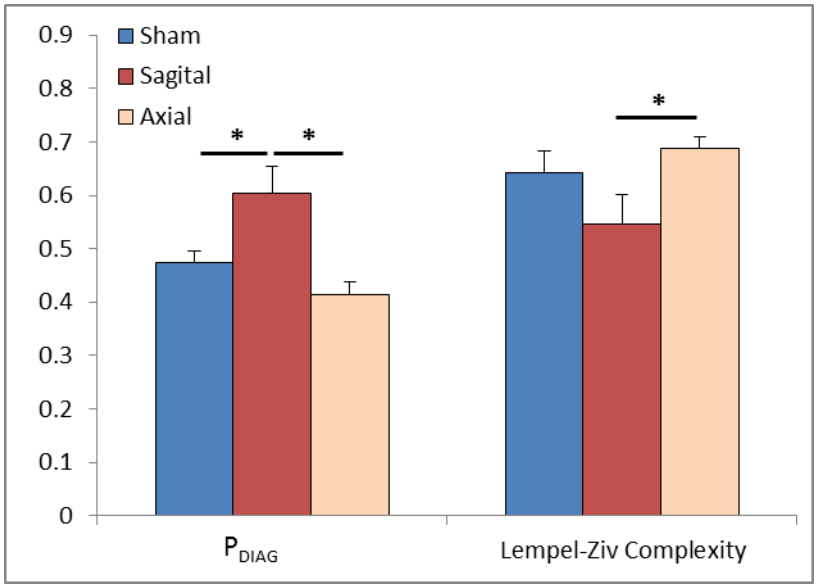


Composite image of representative b-amyloid precursor protein immunostaining from four different animals, but taken from the same region for direct comparison (area outlined in inset, upper left). Bar = 100 um.

(Weeks, Sullivan, Kilbaugh, Smith, & Margulies, 2014)

Direction Matters: Comparison of Locomotion Across Injury Planes

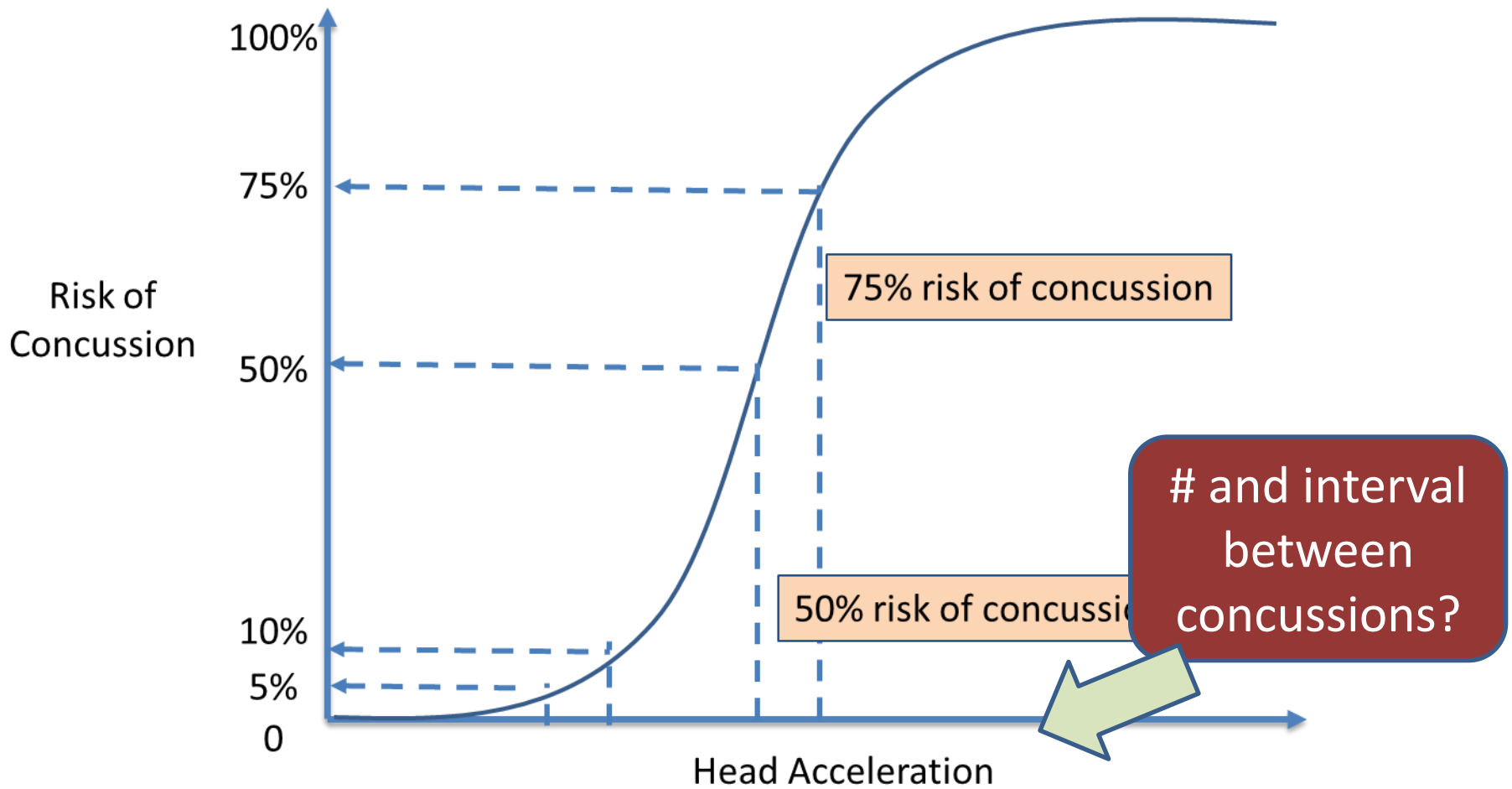
- 3-5 day old piglets
  - N=8 sagittal plane injury
  - N=13 axial plane injury
  - N=19 uninjured sham
- Sagittal plane injured animals were more stationary in the open field than axial plane injured animals and shams
- Sagittal plane injured animals had less complex motion patterns in the open field than axial plane injured animals



Locomotion at Day + 1 post-injury for different rotational planes of injury. Mean and standard error shown.
P_{DIAG} sagittal to sham $p = 0.01$. P_{DIAG} sagittal to axial $p < 0.001$.
Complexity sagittal to sham $p = 0.08$. Complexity sagittal to axial $p = 0.0125$.

(Sullivan et al., 2013)

Injury Risk


100%
75%
50%
10%
5%
0
Risk of Concussion
75% risk of concussion
50% risk of concussi
and interval between concussions?
Head Acceleration

Risk May Vary With Prior TBI, Time Since TBI and Number of Prior Hits

- Studies of the effect of repetitive head impacts mixed (without symptoms – “sub-concussive”)
  - Some show negative outcomes, some show no effect
- Observations
  - Symptom load increased in those with 2+ concussions
- [illegible] injuries
  - Do frequent head impacts or multiple concussions alter injury threshold?
  - Are two concussions in one season different than two concussions five years apart?
  - Are injury thresholds for tissue that is physiologically compromised lower than normally functioning tissue?

Research is needed at the intersection of biomechanics and physiology

Risk May Vary With Prior TBI, Time Since TBI and Number of Prior Hits *continued*

- Until these risk curves are defined, it is difficult to assess the injury-mitigating ability of:
  - Helmets and other protective equipment
  - Playing surfaces

We don’t know what to ask the protective device to do…

Other Protective Devices

- Soccer and rugby head gear, mouthguards, facemasks
- Do reduce the risk for other injuries (skull fractures; injuries to the eyes, face, mouth and teeth) and their use should be promoted
- Advertisement that these devices reduce concussion risk has no scientific merit

Methods to Determine Injury Risk Curves

- Animal models
- Study of real world injuries with sensors to measure input

Animal Models – Do We Have an Adequate Model for Concussion?

Advantages

- Reproducible mechanical loads
- Known TBI history
- Can measure physiology
- Can quantify injury to axons, neurons, etc.
- Can measure changes in motor, memory, learning and behavioral aptitudes

Limitations

- Difficult to measure changes in mental status without LOC
- Most current models create focal cortical lesions, not diffuse injury
- Most models are adult
- Developing rodent brain not equivalent to the human child

Study of Real World Injury Events

- True intersection of physiology and biomechanics
- Sensors affixed to helmets, mouthpieces, etc.
  - Mechanical data correlated to clinical outcomes
- Must ensure validity of data obtained from sensors
  - Accurate assessment of head motion – errors have been reported of 10-30% (Jadischke, Viano, Dau, King, & McCarthy, 2014; Allison, Kang, Bolte, Maltese, & Arbogast, 2014)
- Must measure both linear and rotational components of head motion
- Need objective systematic clinical measures – combat underreporting
- Challenging to account for variability in impact direction, genetics, previous TBI or impact exposure

Risk Compensation: A Critical Piece of Technology Evaluation

- Athlete feels empowered by the protective device and takes additional safety risks
  - "Increased confidence…", "Ability to play harder…", "Play more aggressively…"
- Example – sensors that light up or signal when a helmet reaches a certain threshold
  - Validity must be evaluated by independent labs
  - Variability in "threshold" with age, genetics, impact direction not accounted for
  - Can lead to false sense of security, increased aggressive play

Fundamental Questions to Answer

- What is the clinical entity that is a mTBI?
  - Objective, age-specific markers and metrics for diagnosis and monitoring of recovery
- What is the mechanical event that leads to mTBI?
  - Quantifying the biomechanics at a global head kinematic level and a brain tissue level

Answers to these questions will lead to advancements in injury prevention

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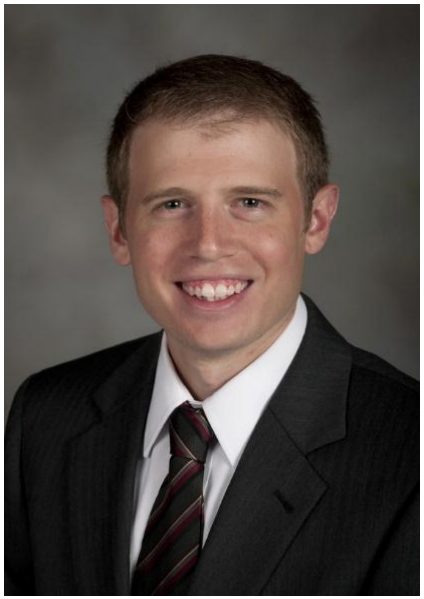
Presenter: Steven Rowson, Ph.D.



Steven Rowson, Ph.D.

- Assistant research professor of biomedical engineering, Virginia Tech
- Research faculty in the Center for Injury Biomechanics, an interdisciplinary research center that combines the Virginia Tech College of Engineering with the Wake Forest University School of Medicine
- Primary research focus is investigating the causation and prevention of concussion
- Has been instrumenting football helmets with accelerometer arrays to collect data that can biomechanically characterize concussions
- Developed the STAR Evaluation System to evaluate the ability of football helmets to reduce the probability of concussion
- STAR Evaluation System resulted in a paradigm shift in the way consumers purchase football helmets as well as how helmets are designed

The Ability of Helmets to Reduce Concussion Risk

Steven Rowson, Ph.D.

Virginia Tech
Wake Forest University
School of Biomedical Engineering and Sciences

VCOM
Edward Via College of Osteopathic Medicine
VIRGINIA CAMPUS

ICTAS

Financial Disclaimer

- No financial interest in SIMBEX, HITS, or **<u>any</u>** other helmet related sensor or product
- No financial interest in Riddell, or **<u>any</u>** helmet manufacturer
- No helmet expert witness consulting
- The views expressed in this presentation are those of the presenter and do not reflect the official policy of the Defense Department or U.S. Government.

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Virginia Tech
Wake Forest University
School of Biomedical Engineering and Sciences

VCOM
Edward Via College of Osteopathic Medicine
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ICTAS

Acceleration-based Brain Injury

- <u>Inertial Loading (everyday case)</u>
  - 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

Images courtesy of Virginia Tech Wake Forest University

Impact response can be tuned to meet design requirements

Helmets can be designed to reduce concussion risk

Football helmets used as an example, but other applications

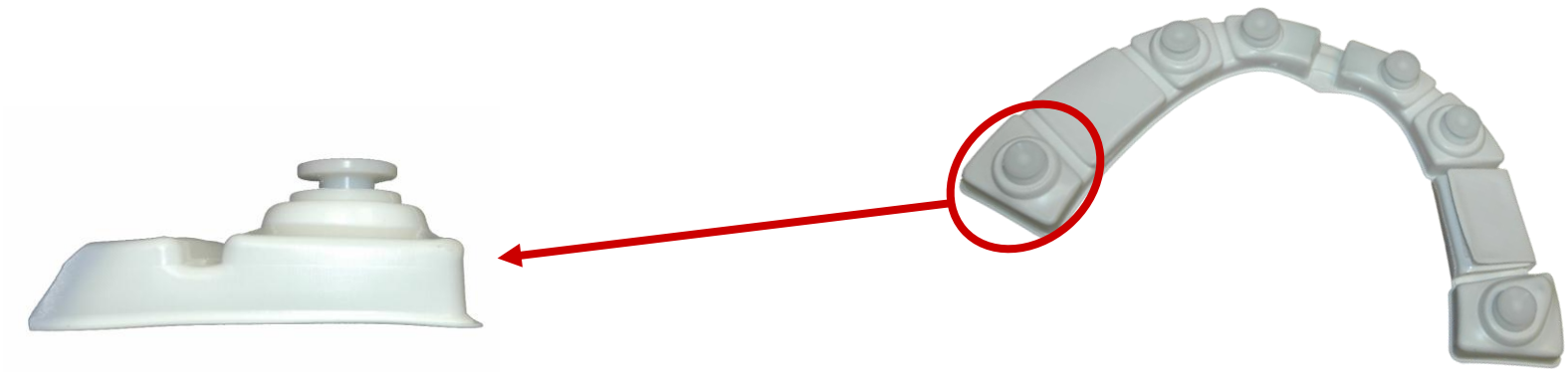
Brain Injuries in Football

- 1.6 to 3.8 million sports-related concussions each year in the U.S.
- Increased occurrence in collegiate sports
  - Football has largest total of any sport
  - "Human volunteers" for onset of concussion
- Instrument and observe a high risk population
- Head acceleration data collected from
  Virginia Tech (VT) football players for over a decade

Photo courtesy of Virginia Tech

HIT System Hardware

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



Images courtesy of Virginia Tech

Head Acceleration Data Collection

- Helmet instrumentation
  - ‘Real-time’ data transfer 1000 Hz sampling frequency
  - Data acquisition triggers when any accelerometer experiences 10 g
  - 40 ms of data collection
  - Each event is time-stamped and compared to video

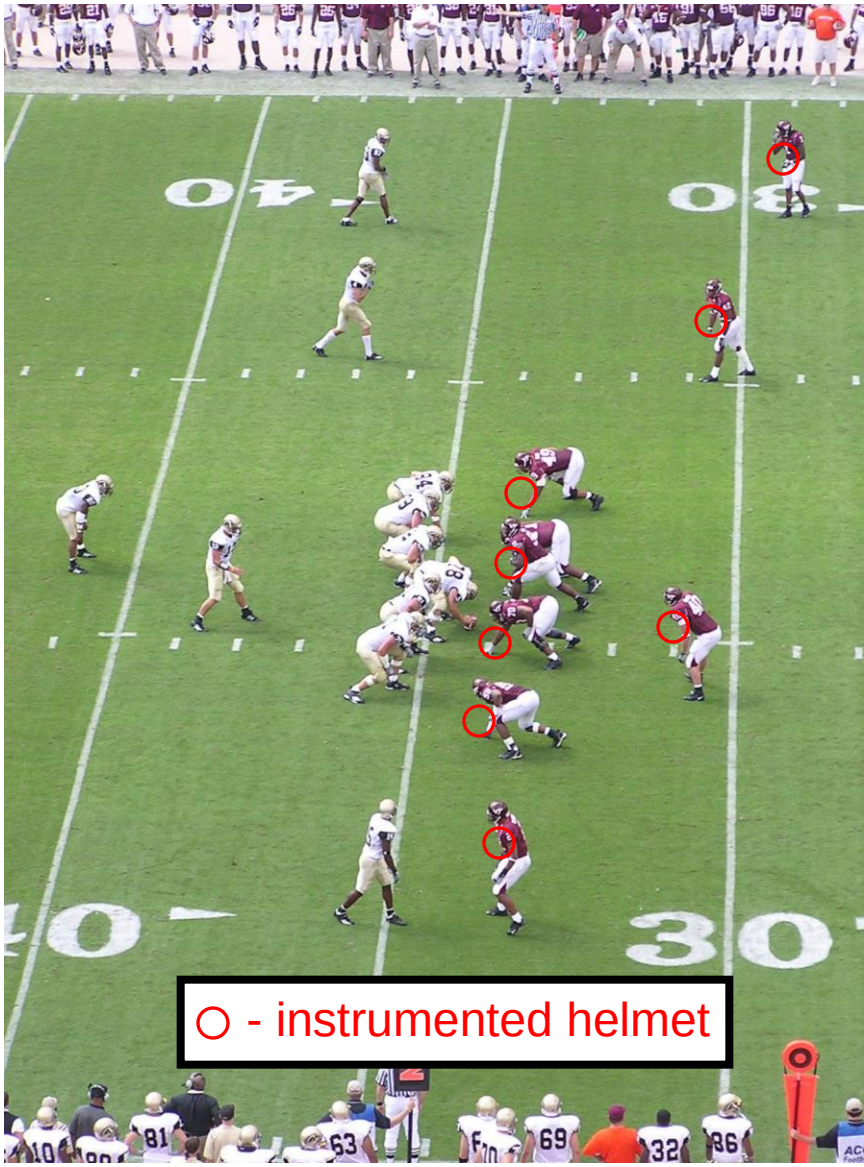
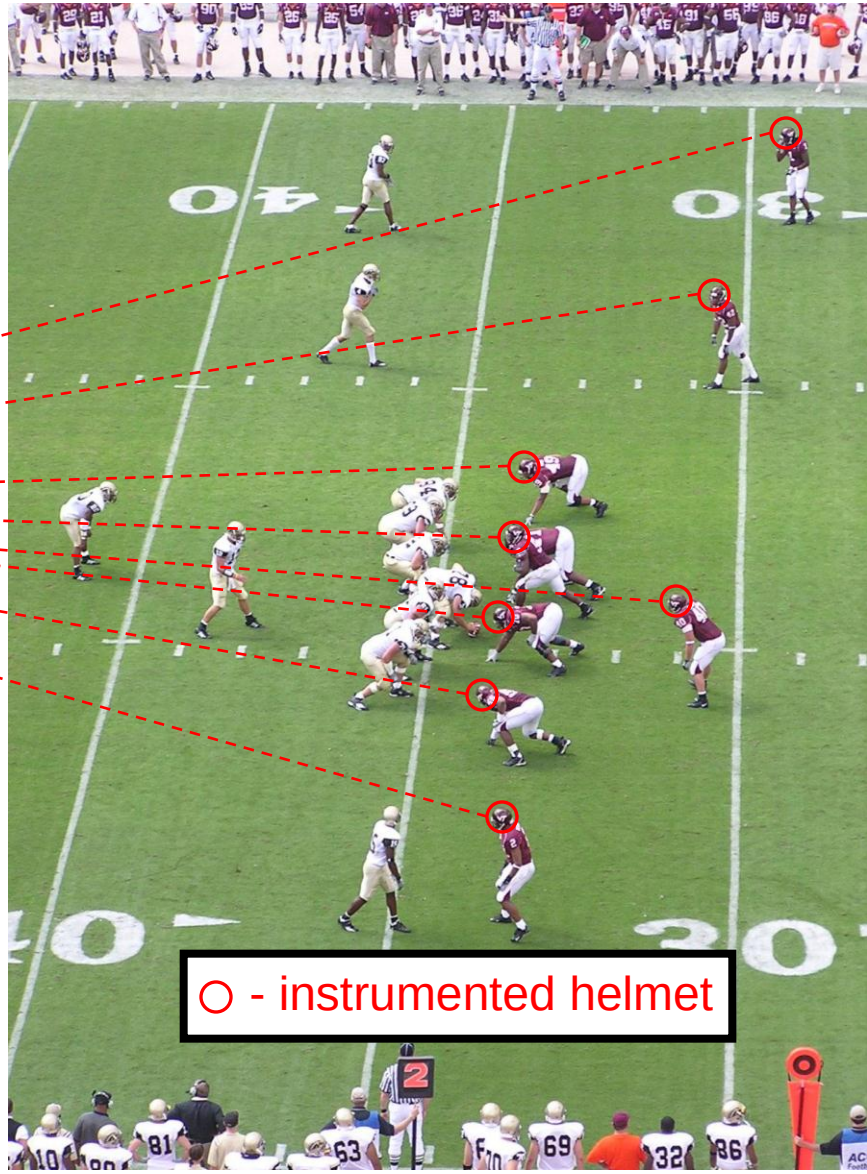


Photo courtesy of Virginia Tech

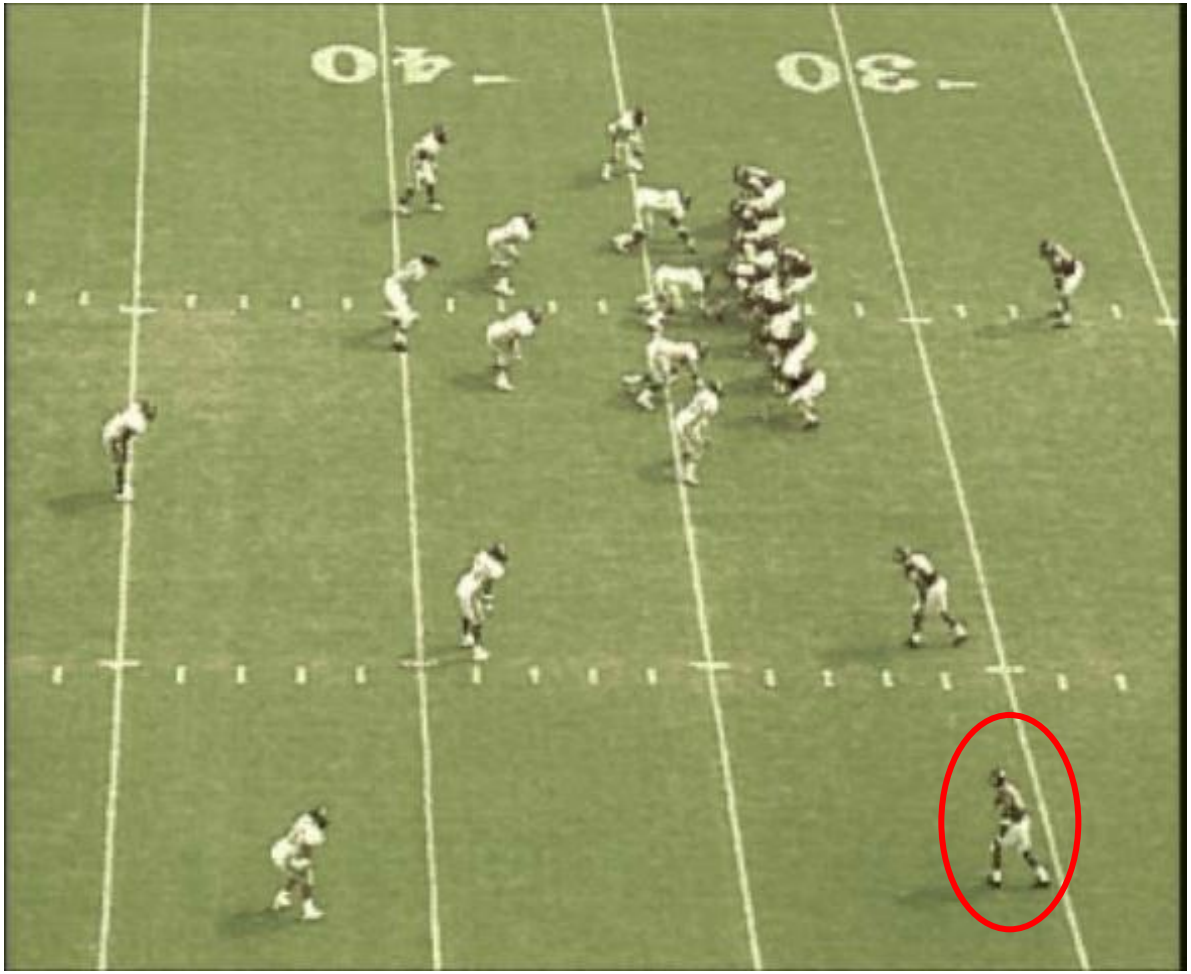
Head Acceleration Data Collection

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



Photos courtesy of Virginia Tech

Example Concussive Event



Video courtesy of Virginia Tech

Example Concussive Event

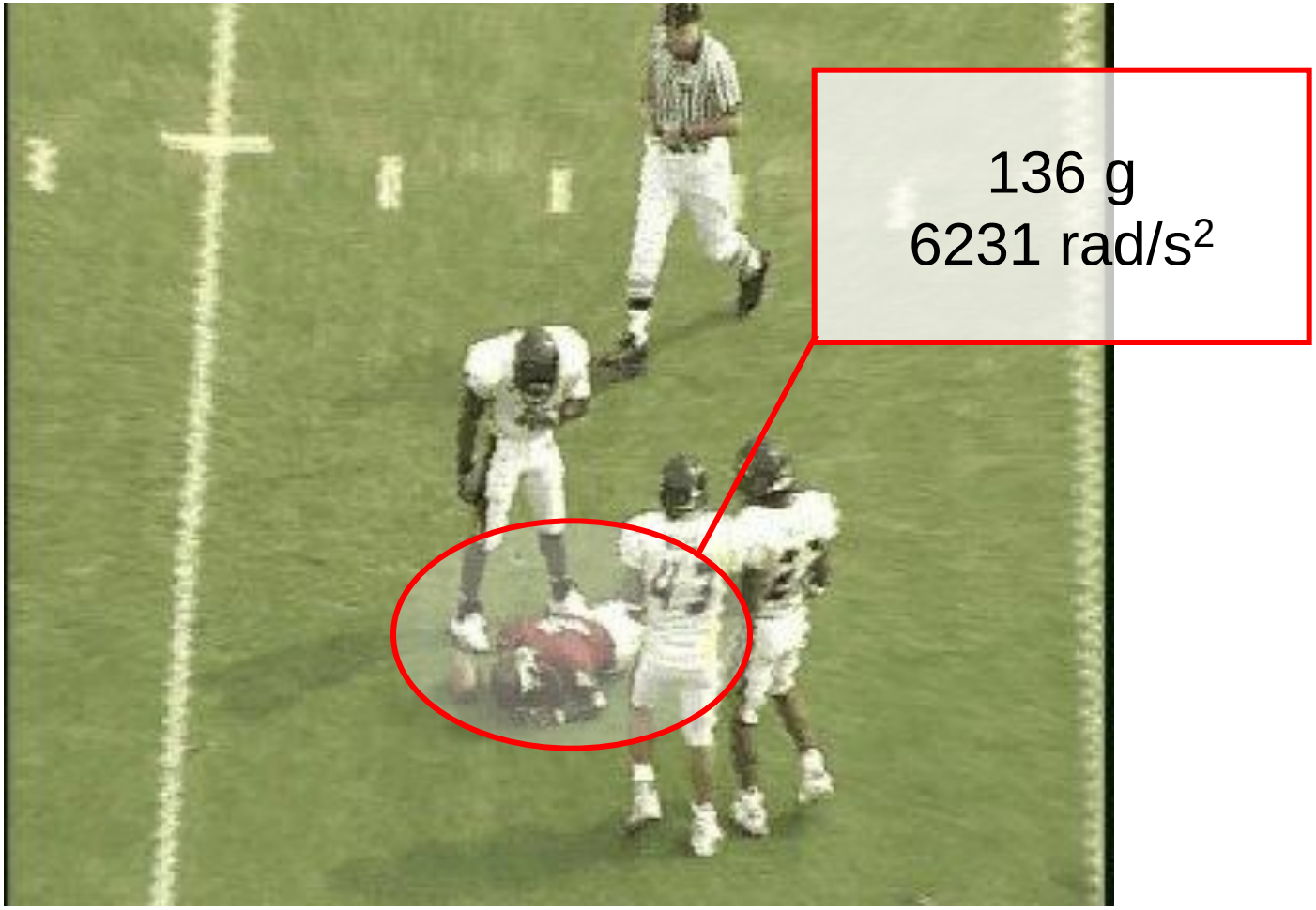


Photo courtesy of Virginia Tech

Clinically diagnosed concussion

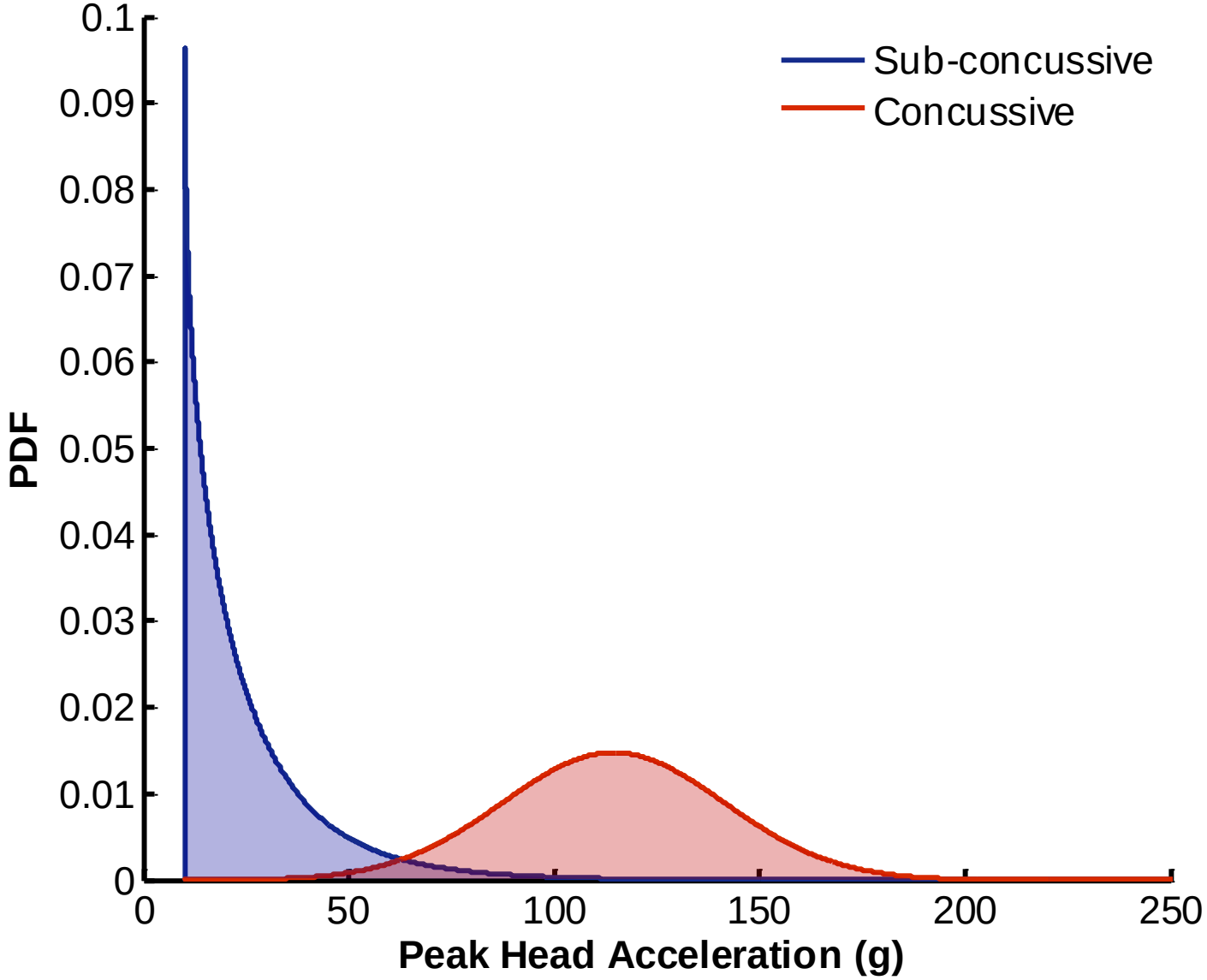
In Situ Head Acceleration Data

- Helmet instrumentation has allowed us to compile a large biomechanical dataset
  - Dataset compiled from several schools
  - Understand the kinematics associated with concussive and sub-concussive impacts

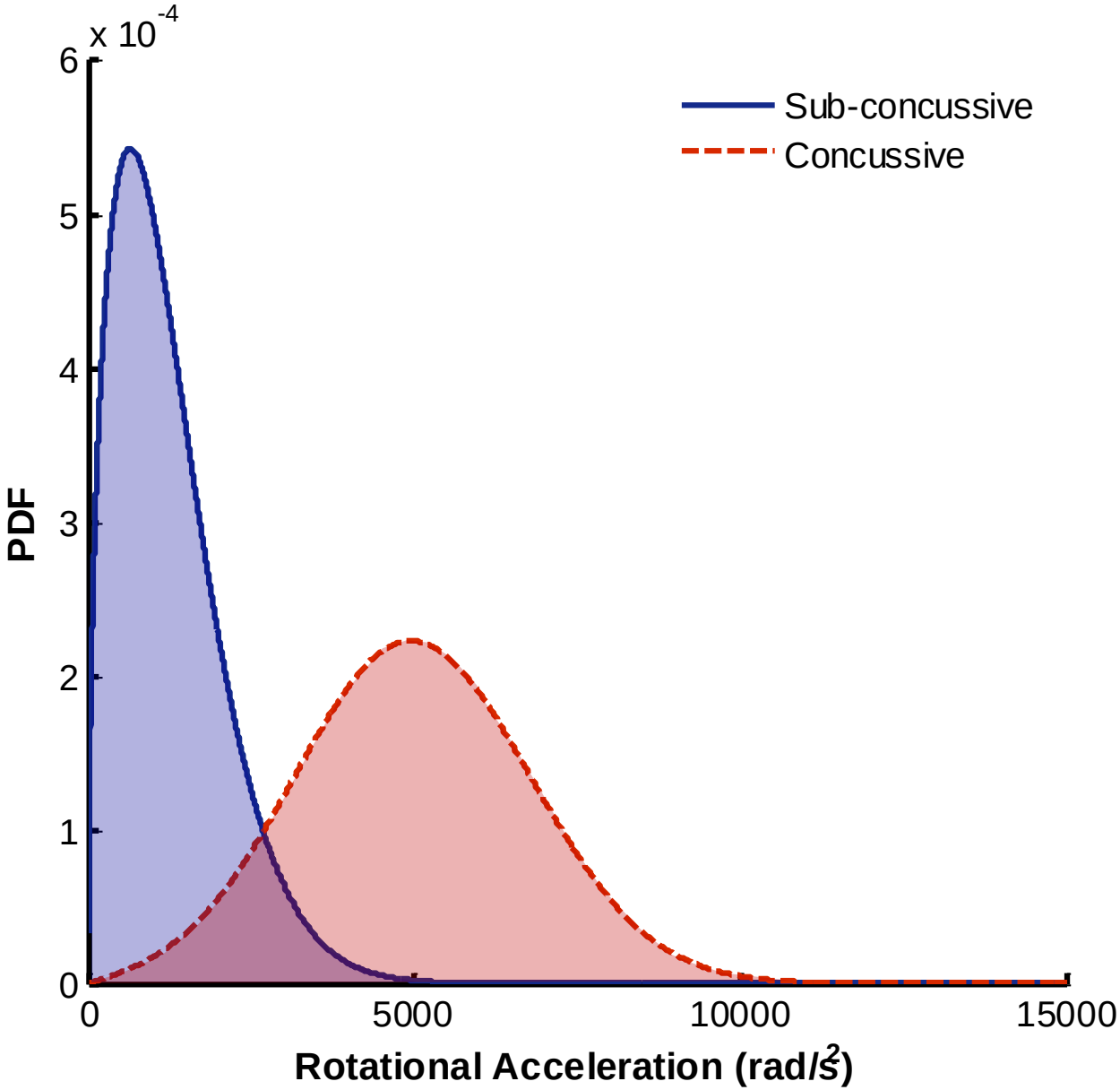
- Real-world impacts comprised of linear and rotational acceleration

- Data are collected from human volunteers
  - Cadavers have no physiologic response
  - Animal data cannot be directly applied to humans

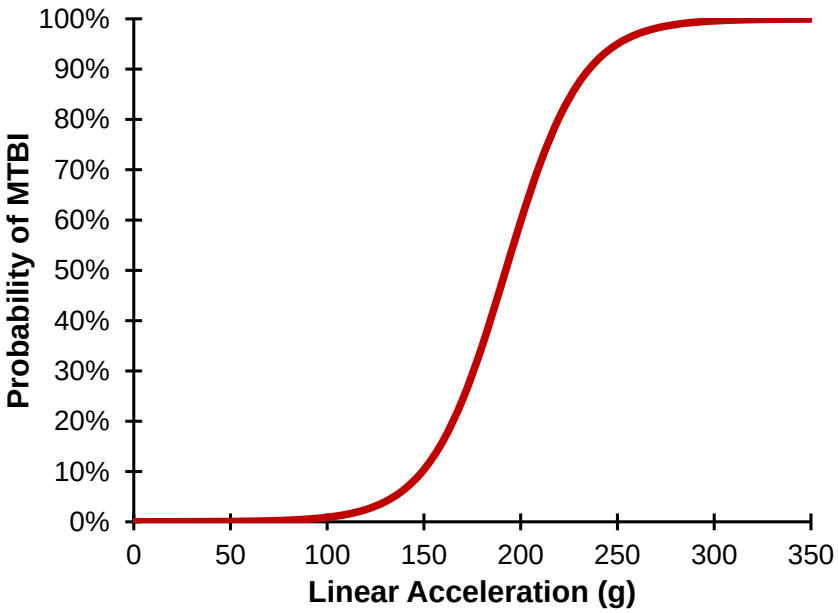
Linear Acceleration Distributions

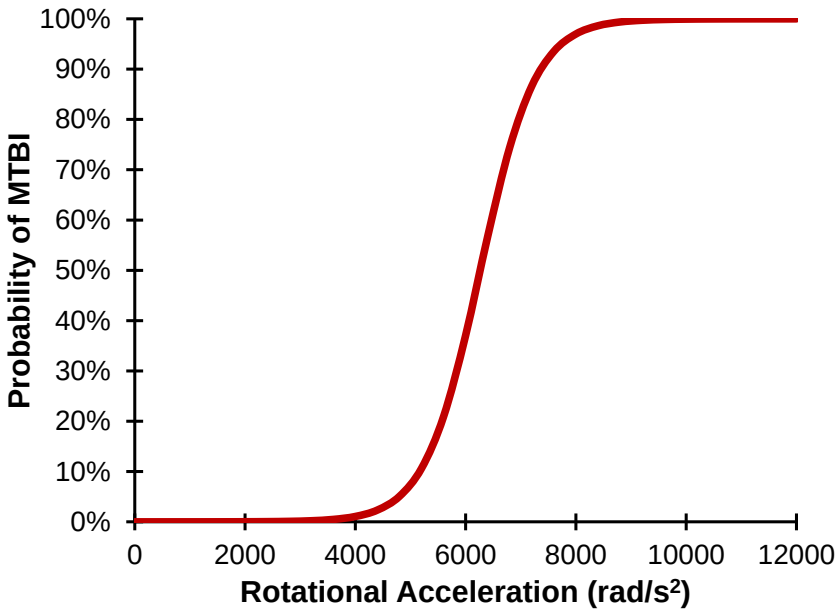


Rotational Acceleration Distributions



Nominal Concussion Risk Values



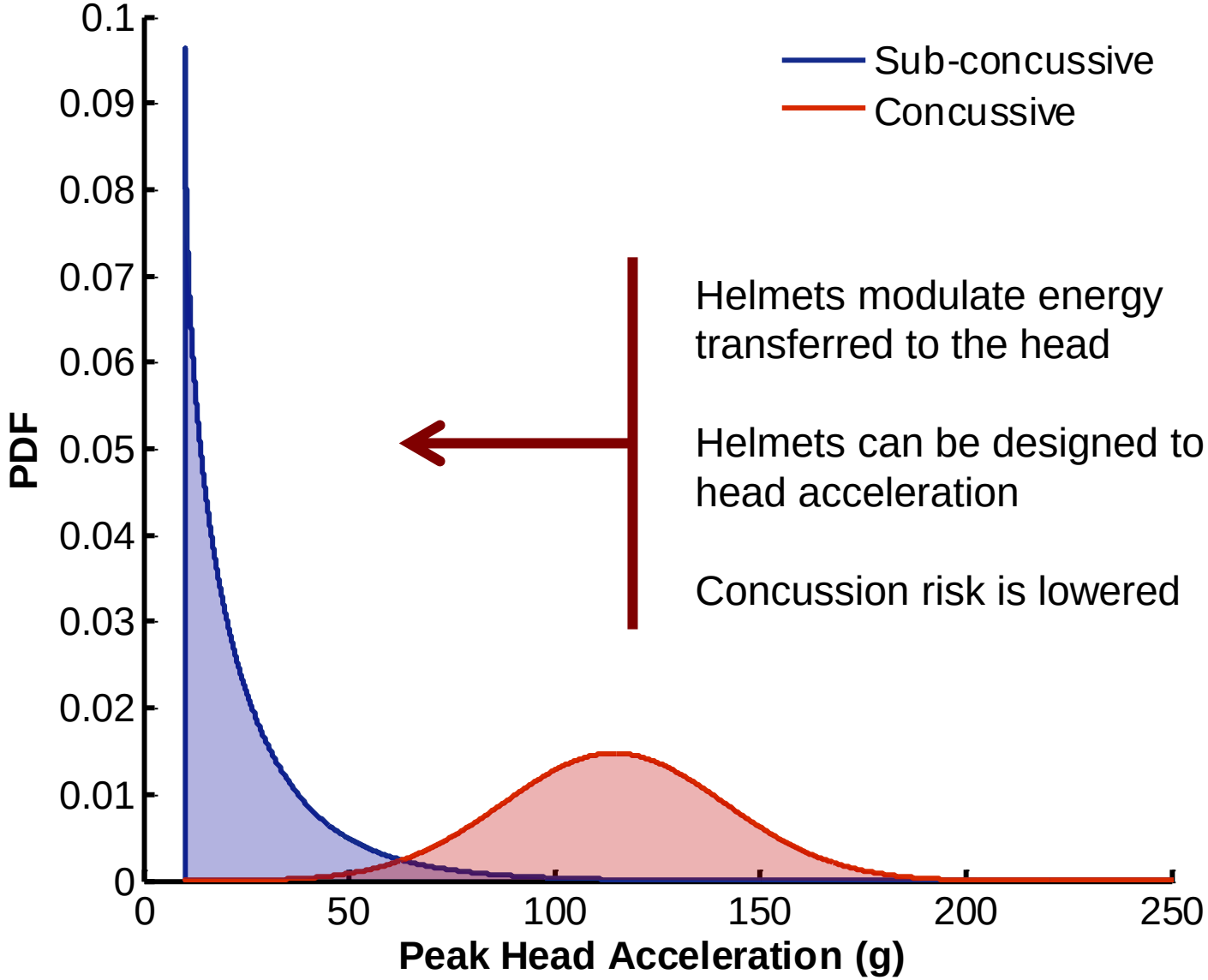


Risk	Linear Acceleration	Rotational Acceleration
10%	149 g	5167 rad/s^2
25%	171 g	5716 rad/s^2
50%	192 g	6266 rad/s^2
75%	214 g	6815 rad/s^2

(Rowson & Duma, 2011)

(Rowson et al., 2012)

Head Acceleration Distributions



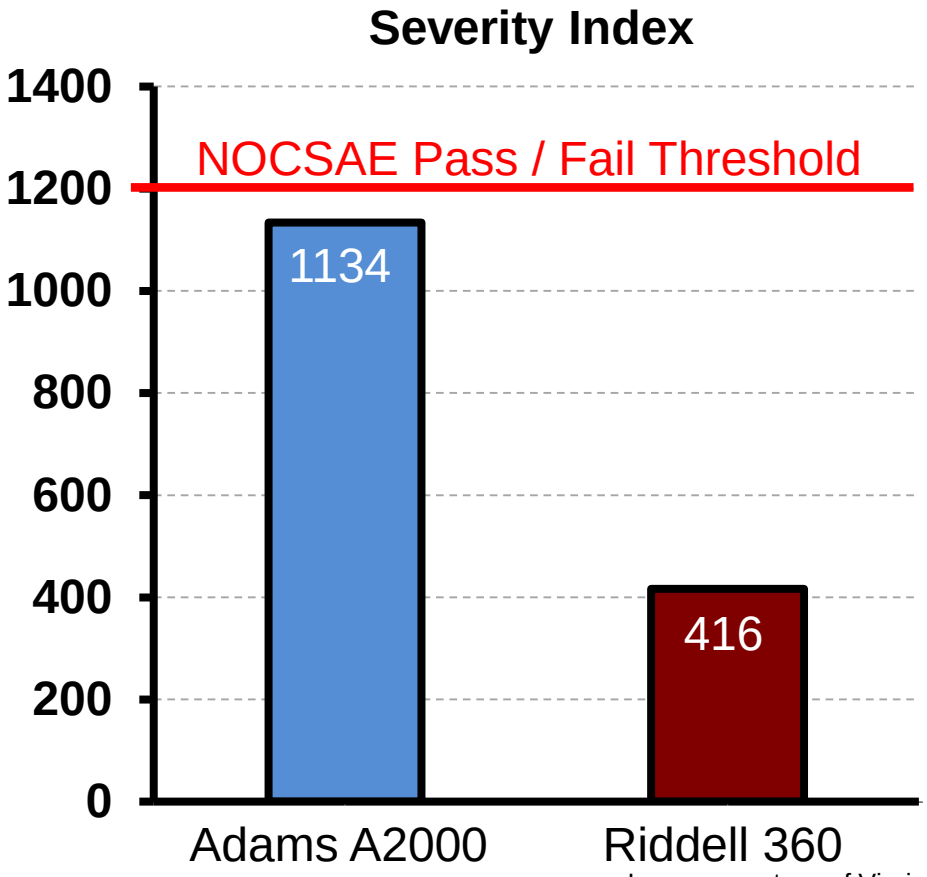
Helmets modulate energy transferred to the head

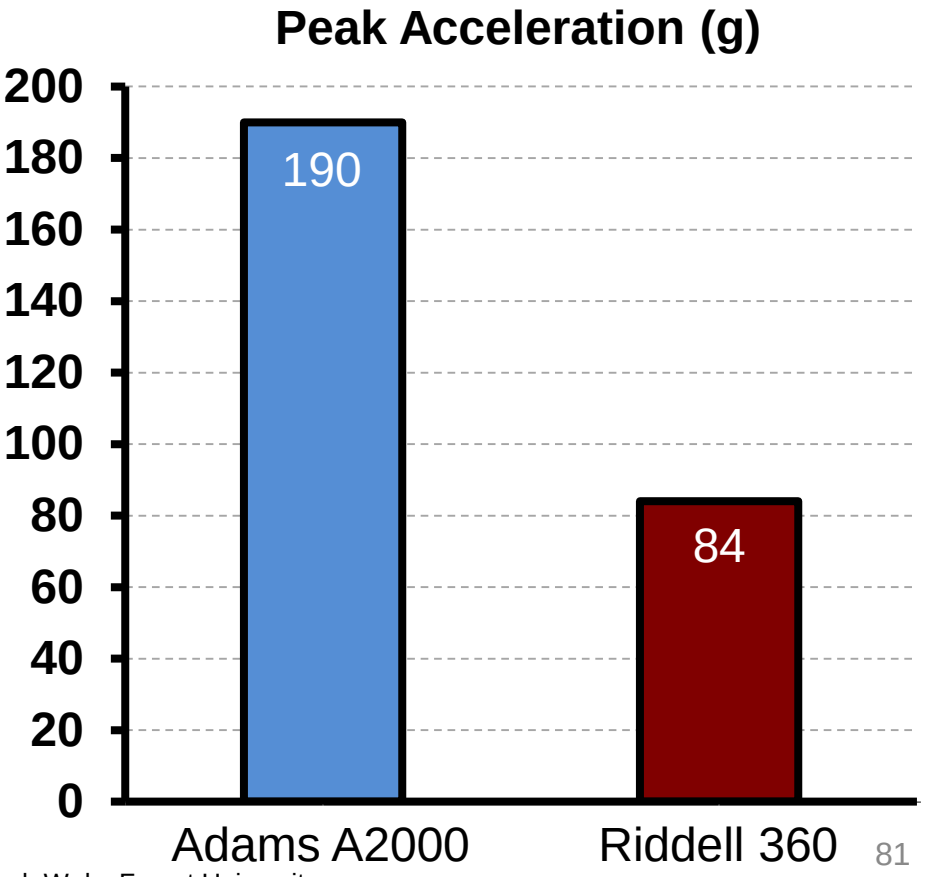
Helmets can be designed to reduce head acceleration

Concussion risk is lowered

Helmet Comparison: Top Impact from 60 inch Drop Height

Adams A2000 Riddell 360

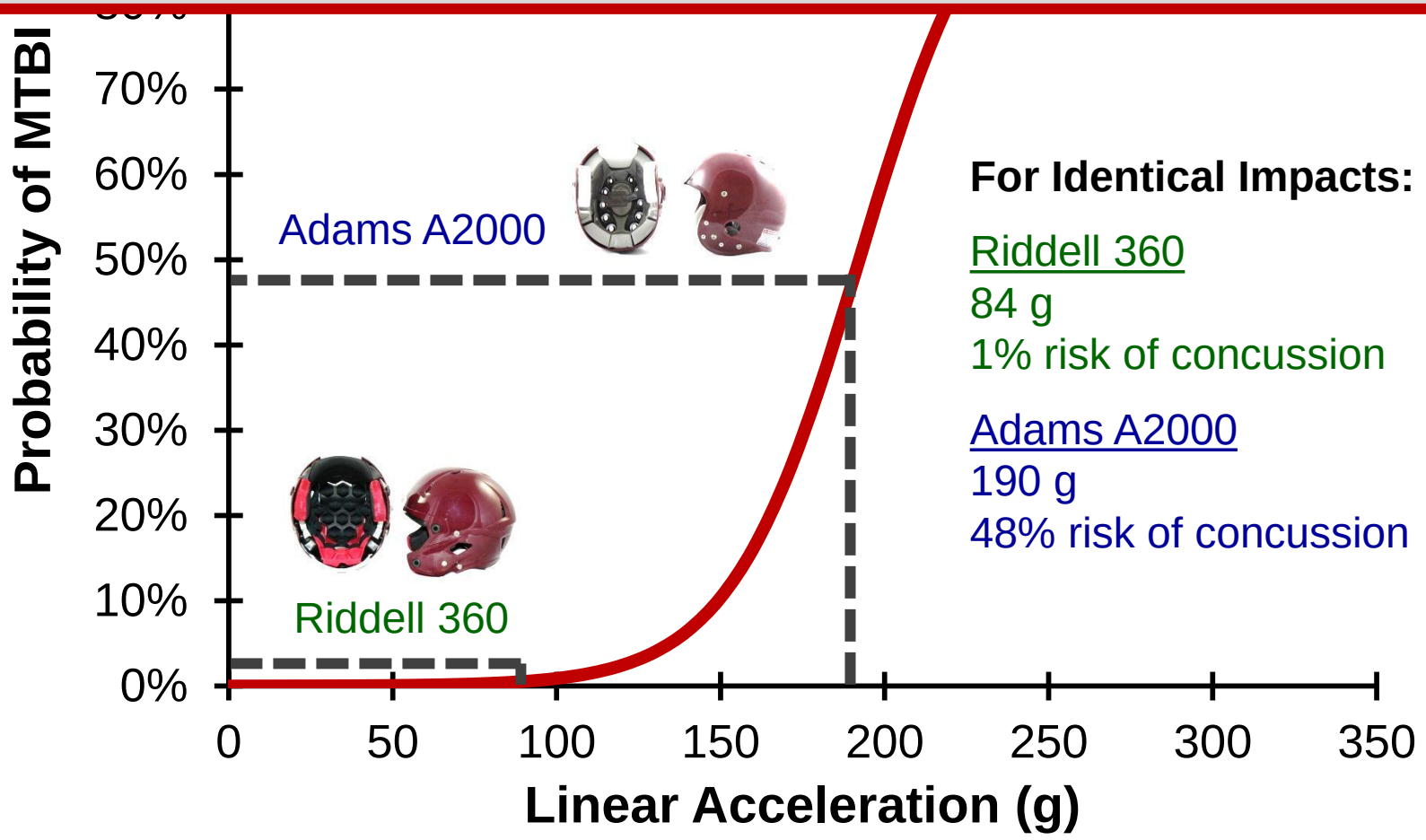




Images courtesy of Virginia Tech Wake Forest University

Let's Consider Concussion Risk

Which helmet would you choose?



For Identical Impacts:

Riddell 360
84 g
1% risk of concussion

Adams A2000
190 g
48% risk of concussion

Images courtesy of Virginia Tech Wake Forest University

Football Helmet Evaluations

All head impact data was used to create:

VirginiaTech

Helmet Ratings

Combines impact exposure with a risk analysis using real world biomechanical data to assess helmet performance for consumers.

STAR Rating System for Football Helmets

STAR: Summation of Tests for the Analysis of Risk

$$STAR = \sum_{L=1}^{4}\left(\sum_{H=1}^{6} E(L,H) \bullet R(a)\right)$$

Through a series of drop tests, helmets are evaluated using <u>2 fundamental concepts</u>:

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

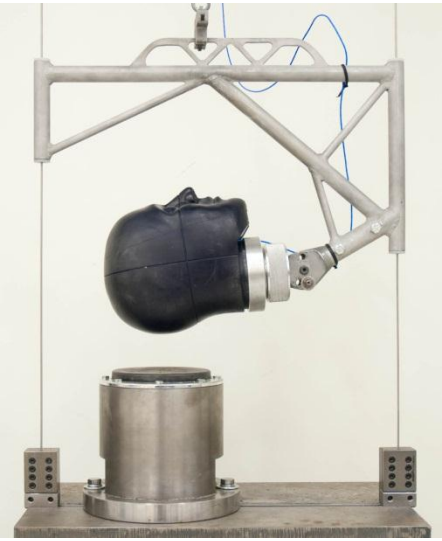
Exposure x Risk = Incidence

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

(Rowson, Daniel, & Duma, 2013)

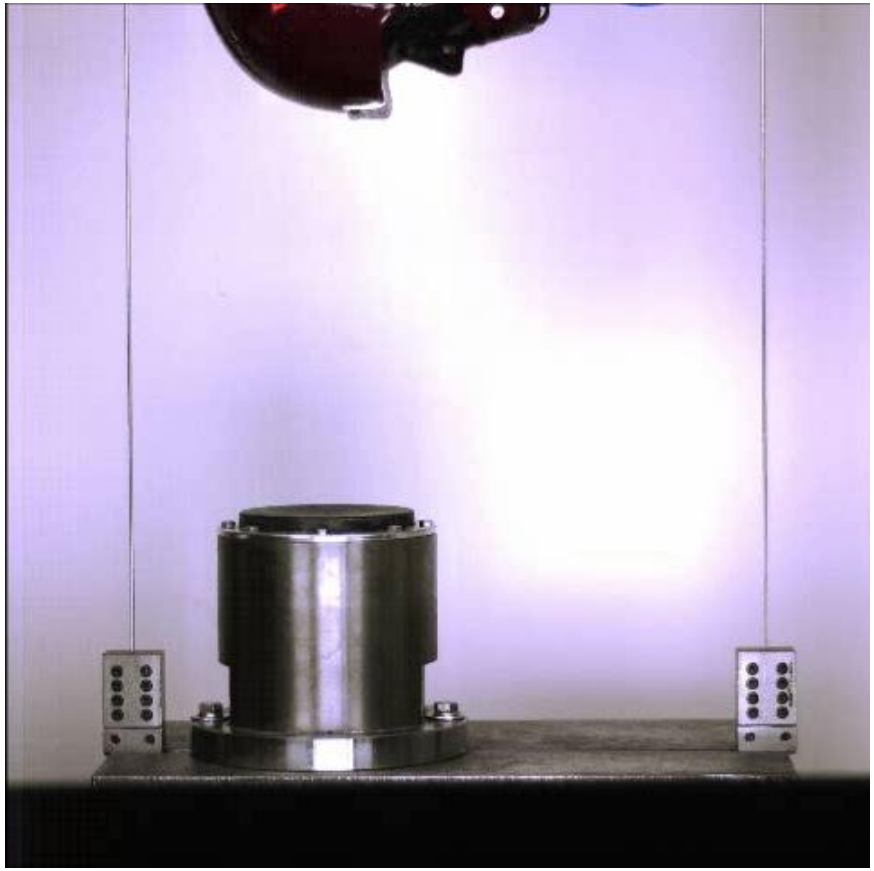
Head Impact Exposure

Exposure is defined as a function of drop height and impact location

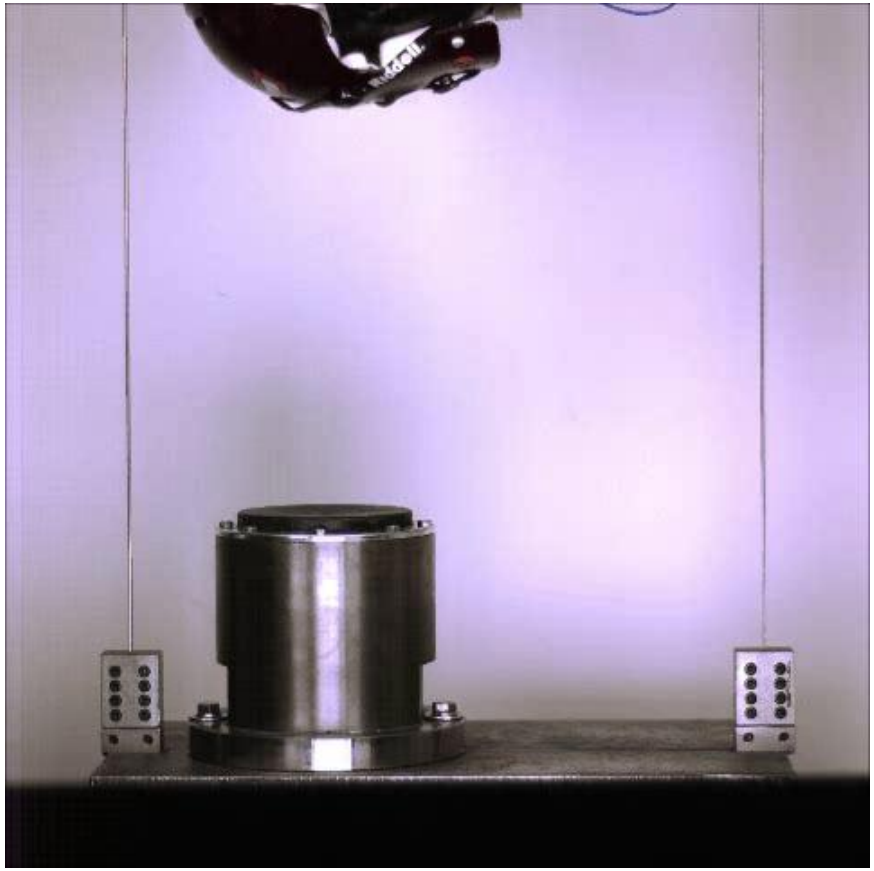
	Front	Rear	Side	Top
< 19 g	164	139	81	63
12 in	138	165	75	85
24 in	31	11	4	14
36 in	10	2	1	5
48 in	3	1	1	2
60 in	1	1	1	2
Total	347	319	163	171

1000 impacts per season

Drop Test Videos



Front Impact – 36 in Drop

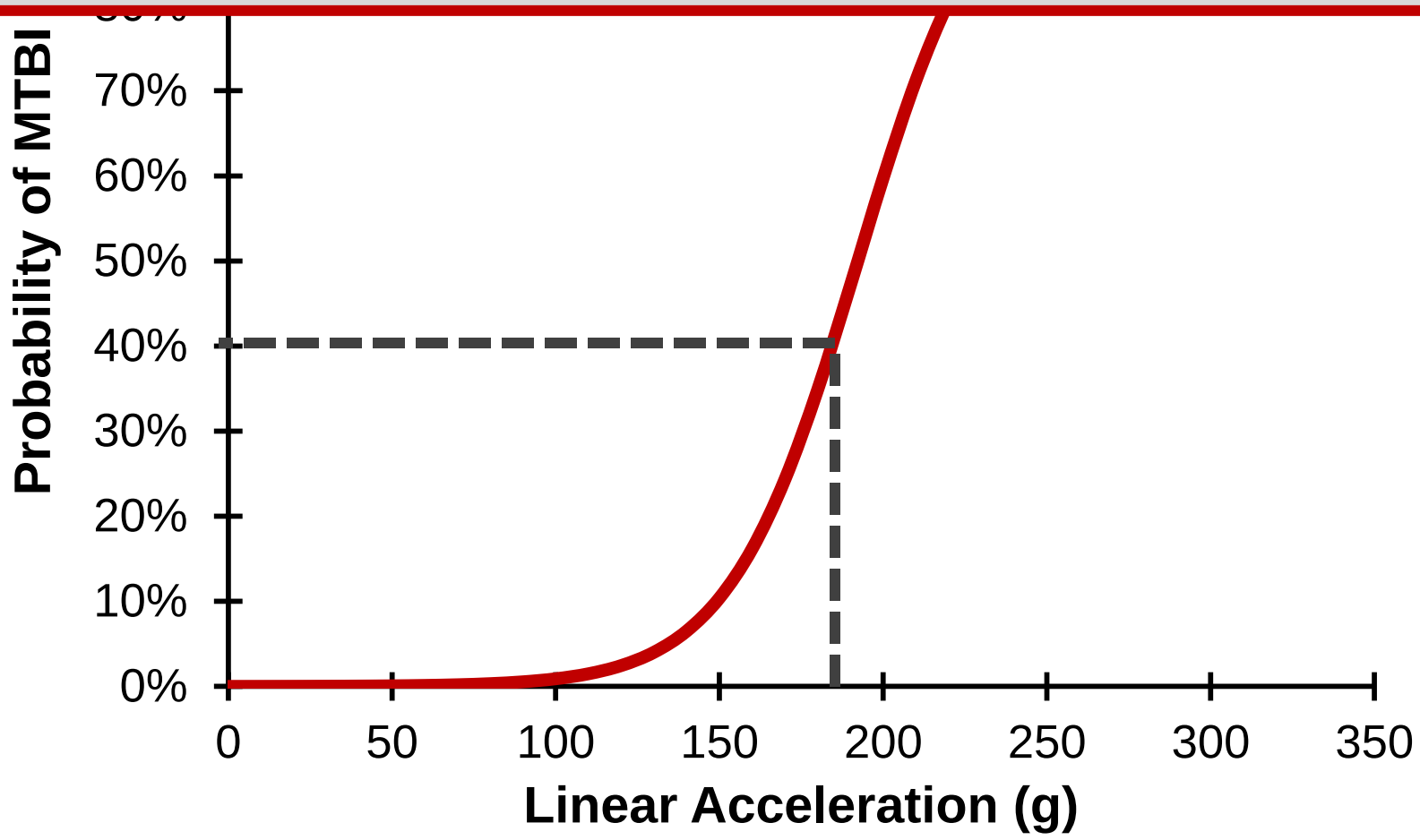


Side Impact – 36 in Drop

Linear Acceleration Risk Curve

Exposure x Risk = Incidence

10 Impacts x 40% Concussion Risk = 4 Concussions



STAR Ratings of Current Helmets

5 Stars: Best Available ★★★★★

	Schutt AiR XP Pro VTD	STAR Value: 0.207 Cost: $199.99
	Schutt Vengeance VTD	STAR Value: 0.213 Cost: $254.99
	Riddell 360	STAR Value: 0.239 Cost: $374.95
	Rawlings Quantum Plus	STAR Value: 0.245 Cost: $259.99
	Rawlings Tachyon	STAR Value: 0.262 Cost: $299.99
	Xenith EPIC	STAR Value: 0.281 Cost: $299.95
	Xenith X2 *Note: Helmets dated before 2013 rated as 3 Stars	STAR Value: 0.284 Cost: $235.00
	Xenith X2E	STAR Value: 0.285 Cost: $235.00
	Riddell Revolution Speed	STAR Value: 0.297 Cost: $264.99

4 Stars: Very Good ★★★★

	SG Adult	STAR Value: 0.309 Cost: $398.00
	Schutt ION 4D	STAR Value: 0.327 Cost: $244.95
	Rawlings Impulse	STAR Value: 0.355 Cost: $149.00
	Xenith X1	STAR Value: 0.356 Cost: $299.99
	Riddell Revolution	STAR Value: 0.362 Cost: $239.99
	Rawlings Quantum	STAR Value: 0.364 Cost: $179.99
	Schutt Vengeance	STAR Value: 0.365 Cost: $254.95
	Riddell Revolution IQ	STAR Value: 0.369 Cost: $222.99

(Virginia Tech Wake Forest University, 2014)

STAR Ratings of Current Helmets

3 Stars: Good ★★★

Schutt Air XP

STAR Value: 0.420

Cost: $174.95

Schutt DNA Pro +

*Note: Helmets dated before 2013 rated as 4 Stars

STAR Value: 0.450

Cost: $194.99

Schutt Air XP Ultralite

STAR Value: 0.482

Cost: $254.95

2 Stars: Adequate ★★

Schutt Air Advantage

STAR Value: 0.678

Cost: $159.99

1 Star: Marginal ★

Riddell VSR4

STAR Value: 0.791
Cost: Not Applicable
Used helmets were tested to provide a reference

NR: Not Recommended

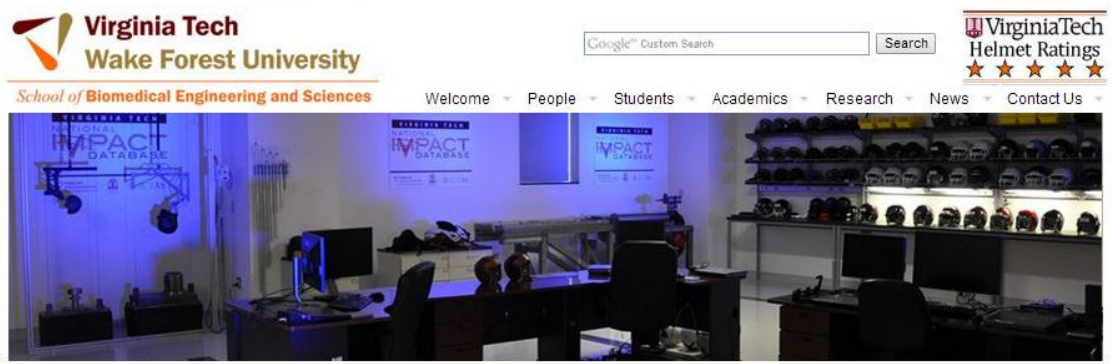
Adams A2000 Pro Elite

STAR Value: 1.700

Cost: $199.95

(Virginia Tech Wake Forest University, 2014)

Publicly Available Data for Consumers



Virginia Tech Helmet Ratings™

Adult Football Helmet Ratings - May 2013

A total of 18 adult football helmet models that have been evaluated using the STAR evaluation system are included in the May 2013 Virginia Tech Helmet Ratings™. All 18 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 ★★★★★	
Riddell 360	STAR Value: 0.239 Cost: $374.95
Rawlings Quantum Plus	STAR Value: 0.245 Cost: $259.99
Xenith X2 *Note: Helmets dated before 2013 rated as 3 Stars	STAR Value: 0.284 Cost: $235.00
Riddell Revolution Speed	STAR Value: 0.297 Cost: $264.99
4 Stars: Very Good ★★★★	
SG Adult	STAR Value: 0.309 Cost: $398.00
Schutt ION 4D	STAR Value: 0.327 Cost: $244.95

Donations

Download Printable pdf files:

Linear and Rotational Acceleration Risk Function Publication

Five Year Helmet Rating Plan

STAR Methodology

Peer Reviewed Methodology in Annals of Biomedical Engineering

Frequently Asked Questions

Additional Research:

(Virginia Tech Wake Forest University, 2014)

Effect of Helmet Ratings

- **Players**
  - In 2010, 40% of NFL players were in a 1 star helmet
  - In 2010, half of VT football team in 1 star helmet
  - All players in college and most in NFL have switched to better performing helmets

- **Coaches and Parents**
  - Make informed decisions when purchasing new helmets

- **Manufacturers**
  - Design to STAR testing methods to improve helmet performance
  - Rawlings designed Quantum Plus helmet to be 5 stars

On-Field Study of Concussion Rates

- Can Helmet Design Reduce the Risk of Concussion in Football? in *Journal of Neurosurgery* (2014)
- Exposure to head impact controlled for
- 1833 players over five years
- Data compiled from eight collegiate football teams:

  Virginia Tech, University of North Carolina, University of Oklahoma, Dartmouth College, Brown University, University of Minnesota, Indiana University, University of Illinois

Riddell Revolution reduces risk of concussion by 53.9% compared to Riddell VSR4 ($p = 0.03$)

(Rowson et al., 2014)

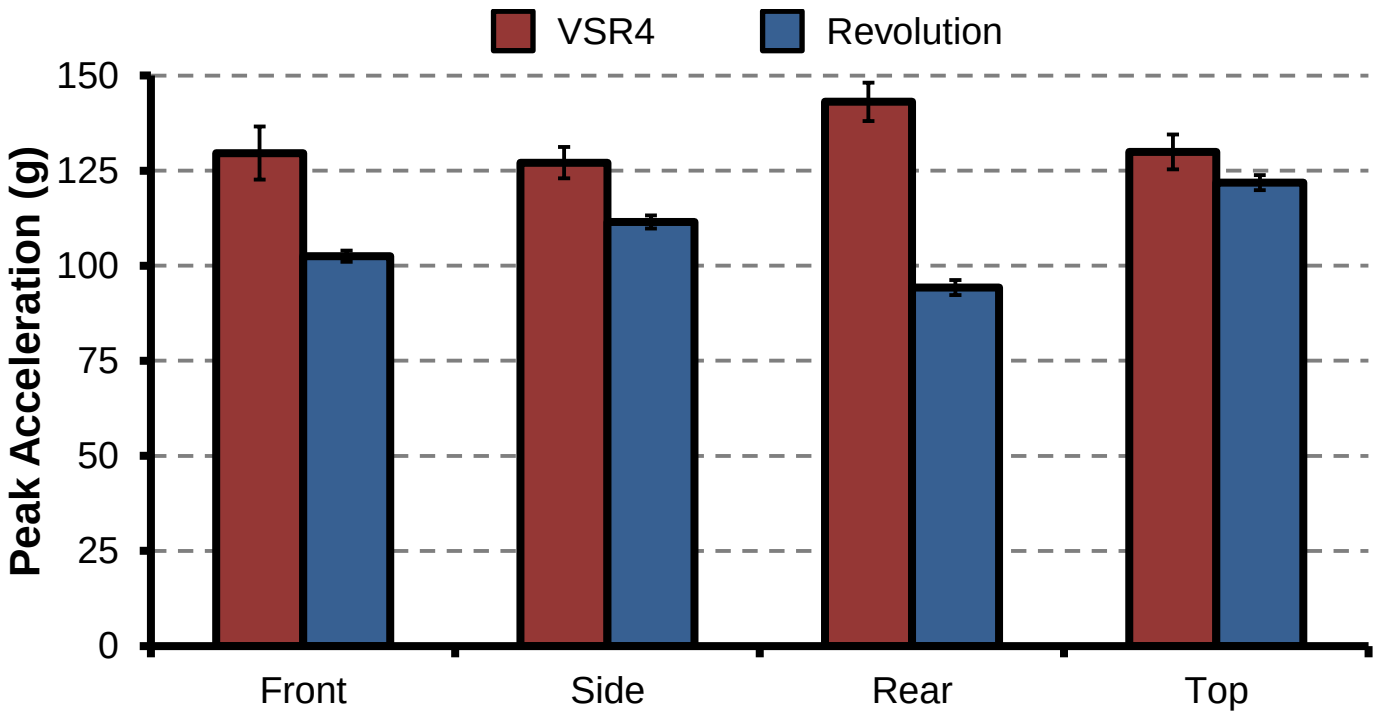
Differences in Helmet Design

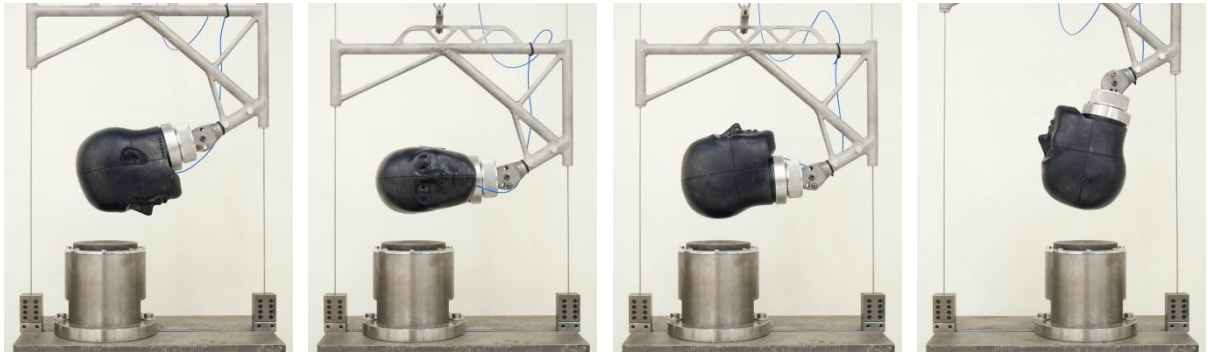
Riddell VSR4

Riddell Revolution

(Rowson et al., 2014)

Impact Management Comparison



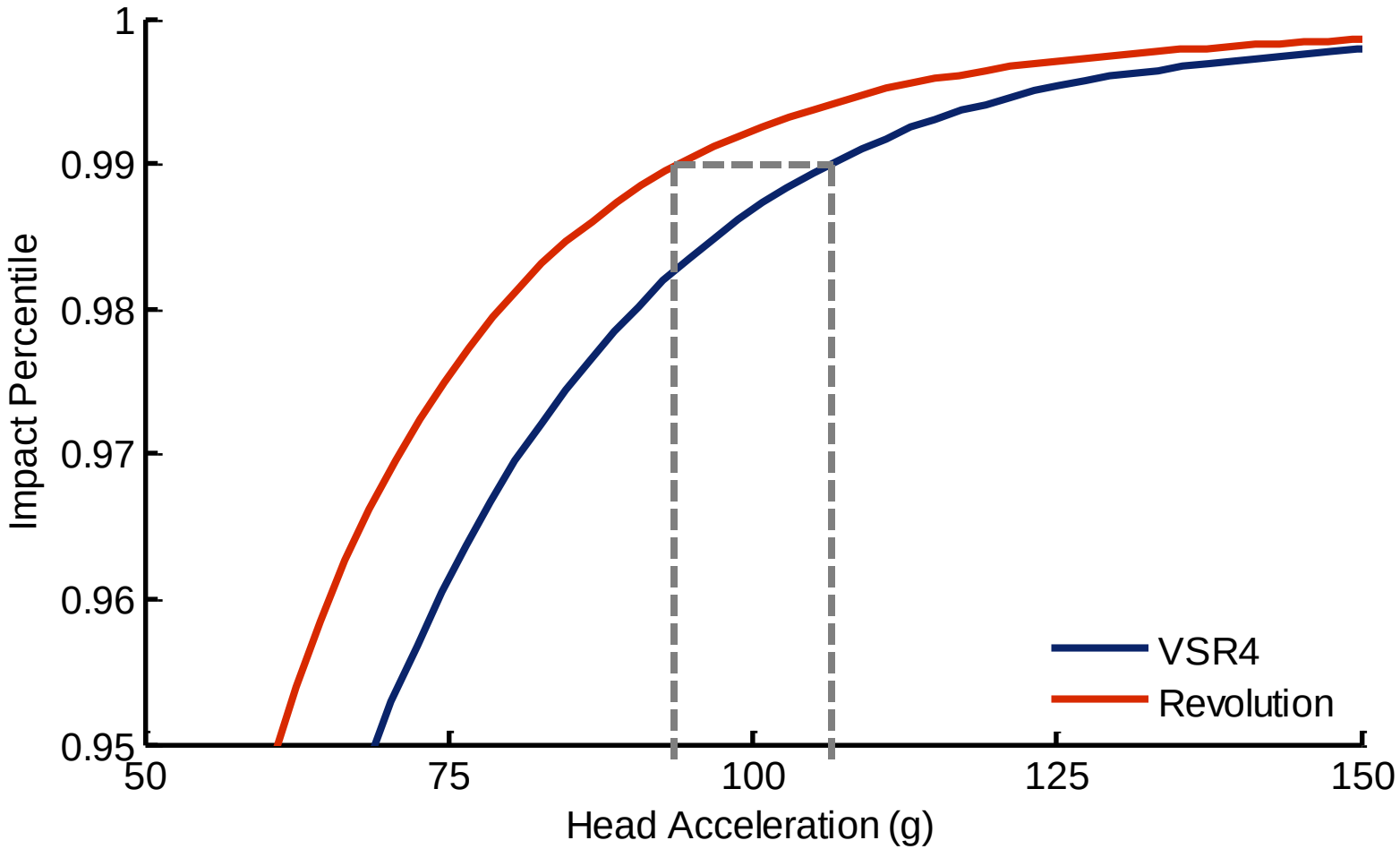


60 in Drop Height for Each Impact Location

(Rowson et al., 2014)

Differences Translate to the Field

Comparison of the top 5% of impacts in each helmet



(Rowson et al., 2014)

Head Accelerations by Position

99th Percentile Head Accelerations (g)

Position	VSR4 Helmets	Revolution Helmets	Difference
DB	101.6 [100.3 – 103.3]	99.1 [97.2 – 101.5]	2%
DL	97.3 [95.2 -99.2]	89.3 [88.5 – 89.8]	8%
LB	99.4 [97.5 – 101.1]	96.2 [95.0 – 97.3]	3%
OL	103.3 [101.4 – 105.2]	90.1 [89.5 – 90.7]	13%
QB	122.7 [119.5 – 125.3]	112.5 [107.5 – 121.2]	8%
RB	110.1 [107.8 – 112.2]	105.2 [103.4 – 107.0]	4%
WR	106.0 [104.3 – 108.4]	101.0 [98.7 – 103.5]	5%

(Rowson et al., 2014)

Laboratory and On-Field Studies

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

Riddell Revolution

★★★★

STAR Value
0.362

>

Riddell VSR4

★

STAR Value
0.791

Exposure Controlled On-Field Study: **53.9%**
Laboratory-Based STAR Evaluation: **54.2%**

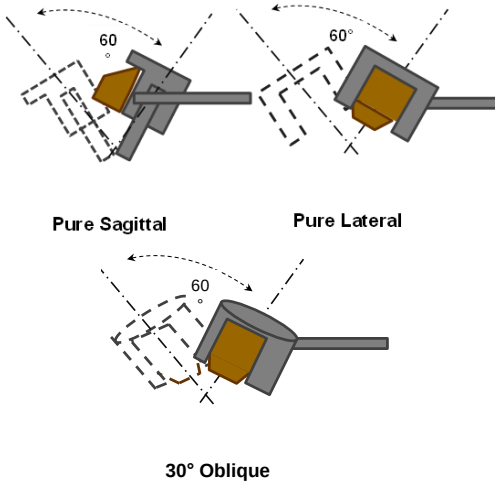
Laboratory and clinical agreement on ability to reduce concussion risk

(Virginia Tech Wake Forest University, 2014)

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

Fixed to the Head



(Gennarelli, Thibault, Adams, Graham, Thompson, & Marcincin, 1982)

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

Can All Concussion Be Prevented?

- No, any player in any sport can sustain a head injury with even the very best head protection
  - Individual tolerances
  - Genetic predispositions
  - Extrinsic factors

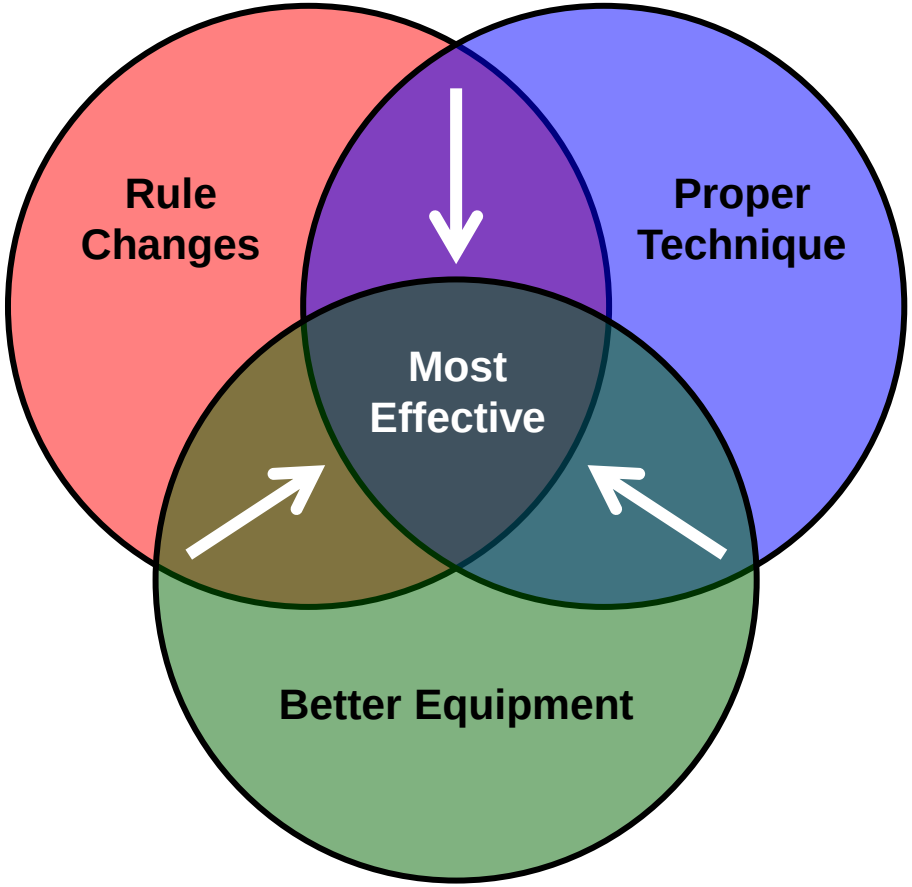
- Helmets don’t cover entire head
  - Only reduce risk for impacts to covered regions

- Until there are more advanced materials, helmets are limited by padding size and thickness

Not all concussions can be prevented with helmets, but concussion risk and incidence can be minimized

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

Do Helmets Work?

- Yes! Helmets work and can reduce the risk of concussion, but helmet design can be 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

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A Head for the Future

A Head for the Future is an initiative designed to promote traumatic brain injury (TBI) awareness, education and prevention

Designed for service members, line leaders, veterans, medical providers and family members to access the latest information on TBI diagnosis, treatment and recovery

dvbic.dcoe.mil/aheadforthefuture

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