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For Psychological Health & Traumatic Brain Injury

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"Do Helmets Prevent Concussion?"

Welcome and thank you for standing by. At this time all participants are in a listen-only mode and will remain so throughout today's conference. Today's conference is being recorded. If you have any objections, please disconnect at this time. I would now like to turn the meeting over to Dr. Robert Labutta. Go ahead, sir, you may begin.

Great. Thank you. Good afternoon, everyone, and thank you for joining us today at the DCoE trauma brain injury July webinar, Do Helmets Prevent Concussion. My name is Dr. Robert Labutta, and I am a Clinical Affairs Senior Advisor providing contract support to the Defense and Veterans Brain Injury Center. I will be your moderator for today's webinar.

Before we begin, let us review some webinar details. If you experience technical difficulties, please visit dcoe.mil. D – C – O – E dot mil forward slash webinars to access troubleshooting tips. Please feel free to identify yourself to other attendees via the Chat box but refrain from marketing your organization or products.

Today's presentation and resources and references are available for download from the Files box and will be archived in the Online Education section of the DVBIC website. If you preregistered for this webinar and would like to obtain Continuing Education or CE Certification of Attendance, you must complete the online CE post-test and evaluation. After the webinar, please visit the Continuing Education site at DVBIC.edu to complete the online CE evaluation and post-test and download your CE Certificate or Certificate of Attendance. The Duke Medicine website online CE evaluation and post-test will be open through Thursday, 17 July 2014, until 2359.

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The incidence of athletes sustaining concussions during sporting events continues to rise despite increases in the uses of personal protective gear. Sports medicine experts recently published statements about lack of effectiveness that helmets and other equipment have on the incidence and severity of concussion. However, more recent studies indicate helmet design can, in fact, reduce the transmission of impact forces to the brain and possibly reduce concussion incidence. 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, and discuss the use of acceleration information as a metric for characterizing brain injury risk. Also by the end of the conference, it is my hope that the participants will be able to relate the concussion risk in football to the relationship of better equipment, rule changes, and proper techniques.

I would now like to introduce the first of our three presenters. It's my pleasure to introduce Dr. Donald Marion. He's the Clinical Affairs Senior Advisor who provides contract support to DVBIC. Dr. Marion is an academic neurosurgeon who has focused on a clinical and pathophysiological effects of traumatic brain injury for more than 30 years. He has authored or coauthored more than 200 journal articles and book chapters, mostly related to TBI. He has held previous academic appointments as a former professor and Chair to the Department of Neurosurgery at the Boston University School of Medicine. He has been a professor and Vice Chair of the Department of Neurosurgery at the University of Pittsburgh School of Medicine, and also the Director of the Brain Trauma Research Center at the University of Pittsburgh. Thank you very much for joining us today, Dr. Marion.

Thank you Dr. Labutta. I'd like to start out by just making sure everyone is aware I don't speak for the federal government or for the Army or for the Department of Defense, and my comments are my own.

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So that's that.

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So I'm very excited about this webinar today and about the whole notion of the possibility that helmet design, or better helmet design, might limit the risk for concussion. I think that this has been a hotly debated issue for a number of years now, and some very exciting work is being published, I think in large part as a result of the advancement of helmet accelerometer technology, the ability to actually document what forces are impacting the helmet. And so my role in the talk today is going to be fairly brief, but I just wanted to kind of set the stage for what it is we're going to be looking at. It can be kind of summarized as follows: Is it possible to reduce the risk of concussion? What are current helmet design standards? What is the consensus of the experts? And ultimately, can a better helmet design actually lower the risk of concussion?

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A number of investigators have utilized these helmet sensor devices to be able to come up with some pretty interesting risk associations or sinusoidal curves that you see here that suggest that as the acceleration of the head goes up, the risk of, or probability of an injury, of a concussion, goes up fairly dramatically in a sinusoidal fashion. The curious thing here, though, or problematic thing of this curve is that there's quite a wide range, anywhere from 50 to 200 g's before you go on the upslope of that curve.

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It seems likely that certain physical and environmental factors can influence the risk of concussion, and certainly a number of articles, two just in June as well as this one by Echner (sp), suggest that greater neck strength and anticipatory cervical muscle activation can help you brace for impact and reduce your risk of concussion.

Perhaps even a more interesting study is this second study by Myrel (sp) that suggested that the incidence of concussion might depend to some extent on what elevation your playing. In this particular NFL study, they found that the incidence of concussion was reduced somewhat when teams were playing at higher elevations like Denver.

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But it too seems that there is a benefit to having better protective equipment. In 1968 there were published 32 deaths related to organized football. The following year, in 1969, the National Operating Committee on Standards for Athletic Equipment, or NOCSAE, was formed to address that problem. The United States athletic concerns weren't happy about that and thought something needed to be done, and

they felt that if they could make sure that every high school, every college, every professional sports team was using a helmet that met some minimum standards, maybe they could reduce the incidence of concussion. And whether this is the direct cause and effect, or something else, the reduction of spearing for example, we certainly found that the incidence went down. Went down rather dramatically. And so you can see that the incidence dropped from 4.25 per 100,000 players to 0.51 per 100,000 players in the 2002 to 2006 seasons. And in fact, in 2012, there were only two reported deaths associated with organized football. And neither of those deaths were described as due to a head injury, but rather to cardiac problems or heat stroke.

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However, have we gone too far? Have the football helmet manufacturers started making claims that aren't appropriate? And certainly in 2013 the New York Attorney General Eric Schneiderman thought so. He was concerned that marketing boasts about concussion proof or anti-concussive helmets were misleading and would give young players and their parents a false sense of security. He also sounded alarms about helmet add-ons, such as extra liners, pads, and so forth, noting that there was little research to demonstrate the effectiveness.

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So as a result of those warnings, certainly the helmet manufacturers now post clear warnings on their products and on their websites, and I'll just quickly go through.

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So Guardian Caps has this red warning. It pops up when you go to their website.

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Riddell, this warning.

And then next slide.

My favorite is the Chute warning, and the lettering is a little bit small, I don't know if you can read it, but my favorite part of this is at the bottom – you have to check that box, by the way, that you've read this to move on through their website. And my favorite statement is at the bottom, the final statement is to avoid risks of getting a concussion with their helmet is don't play football. So there you have it.

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There is a general consensus of sports medicine experts about what they think helmets can and can't do, and team physicians consensus statement on concussion and the National Federation of State High School Associations has stated as an official statement that there is no football helmet or mouth guard that can prevent a concussion. The American Medical Society for Sports Medicine physicians statement is that helmets are best suited to prevent injuries such as fractures, bleeding and lacerations, but have not been shown to reduce the incidence or severity of concussions. Likewise the American Academy of Neurology, Dr. Labutta's association, say that data are insufficient to support or refute the superiority of one type of football helmet over another in preventing concussions, and so forth.

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I do applaud Dr. Rowson, and I'm thrilled that he's going to be one of our next speakers. He's done a tremendous amount of work at Blackburg (sp) looking at or trying to break this down and trying to understand mechanisms and see how we might, at least, try to get toward a better helmet. They recently came up with the star system of rating helmets. And there is the equation. You'll be tested on that after

the end of this talk, so I hope all of you memorize that. But anyway, he found you can use the system in testing helmets to come up with the best ranked helmet, which would be five stars, down to the worst helmet, which was no stars. And one of the papers that we're going to be talking about a little bit today compares the Riddell VSR4 helmet, which gets a one star, versus the Riddell Revolution helmet, which is a four-star helmet.

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So, the impetus, really, to get rethinking about this issue was this paper by Dr. Rowson which was published this year. And it's a retrospective analysis of head impact data collected on nearly 2,000 collegiate football players who were instrumented with helmet-mounted accelerometer arrays for games and practices. And then the concussion rates were compared between players wearing the one-star Riddell helmet, the Riddell VSR4, and the four-star, or Riddell Revolution helmet, while controlling for head impact exposure of each player. There were a total of over a million head impacts that were recorded. Sixty-four concussions were diagnosed. And the bottom line is when controlling for each player's exposure to head impact, there was a significant difference found between concussion rates for players with the one-star VSR4 helmet versus those with the four-star Revolution helmet. And so from what I could tell, this is one of the very first studies to really objectify this and strongly suggest a benefit from an improved helmet.

So with that, next slide, I will turn it over. The references will be up for you, and I'll turn it back to you, Dr. Labutta.

Great. Thanks a lot, Dr. Marion. That's a great setup. And I'd also like to point out, a fair number of people have probably joined recently. I think the use of helmet sensors just became mandatory in June in the first professional sport. The Arena Football League has mandated the use of helmet sensors for their next season.

At this time I'd like to introduce our second presenter, Dr. Kristy Arbogast, who is the Director of Engineering for the Center of Injury Research and Prevention at the Children's Hospital of Philadelphia. Dr. Arbogast holds a Ph.D. in Bioengineering with a focus on brain injury mechanics. She's a Research Associate Professor of Pediatrics for the University of Pennsylvania, and has led efforts to standardize clinical care of concussion throughout the hospital's healthcare network. I am pretty sure Dr. Arbogast was also sat on the recent IOM Committee Report for Concussion in Youth Sports that was released in October 2013. She also co-directed the National Science Foundation sponsored Center for Child Injury Prevention Studies, an industry University cooperative research center focusing on 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 injury. We're really happy to have Dr. Arbogast joining us today. Thank you.

I'm pleased to have an opportunity to talk to you today, and just to give you a lay of the land, my presentation hopefully will lay the groundwork by going over some of the fundamental principles and scientific foundation regarding head injury prevention.

So as Dr. Labutta described, my academic home is Children's Hospital Philadelphia and the University of Pennsylvania, but my comments today are my own and represent my thoughts on these issues.

So I think as we begin to think about this topic, it's important for us to have consensus on what we're talking about with regards to a concussion or a mild traumatic brain injury. I think the fundamental component of the definition is that a concussion occurs when the brain decelerates. That doesn't necessarily require an impact to the head. You can envision an impact to the torso that would cause the brain to accelerate and decelerate. And we know from animal studies that the rotational component of that acceleration is important in understanding the mechanisms of concussion.

And I think from a physiologic standpoint and a clinical standpoint, the other important characteristic of the definition of concussion, is that concussion is a functional injury of the brain, not a structural injury. And what I mean by that is that traditional imaging methods will not identify something you can see on an x-ray, a CT scan, or an MRI. It is a deficit in the functioning of the brain, and therefore presents challenges in trying to understand when it is there or not. If you think of a broken leg, you can do an x-ray and say yes, the leg is broken, or it is not. With concussion we don't have that option.

There are several myths that are associated with concussion, some of which I've already mentioned before. First of all requiring a blow to the head. It is the brain deceleration that is required. The concussion does not require loss of consciousness. Most data sources suggest that only about ten percent of concussions are associated with loss of consciousness.

There's also the misnomer of mild traumatic brain injury. That that means it's a mild injury. I think mild has to do with the acute threat to life in contrast to moderate or severe traumatic brain injury. But mild does not necessarily mean that there are mild consequences.

And then the last myth, which I learned from my clinical colleagues here at the hospital, is that you really can't tell how bad a concussion is from the very beginning. So we've moved away clinically from rating severities of concussion on presentation. The clinicians tell me you can always tell how severe a concussion is after it gets better because it has to do with the complexity and length of symptoms.

So as Dr. Labutta indicated, there has been tremendous national attention to this issue. I was fortunate to sit on the Institute of Medicine Committee on Sports Related Concussion in Youth, and we released our report in October 2013. Our task was to dive deeply into the literature on concussions in youth related to the causes and consequences of concussions, the current state of the art of diagnosis and management, the effectiveness of protective equipment and sports regulations for the prevention of injury, and to recommend actions to really a diverse set of stakeholders, all of which have a stake in understanding how to prevent, diagnose, and manage concussions for youth.

And so I'm going to highlight some of the findings today from that third aspect of our tasks, centering on the effectiveness of protective equipment. What do we know? What do we not know? What can we ask of protective equipment? What can protective equipment not do?

One of the key recommendations from the Institute of Medicine report with respect to prevention was this: that the NIH and Department of Defense should fund research on age and sex-related biomechanical determinants of injury risk for concussions in youth, including how those injury thresholds are modified by the number of concussions and the time interval between head impacts and concussions. And I think with regard to prevention, this is really the core issue that we need to understand as we think about preventive equipment like helmets.

So let's get back to helmets. And I'm going to use the word "helmet" throughout this presentation, but it really does apply to other protective devices such as headgear and other kind of not – anything that goes on your head to prevent brain injury and head injury and not necessarily just a helmet.

So you can't turn on the television or open up a newspaper or magazine in the last year or so and not hear something about helmets. There really is a barrage of conflicting information. This was a Google news search that I did of really just the last six to 12 months, and you can see that there really is confusing information. I think it's confusing for parents. I think it's confusing for professionals to understand really what role do helmets and protective devices play in prevention.

So I believe there are really two fundamental questions to answer to help us to understand that question. The first is what is the clinically entity that is mild TBI? We need objectives, age-specific markers and metrics for the diagnosis and monitoring of recovery.

As an engineer, that's not my area of expertise. And so what I want to focus today on is really that second question. What is the mechanical event that leads to a mild traumatic brain injury or concussion? And really the question is and the work that needs to be, or has been done to some degree, to answer that question, is quantifying the biomechanics at a global head kinematic level. So understanding how the head needs to move, and then what happens to the brain as a result of that movement. And so relating the mechanics to the physiology. And so we'll focus on that piece today.

And so there's some fundamental biomechanic principles to understand. And I know I have a diverse audience on the webinar, so I apologize if this is elementary for some of you. So we know that head kinematics and resulting brain injury come from a combination of linear movement, where the head is moving along a line, and rotational movement, where the head is rotating.

Now out in the real world, either on the athletic field, in the military environment, or in a motor vehicle crash, we know that the head doesn't move in one or the other of these ways. It's a complex combination of both linear and rotational movement. You rarely have pure linear or you rarely have pure rotation. So what we're trying to prevent, what we're trying to minimize the impact of, is this complex head movement that is a combination of linear and rotational kinematics.

So what do we know about helmets? They were originally designed, as Dr. Marion highlighted, to prevent skull fractures and more serious brain injury. That was the problem that they were trying to address when they were introduced many decades ago. And really the data suggest that they do an excellent job at doing that. They were primarily designed and tested to reduce linear acceleration. Thank Dr. Rowson, who you are going to hear from in a moment, for this video that is showing the typical test standard for helmets. And I play (inaudible), right? There we go.

So you can see that the helmet test involves the helmet being dropped in a linear fashion onto a given surface, and we measure the linear acceleration of that helmet such that it needs to keep the acceleration below a given threshold. So, as I explained to you previously, we know that on filed impacts are really this combination of linear and rotational acceleration. And so the current test standards don't measure rotational acceleration, nor do they really test the helmet in a way that would probe its ability to mitigate rotational acceleration. So our test standards right now are not really directed towards concussion prevention. They were designed and are directed towards preventing skull fractures and more serious brain injury.

There are some new designs emerging, both in athletic sports as well as things like alpine skiing and bicycle helmets, that are focused on reducing rotational acceleration, so there's some novel designs coming out there, but that was not the primary design feature of helmets.

And so fundamental to understanding what we can ask a helmet to do are these injury risk curves that Dr. Marion presented. So basically on the horizontal axis we have head acceleration or some other engineering metric, and on the Y axis we have the risk or concussion. And so, as Dr. Marion pointed out, this is not a linear relationship. This is a sigmoidal relationship such that the similar reduction in head acceleration doesn't necessarily correspond to the same reduction in injury risk. If you look at the two examples I have illustrated on here, you could have the same reduction in head acceleration, that would result in either a 25% reduction in the risk of concussion or a five percent reduction in the risk of concussion. And so knowing where we are on this curve, knowing what this curve is, is really central to us understanding what protective devices can do.

And so there's some important questions to think about as we interpret these curves. First of all, what level of risk is acceptable? If we go to the auto safety world, you can see that this concept of acceptable risk. So this is an injury risk curve for chest injury. So on the X axis we have chest acceleration, on the Y axis we have the probability of thoracic injury. And so you can see that – so we have one star cars which are out on the road today that carry with them a 45% risk of thoracic injury. If you think about two star cars, 35% risk. Even a five star car, which we all would consider kind of the highest level and the most safest vehicle, has an inherent risk of ten percent of thoracic injury. So we need to be answering these questions for concussion risk as well.

The second question to ask is, does it vary by age? Coming from a children's hospital, this is a question that's particularly important for me. So the way to answer that question is I think we need to go back and think about the physiology of concussion. So I told you before that this is a functional injury, not a structural injury. The metabolic needs are changing. Cerebral blood flow is reduced. There are deficits in how the brain functions. Synaptic transmission signaling membrane permeability is all reduced during the acute period of concussion. And so why that matters when we think about the effect of age is that we know the brain in undergoing dramatic development really well through young adulthood. And so this is a figure from the IOM report that shows the regional time course of synaptic formation, cerebral blood flow and metabolic changes that happen with brain development. And so you can imagine that the effect of an injury producing head movement at age four is going to be very different than the impact of that same movement at age 14 because the physiology, the underlying physiology, is changing.

There is some evidence in the animal literature to suggest that there really is an age dependency in brain injury tolerance. So this is data from a porcine model that looks at a single rapid rotational injury. And so this was porcine that were five days old and four weeks old, kind of representing infants and toddlers in a porcine time course. And so with the same input, you can see in the graph on the left of the percentage of traumatic axonal injury, the graph on the right a percent intracranial hemorrhage, you can see that the response is different depending on what age the subject was. So this work was done in moderate and severe traumatic brain injury. We don't know whether these findings apply to mild traumatic brain injury or concussion.

Third question when we think about injury risk. And this is the one that we have the most data to support. Is whether these curves vary by the direction of head impact. So we know that there is an effect of impact direction on symptoms. So this is the same porcine model. Three different impact directions. Sagital movement, kind of shaking your head yes, horizontal, shaking your head no, and then coronal, kind of moving your ears to your shoulder. And we can see that, both in measuring the time period of unconsciousness or the percent of animal subjects that were apneic, you can see that sagital rotation produced the worst incidence of apnea and the longest unconsciousness time. So it suggests that impact direction influences symptoms.

We've also shown that impact direction influences cerebral blood flow. So same animal model. Now we're looking at the cerebral blood flow on the left, at one hour post-injury and six hours post-injury, and what to take away from that graph on the left is that the green bars, which are the sagital loading, have the most reductions, the greatest reductions, in cerebral blood flow, and that those reductions are sustained. The graph on the right illustrates that long-term nature of that reduction in cerebral blood flow for sagital movement.

We also know that injury depends on the direction of impact. So same porcine model, three-to-five-day-old piglets, and this data shows that axonal injury is more persistent when you load in the sagital plane, again shaking yes, versus the axial plane. And so the graph on the left shows at six hours in the white bars, six days post-injury in the shaded bars. You can see that the percent axonal injury in the sagital loading is greater and it's extended a longer period of time.

And then lastly it's been shown that direction influences behavior post injury. So this is a comparison of locomotion of the piglets post-injury. And in the sagital plane those animals were more stationary after injury than animals injured in other directions. They had less complex motion pattern when they did move. So their behavior, which we know that this injury kind of manifests itself clinically, the behavior is different depending on the impact direction.

So the last kind of influence on this risk curve that I think is really intriguing, and we don't know a lot about this, is whether that injury risk curve varies between the number and interval of concussions or head impacts. So what we do know is that the studies of the effects of repetitive head impacts is really mixed in the literature. And this is this concept of sub-concussive impacts. Some show negative outcomes, some show no effects. What we know from the literature is that symptom load appears to increase in those that have more concussions. So they have more symptoms the greater number of concussions they have

experienced. And those with more than one concussion have a longer recovery for those subsequent injuries that they experience.

But the questions that I don't think we have good answers to are do frequent impacts or multiple concussions alter those injury thresholds. And what does multiple concussion mean? If you have two concussions in one season, or you have two concussions five years apart, are they the same thing? Are they the same two? And basically are the injury thresholds, does that curve vary for tissue that is physiologically compromised compared to normally functioning tissue. So this is an area that I really think future research needs (audio break).

So really what this data suggests is that until these risk curves are defined it's difficult to assess the injury mitigating ability of helmets and protective equipment. We simply don't know what to ask the protective equipment to do.

(Audio break) wrap up here. So as I mentioned, my comments were primarily on helmets, but really the fundamental concepts apply to soccer and rugby headgear, mouth guards, face masks, all of the protective devices. And so the data just simply isn't there to support mitigating concussion risk for these products.

We think about methods to determine injury risk curves, I've shown you some animal models, and then Dr. Rowson is going to talk at great length about the study of real-world injuries with sensors to measure the input. And so animal models have advantages. You know what you did. You have reproducible mechanical loads, you know the injury history, you can measure physiology and you can measure injury. But it's an animal model. We need to translate that to humans, and so it's difficult to kind of measure some of these more subtle symptoms.

The study of real-world events. I won't spend a lot here because Dr. Rowson will talk about it. But these are the sensors affixed to helmets, mouthpieces that measure the mechanical input. There are a few things to think about as we interpret this data. We must ensure that the sensors are reliable. They need to provide an accurate assessment of head motion. And we've looked at one particular sensor. Others have looked at other different manufacturers, and so the errors have been reported of to ten to 30%. They need to measure both linear and rotational components. And then we need to understand the clinical piece. How do we combat this issue of under reporting that we know happens.

The last concept I want to highlight is risk compensation, which I think is important. There's clear data in the literature that when you put a protective device, an advanced protective device, on youth in particular, that athlete feels empowered to take additional safety risks. And so thinking of this from a public health perspective, we may not have done any, in the end, improved the safety because they're acting more aggressively, they're playing harder, and they have increased confidence. And so I think we need to think about this issue and understand that it's a person that's using this technology and understand their behavior in reaction to it.

So in summary I come back to my fundamental questions. We need to define the clinical entity that is mild TBI, and there is great work going on right now to develop objective, age-specific markers and metrics. And then this piece about the mechanics. We need to quantify the biomechanics at a global head level and a brain tissue level that leads to concussion. And I believe it's the answers to these questions that will help us understand whether helmets can play a role in injury prevention.

And here is my list of references.

And I will hand it back to Dr. Labutta.

Great. Thanks so much, Dr. Arbogast. As we go forward, we're only becoming more and more aware of how important both the clinical and the mechanical information is. So as a clinician I really appreciate understanding a little bit more of the mechanics thanks to folks – your work and folks like you.

I'd also like to point out, and many on the webinar probably know this, that the NCAA and the DOD now have a grand alliance looking at these issues, so the issue of helmets and sports-related issues are something that clearly both the NCAA and the DOD are heavily invested in.

With that I'd like to introduce our third presenter, Dr. Steven Rowson. He's Assistant Research Professor for Biomechanical Engineering at Virginia Tech. He's a research faculty member at the Center for Injury Biomechanics, which is an interdisciplinary research center that combines the Virginia Tech College of Engineering with the Wake Forest University School of Medicine. Dr. Rowson and his colleagues really developed, as Dr. Marion previously alluded to, the star evaluation system for football helmets to reduce the probability of concussion. Largely from that work you see that there has been a paradigm shift in the way that consumers now look at football helmets for purchasing and how football helmets are designed. So thank you very much for joining us Dr. Rowson, and we're very interested in hearing your presentation at this time.

Thank you for that introduction. I'm excited for this opportunity to present some of our research at Virginia Tech studying concussions on the field and in the laboratory.

To begin, I or anyone else in our group have nothing to disclose. More specifically, we have no financial interest in the helmet manufacturer or sensor company, and we have a policy declining any opportunities for helmet expert witness consulting. Furthermore the views expressed in this presentation are my own.

Funding for the presented research has come from NIH, the Department of Transportation, the Department of Defense, and Toyota Motor Corporation.

In this presentation I'll be talking a lot about head acceleration, so prior to staring I want to introduce the idea of acceleration-based brain injury. Because the brain is not rigidly attached to the skull, when the skull is accelerated, the brain motion lags behind that of the skull. This results in inertial loading of the brain tissue. These inertial loads experienced by the brain are difficult to measure, so we use acceleration of the skull as a metric for characterizing injury risk because it is indicative of the inertial response to the brain's impact loading.

It is important to keep in mind that the acceleration of the skull doesn't cause injury, but rather the brain, the pressure and strain response of the brain tissue that does.

Hardy (sp), et al. confirmed this experimentally through a complicated series of high-speed x-ray tests where they used cadaver skulls that were instrumented. And they quantified relative brain motion between the skull and the brain during impact loading. What they saw was that the brain moves actually very little, on the order of five to seven millimeters. And they quantified strain as around ten percent. They also saw that the skull kinematics were correlated to the brain injury mechanism, so strain and pressure.

I also want to give you a quick introduction to basic helmet function. There are two primary components of the helmet to protect from injury. There's the helmet shell which deflects to distribute force over a larger area. And there's the helmet liner, or padding, inside the helmet, which modulates the energy transferred to the head. So it doesn't always reduce it, but it changes the way energy is transferred to the head.

These two components can be tuned to meet design criteria and specifically optimized to reduce concussion risk. I use football helmets in the presentation as an example, but the principles discussed here will be translatable to other applications.

It's estimated that as many as 3.8 million sports related concussions occur in the United States each year. Of all sports, football has the highest incidence. As a scientist we view this as a unique opportunity to collect biomechanical data to characterize concussion in humans. So the idea of this research was to instrument and observe a population that is at high risk for concussions, being the football players, because they willingly hit their heads on a day-to-day basis.

About ten years ago we didn't know that much about the biomechanical forces associated with injury. But over the last ten years, ourselves at Virginia Tech and other institutions since then, have been instrumenting football players with helmet accelerometry to define the biomechanical components of concussion. To do this, we use something known as the hit system. It's a commercially-available accelerometer array that gets installed in the empty space inside helmets. They consist of six accelerometers that are spring mounted. And this part is important. The fact that they are spring mounted allows the accelerometer to maintain in contact with the head and it decouples it from the helmet. This ensures that we're measuring head acceleration and not helmet acceleration. From this device we can measure (inaudible) linear accelerations, and we get a pretty good idea what the rotational accelerations are.

So for every game and practice that our players participate in during the season, they have these sensors equipped in their helmets. When the helmet is on the head, we continuously sample data at 1,000 hertz. Any time an accelerometer senses a head impact over ten g's, data acquisition is automatically triggered, and we collect data for a period of 40 milliseconds. So we get eight milliseconds, or a little bit of data before the impact occurs, and then 32 milliseconds following impact. To give you an idea of how long these impacts last, they are on the order of about ten milliseconds.

In addition to that data, each event is also time stamped so we can compare it and verify each impact on video. And that's something we spend a lot of time doing in the lab.

So for any given season we've had as many as 64 Virginia Tech football players instrumented, and we've collected data from these players for every game and practice that they participated in. And it's very important to note this is a huge team effort. We work very closely with the Sports Medicine Department, the athletic trainers, the team physician, the coaches allow this research to happen. And it's really allowed us to collect a unique data set.

So this is going to be a video of an example of a concussive event. It's taking a minute to load. So the player in the bottom right is going to catch a screen pass, he's going to run about ten yards and he's going to impact his head on ground while being tackled. For this particular impact, the helmet sensors tell us that he experienced 136 g's and a rotation acceleration a little over 6,200 (inaudible) per second squared. This particular impact resulted in clinically diagnosed concussion, and it's an example of how we compare our biomechanical data from the helmet sensors to clinical data we're collecting at the field level.

So this helmet instrumentation has allowed us to compile a very large biomechanical data set that we can use to understand the kinematics associated with concussive and sub-concussive impacts. While we started this research and were the first ones to do it in 2003, many other schools saw the value of this type of research, and in 2004 several other schools started using this technology to collect data from their football players. And by 2010, there were over ten schools doing it.

These are real world head impacts that we're collecting data for, and they are comprised of both linear and rotational acceleration. And what is also unique is that these data are collected directly from human volunteers. You know, brain injury – concussion is a functional response, as Dr. Arbogast mentioned. You can't identify it structurally, so it's difficult to identify injury in cadavers. And while cadaver and animal experiments are important, you need that third piece of the puzzle to supplement them, data collected from humans because it's difficult to translate animal data directly to humans as well.

This figure is going to give you an idea of the distribution of the data that we're collecting. And if we think about all the data that we've collected over the years, we can categorize them in two classes, impacts that caused concussion and impacts that did not result in concussion. So these are probability density function, so they're normalized. So the scales of these distributions are pretty similar. If these were raw count numbers, the blue would be much, much, much taller than the red because we have so many more sub-concussive points than we do concussive.

But to give you an idea of what these distribution shapes is, the sub-concussive distribution in blue is a heavily right-skewed distribution, so the majority of the impacts are very low severity. And at higher

severity you can see our red distribution. The concussed distributions normal in shape. But what's unique about these is we want to focus on the overlap between these two.

Trying to draw.

So this area right here, between 50 and 100 g's, see the blue distribution overlap the red distribution. This is the interesting part of the curve. This is where risk changes in humans. So as you're getting above 50 g's, concussion risk is beginning to increase. And you'll see that in the risk curves I show you later.

We can have the same type of plots for rotational accelerations. We have the blue distribution representing our sub-concussive data set and the red distribution showing our concussive distribution. Again, the concussive data set is normally distributed. The sub-concussive is heavily right-skewed with the majority impacts being of low severity. And the two distributions overlap. This is where risk changes.

So we've quantified this. These are risk curves we developed for linear acceleration and rotational acceleration. And it gives you an idea of how risk changes the function of linear and rotational acceleration. So at the bottom of this slide I have a couple of nominal risk values. For example, a linear acceleration of 149 g's and a rotational acceleration just over 5,000 radiants per second squared represents about ten percent risk.

So the idea with the helmet is the helmets modulate energy transferred to the head. If you can design that helmet to manage that injury in such a way that it reduces head acceleration where you would have a data point in that red distribution, and you could lower it to the point where it approaches the blue distribution, you can reduce concussion risk and thus reduce the incidence of injury. And this is the primary principle I'll be discussing today. The way helmets currently do this and the direction they may be going.

So before I get into the specifics I want to compare two helmets. These are two commercially-available helmets, and we'll be comparing the same exact impact between these two helmets. It's an impact to the top of the helmet from 60 inches.

NOCSAE certified each one of these helmets, and both of these helmets are considered safe to be on the field. There's a severity index threshold of 1,200. Both helmets meet that criteria, so they're considered safe on the field, they're not going to result in catastrophic injury. Skull fracture, brain bleed, they're highly unlikely in both these helmets. However, one of these helmets, the Adams, barely passes that threshold, while the other helmet more than exceeds that threshold. And while both are considered safe to be on the field, this has big implications in the differences in these helmets to manage impact energy.

If we look at peak acceleration for these specific impacts, severity index, for those who are unfamiliar with that, is a function of peak acceleration, so these two values are closely related. So it's not surprising that you see this same relationship. For the same impact, the Adams helmet results in a head acceleration of 190 g's while the Riddell 360 resulted in a head acceleration of 84 g's. We can think about these numbers in terms of risk. So this is our risk curve, and it's sigmoidal. If we look at the Riddell 360, we saw 84 g's. And if we look at the Adams helmet, we can quantify risk using this curve as well, and we saw 190 g's. So the Riddell 360 at 84 g's had a one percent risk of concussion. The Adams helmet, at 190 g's, had a 48% risk of concussion. So for the same impact, there's substantial difference in risk of concussion. And the reason this risk of concussion is so different is because of the non-linear nature of this curve, which Dr. Arbogast touched on.

So there are a lot of people who say that it doesn't matter which helmet you wear, a helmet is a helmet and they are all as safe as they are going to be. I like to show them this slide and ask them which helmet would they choose. Given this limited data set, I would hands down pick the Riddell 360 over the Adams. But not everyone experiences this same exact impact all the time.

So what we wanted to do was create a method to consider all the head impacts that players experience over the course of a season, and summate this data in such a way that we can quantify on a global scale how risk differs between helmet types.

And what resulted from that were the Virginia Tech helmet ratings. The idea is that we combine the impact exposure with the risk analysis using our own field data to assess helmet performance for consumers.

This is the equation you saw earlier. The specifics aren't that important. I'm going to break it down in very simple terms. So the idea is we're translating our own field data to tests in the laboratory. So we want to make sure our tests in the lab are representative of what we're measuring on the field. So through a series of drop tests, we evaluate helmets using two fundamental concepts.

One, tests are weighted based on how often they occur. And two, helmets that lower head acceleration reduce risk. If I wanted to simplify the equation in the middle of this slide, I would say exposure times risk equals incidence. So we have the star value, and that's our incidence of concussion. It's what we're predicting. The E in that equation represents exposure, and it's a function of impact location and impact energy. And the R represents risk, which is a function of head acceleration.

For our drop tests, we test four impact locations. The front of the helmet, the back of the helmet, side, and the top of the helmet. And we test each of these locations at five impact energies ranging from 12 inches to 60 inches.

And the idea is we map those impact configurations to exposure that the player sees on the field. So like I mentioned earlier, our impacts are heavily right skewed. Low severity impacts are much more common than high severity impacts. So if we look at this table, we see that impacts to the front of the helmet at 12 inches occur 138 times to the average player, while impacts to the front of the helmet at 60 inches, a player might only see once a year. And this will differ by location. The front of the helmet is impacted more than the side of the helmet. So these all add up to the total exposure that a player will see over the course of the season.

A player at Virginia Tech who participates at every game and practice will see 1,000 impacts over the course of the season. And this is how we map each one of those impacts to conditions in the laboratory. So these numbers in this table is how we weight the data because each test is weighted based on how often it occurs.

These will be two videos showing examples of drop tests. I think they will pop up in a minute.

I think I lost the presentation. Well that's okay. These videos are very similar to what Dr. Arbogast shared in her presentation. It's an example of a drop test with a helmet, to the front of the helmet and to the side of the helmet.

So for one of those tests, we'll measure head acceleration in the (inaudible). So for example, if in one test we measure 190 g's, we can use the risk curve to relate that to a 40% risk of concussion. If we know for that particular impact configuration a player will see that ten times throughout the course of the season, exposure for that impact configuration is ten impacts. We can multiply that by the concussion risk of 40%, and out of those ten impacts we would estimate that four concussions would occur given this risk curve.

This is how we relate our impact exposure to our risk to predict the number of concussions that a player will experience. So we do 120 tests per helmet model to come up with ratings. And we simplify all this information into a global number that will quantify risk of concussion. And we relate them to a number of stars. And these are the star ratings of the current helmets available. So there are nine helmets that are currently rated as Best Available five star helmets. There are eight helmets that are rated as four stars. Three helmets rated as three stars. And when we initially did the ratings in 2011, there are three helmets

that are rated two stars or below. None of these helmets are currently available on the market anymore, so you are seeing a shift towards better performing helmets.

We make this data publicly available to consumers. So if you go to our website, you can find these helmet ratings online that not only describe the methods that we use to test the helmets and the science behind it, but the general star ratings showing relative performance between different types of helmets. These ratings have had an effect on players, coaches, parents, as well as manufacturers. In 2010, 40% of NFL players were in a one star helmet. And half of Virginia Tech's football team were in a one star helmet. And that's because no one knew any better. No one had data comparing the relative performance of different types of helmets. All players in college, and most in the NFL, at this point have switched to better performing helmets. Coaches and parents are now making informed decisions when purchasing new helmets. And manufacturers are designing their helmets to the testing methods that we use as a method to improve their helmet designs to reduce the incidence of injury.

So everything I've talked to this point in terms of star ratings has related to in-laboratory tests that were based on on-field data. We wanted to look at on field concussion rates. So player A in this helmet versus player B in the helmet, playing for multiple years, who's more likely to have a higher risk of concussion? So we recently published a paper in the *Journal of Neurosurgery*, Can Helmet Design Reduce the Risk of Concussion in Football? And we compiled data from eight different collegiate football teams, Virginia Tech, North Carolina, Oklahoma, Dartmouth, Brown, Minnesota, Indiana and Illinois. And what's unique about these eight schools, between 2006 and 2010, every one of these schools had their players instrumented with the Hit system so they're collecting head impact data. So we studied over 1,800 players for five years, and we were able to control for the number of times each player in each helmet type impacted their heads. This is critical to understanding differences in concussion rates. So we're not comparing one player in a helmet who sits on the bench most of the time and doesn't experience a lot of head impacts and therefore is unlikely to get a concussion to the star linebacker who plays every down and impacts his head on almost every down. And because he's hitting his head more, he's at a higher risk for concussion. That's a confounding variable that we can control for with the head instrumentation. So if we control for impact exposure to the head and compare two helmet types, we can quantify differences in risk of concussion.

Because all the players we studied were instrumented with the Hit system, we had to compare either Riddell Revolution helmets to Riddell VSR4 helmets because those are the helmets that the instrumentation fit in. and what we saw was a 54% reduction in concussion risk in players wearing the Riddell Revolution compared to the VSR4.

If we look at the two helmets, a couple of things are immediately noticeable about differences in design. The Riddell Revolution has about 40% thicker pads than the Riddell VSR4. And what this does is allow the helmet to better modulate the energy transferred to the head. And as a result, that reduces head acceleration. And we can quantify that in a very controlled manner in a lab. For the same exact head impact, this is a 60 inch drop to the front, side, rear and top of the helmet – and these are repeated trials so you have some variance on these bars – but the VSR4 consistently results in higher head accelerations than the Revolution helmet.

Not only do we see this in the lab, but we see it in the field. If we compare the top five percent of head impacts of players in each helmet type experience, so these are cumulative distribution functions that you see here, players in the VSR4 helmet were more likely to experience a higher head acceleration than players in the Revolution helmet. So we saw this on the field as well. So if we look at the 99th percentile head impact on this plot, and this is all the players lumped together in each helmet type, you could see that players in the VSR4 helmet, 99 percentile head impact is greater than 100 g's while the Revolution is below.

We could also break this down by player position. And if we compare the 99 percentile head impact, you can see that average reductions in head acceleration range from two percent to 13%.

So we can use in-laboratory and on-field studies to quantify differences in concussion risk between helmet types. When we're looking at these two specific helmets, where we have ample data in both the lab and on the field, we can specifically quantify and compare the risks between the two different methods. Using our star ratings, which you see here, the Revolution is a four star helmet and the VSR4 is a one star helmet. We can quantify risk reduction by dividing the star value of the Revolution, which is the 0.362 you see on the helmet, by the 0.791 star value for the VSR4. And that's going to give us our risk reduction between those two helmet types.

And what we see is, in our exposure controlled on-field study, we quantified a 53.9% difference in concussion risk. And in our laboratory-based star evaluation, we predict a 54.2% difference in concussion risk. It's remarkable that these two numbers are so similar to one another. This great agreement between our in-laboratory and on-field study gives us a lot of confidence in seeing that these are real risk reductions we're seeing between the two helmet types.

Just a couple quick notes before I wrap this up. You heard a lot about rotational acceleration earlier. I didn't talk much about it when I was talking about risk reduction, how we evaluate helmets in the lab. And that's because pure rotational impacts do not occur. The helmets are smooth and round, so the helmets don't catch and rotate the head much like animal tests in the lab can. The linear component of the impact drives the rotational component. The rotational acceleration is highly correlated to the linear acceleration. For a given impact, if linear acceleration is reduced by a helmet, rotational acceleration will also be reduced.

Another question I get a lot is, can all concussions be prevented? No, any player in any sport can sustain a concussion, even with the very best head protection. Are there differences between individuals? Some people may be genetically predisposed to injury. And there's other extrinsic factors like hydration and neck musculature that we don't know a lot about right now and how they relate to concussion risk. It's also important to note that helmets don't cover the entire head. They can only reduce risk for impacts to the covered regions of the head. This excludes the face mask. And until there are more advanced materials, helmets are limited by padding size and thickness. Not all concussions can be prevented with helmets, but we can minimize concussion risk and incidence.

So when we talk about concussion incidence minimization, we view there as being three strategies to most effectively minimizing the number of concussions experienced by athletes. The first one is rule changes. The second one is teaching proper technique. And the last one is better equipment. And these three used together will be most effective in reducing the number of concussions experienced each year. So you can reduce exposure to head impacts through rule changes and proper technique. When you take a head impact out of the equation, a concussion is very unlikely. And in any sport incidental head contact will occur. You can't eliminate every head impact. So for the remaining impacts, you want to reduce concussion risk by improving helmet design. And those strategies used together will reduce the most concussions.

So do helmets work? Yes, helmets work and can reduce the risk of concussion, but helmet design can be improved. There are data that exist that can improve helmet design available today. The helmet modulates the energy transfer to the head, and helmets that do this better reduce acceleration to the head and a result reduce risk of concussion.

I've showed you some of our risk and how we've quantified risk reduction experimentally in the lab and on the field, and I think that wraps this presentation up and I'd be happy to answer any questions with the remaining time. Thank you.

Great. Thanks a lot, Dr. Rowson. If you have any questions for Dr. Rowson or our other presenters, please submit them via the Question box.

As attendees submit their questions to the presenters, I would like to share this month's DCoE Product Brief, A Head for the Future. In March, the Defense and Veterans Brain Injury Center launched a multi-year traumatic brain injury awareness education and prevention initiative called A Head for the Future.

The campaign is designed for service members, line leaders, veterans, medical providers, and family members. The goal of this campaign is to raise awareness about the signs and symptoms of TBI, encourage individuals to take proper safety precautions during high-risk activities, such as playing sports, conducting military training, or operating motor vehicles to prevent traumatic brain injuries and also to encourage individuals to seek medical attention when needed. DVBIC's downloadable resources through the Defense Department and Veterans Affairs are very useful and publicly available for anyone needing information on the signs and symptoms or treatment of TBI. For more information about A Head for the Future campaign, please visit dvbic.dcoe.mil aheadforthefuture.com.

It's now time to answer a few questions from the audience. If you have not done so already, you may submit questions via the Question box located in the upper left-hand corner of your screen. We will respond to as many questions as time permits.

My first question I think is to Dr. Rowson and to Dr. Arbogast, and the question relates to would either one of you or perhaps both comment on the movement of the brain, since accelerometers are measuring the movement of the helmet, would you comment on the movement of the brain within the skull and also would you comment on the effects of any accelerometer on the helmet itself. Added weight, changing the center of gravity, or any other features that the monitor would have in relationship to the movement of the helmet itself. Thank you.

This is Dr. Arbogast. I think most of these sensors are pretty lightweight and really don't influence the kinematics of the helmet. I know that the Hit system in particular, they've kind of integrated it right within the padding so it's not something I'm concerned about.

With regard to the movement of the brain, I mean that's kind of the Holy Grail. That's is what ultimately leads to injury. And these methods that we're using are the closest we're going to get to understanding how the head is moving globally because we want to do that on living people. But really we want to understand what's happening in the brain. And so I think there are some innovative animal models to look at that as well as computational kind of element models that you could take what you measure on a football field, for example, of the global head kinematics and then you could apply that to a computer model of the brain and look at what the brain is doing.

I agree with Dr. Arbogast on both responses. We've done tests in the laboratory looking at a number of sensor, with the sensor installed and without the sensor installed, and compared the impact response of the helmet. And the sensors are so light and non-intrusive that we see absolutely no difference in head impact response.

Great.

In relation to brain motion, you know, it's going – we use acceleration as a surrogate because it's very difficult, and in an impact environment almost impossible to measure in a human. So we have to rely on those other models to quantify that best.

Great. Thank you both. And I think this goes to all three of you. The question here is, do you have any information or can you relate to us any high school studies that have been done with measuring impacts and their effects on high school athletes, football in particular.

Sure, this is Steve Rowson. We've done some work comparing our data at the collegiate level to that of high school players. And we see a couple of interesting things. One – this one is not surprising – collegiate players impact their heads a lot more than what high school players do. The second thing we see is that the accelerations associated with concussion are very, very similar between collegiate players and high school players. So the average concussion in high school is about 100 g's, the average concussion in college is about 100 g's. Where the interesting difference lies is that risk is different. High school players will experience – if you consider 100 g's, the high school player is more likely to experience concussion when they experience head acceleration of 100 g's than the college football

player is. So it raises the question of is there some sort of difference in tolerance between these two populations? Maybe the people who can't sustain that many head impacts quite playing football before they get to college.

I think one challenge in comparing across age groups is that because we don't have objective markers of concussion, we rely on subjective presentation of symptoms. And what we don't know is whether there is any difference in how a high school player either might be aware of their symptoms. There's surely differences in kind of the clinical attention that a given high school player might receive than a collegiate player at one of these bigger schools. So there's variability, possibly, in how folks kind of report their concussion across age groups. And that becomes really stark when you go even younger than high school age. And so if we kind of refer back to my two fundamental questions, having an objective marker of concussion would really help us be able to interpret that data that Dr. Rowson just highlighted.

Sure thing. So somebody asked a question here, and I'm surprised but I shouldn't have been. It appears that there are commercially available impact indicators that are being marketed to parents of young athletes. I don't know if any of you are aware of those and what your thoughts of those are.

Steve, you want to go first on that one?

Sure. Sure. We currently have purchased everything that's on the market, and one of the things we're going to do is evaluate and quantify what you exactly get from all of these sensors. We've done some of this testing, but I'll just highlight some of our global concerns with that.

Now this data is not very straightforward in interpreting. And these sensors all use a different method of conveying data to the parent, or the consumer, or the coach, or whoever is looking at it. And it creates some challenges. Some of them use lights, so if some acceleration threshold gets exceeded, the sensor will start flashing, a red light or a (inaudible) red light. And that's an indication that maybe the player should come off the field. But not all these school systems have an athletic trainer or a physician on the sideline, so there's no one there to make a concussion diagnosis. And based on the on-field data we've collected, I wouldn't be surprised if ten to 20 players start flashing red suggesting they need to come off the field when you see these things in use. So I think you won't see players go back in because there's going to be serious liability concerns with whose liable if a player who had a sensor that was flashing red came out for a little bit and went back into the game later and then maybe got really hurt versus – another answer – another concern is how many impacts are too many. So a lot of these will quantify the number of impacts that players experience. But no one really has an idea of how many impacts, at what severity, and at what frequency are too many. So there's a lot of questions right now. I think they're going to collect valuable data, but I don't think we know what that data means just yet.

Yeah, I can't echo those comments, you know, any stronger. Concussion is a multi-faceted issue. And to boil it down to a light of yes, no, or even red, yellow, green, I think tremendously oversimplifies the issue in a way that will either increase liability for school districts, leagues, whatever, or lead to a false sense of security for parents, athletes and coaches. And I believe that those sensors are valuable research tools. As engineers we would love to get that kind of data on a regular basis on a large sample of subjects. But I don't think that they are kind of consumer ready.

The other piece that we've heard in our work with adolescent hockey players is what do you think the opposing team is going to do when they know they can turn the light on on the other guy's running back or center. There is a adolescent male reaction to this of wanting to "light him up." And so that, I don't think as public health professionals, is the direction we want to go.

Right. I'd certainly echo those. One of my friend's son played high school hockey, and he was well familiar with the term and introduced me to it, the "light 'em up" term.

So another question came in asking about what's the effect of repetitive hits, repetitive blows, if you will, repetitive accelerations on the same helmet. Is there a helmet fatigue point or does the helmet change in some material way after a certain point?

This is Steve Rowson. We've done quite a bit of testing here looking at repetitive impacts on helmets, and generally what we see is that there is no difference. We haven't tested a helmet to the point yet where, from when it was new to when it's a couple years old, we see any differences in performance. If I had to lean one way or another, it's possible the helmet only gets better, not worse, with time. You know, there's other things you have to be concerned about with an older helmet, and as technology gets better, you'll want to continually upgrade, but the pads if anything will start to stiffen or become more compliant over time. I haven't seen them get to the point yet where they're too compliant and you're going to run the risk of a pad bottoming out.

Great. Thank you. So I have this question for all of you, and it's a combination of a couple questions here but I'm going to try to boil it down as our time gets shorter. And it's kind of a combination of the questions that I think where Dr. Arbogast led us to, but without an available biomarker that can be quantified, how would either or all of you, notion the utility or validity of discussing graduations in concussion severity? Anybody want to take that one? Or just start that one?

I would just echo what Dr. Arbogast mentioned earlier, and you don't really know until the concussion is over, generally how long did it take for symptoms to resolve is I think the only idea of concussion severity you can get.

Yeah. I agree with that. I think that we don't know enough about what mechanically is happening at the cellular level to propose any other gradation of severity. But the symptom load and symptom duration is really all we have. And that really can only kind of be assessed at the end. And even that, I mean a symptom load, so a given patient has ten symptoms, is that worse than the patient that has one symptom that is just really debilitating. So I think because our measures are subjective, it's hard to talk about a gradation.

Great. Thank you very much. So I think we have time for one more question. Would anybody like to comment further on the issue of sub-concussive injuries in any sport or sub-concussive injuries as a whole, especially in the light of recent literature showing some evidence of changes, both anatomically and physiologically.

I think that follows well from our previous question. It's hard to know for certain whether – and I know the term is common both in the lay and professional literature, but I don't love it, of sub-concussive hits or sub-concussive injuries. It's hard to know whether those are actual injuries that aren't being diagnosed either because the person is not attuned to their symptoms, they're not disclosing their symptoms, you know, all of those limitations that go with a subjective assessment of an entity. I think that when the IOM looked at this issue, what the committee kind of came down on from looking at the literature is that there was not evidence to suggest that repetitive head impacts at the youth level led to kind of long-term negative consequences. You know, not every child that plays football and has a series of repetitive head impacts goes on to develop any long-term consequences. There's not clear evidence in the literature that that is a definite cause and effect.

Right. Dr. Rowson or Dr. Marion, would you like to comment further on sub-concussive injury or effects?

Well, you know, this is Don Marion. I think that there is, as you pointed out, there is intriguing MRI, DTI literature that has recently been published to show that you have unexpected suggestion of axonal injury based on the FA values weeks and months after a play when the athlete had no apparent or no clinically recognizable concussion. But the studies are nice because - the one I'm thinking of used helmet sensors. So we know from the sensor data, we know there was an impact, there just was no clinical appearance of concussion and yet there is this anatomic evidence. So I think that's intriguing. And I look forward to large prospective studies as we go along to seeing whether or not these people end up down the road with cognitive problems or long-term deficits.

Great. Thank you both very much. Thank you all very much.

At this point I'd like to try to sum up briefly and say that I know for those in the webinar audience, we concentrated mostly on sports injuries. Some of you had questions on military helmets, padding, different uses for helmets between aviators and paratroopers, the use of neck rolls. I'm sorry we couldn't get to all the questions, but we will have to leave blast detection, military helmets, and some of your questions for a future webinar.

With that, again I'd like to thank Dr. Marion, Dr. Arbogast and Dr. Rowson very much for their presentations. The notions and the principles behind helmet sensors is not going away. It's an important aspect of the concussion story, and will certainly need to be combined with our clinical information.

At this point I'd like to remind everybody to visit the website continuingeducation.dcri.duke.edu to complete your online CE evaluation and post-test and download your CE Certificate or Certificate of Attendance. The Duke Medicine website online CE evaluation and post-test will be open through Thursday, 17 July, until 2359.

To help us improve future webinars, we encourage you to complete the feedback survey that will open in a separate browser on your computer. To access the presentation and resources for this webinar, go to dvbic.dcoe.mil/online-education. An audio recording and an edited transcript of the closed captioning will be posted to that link in approximately one week. The Chat function will remain open ten minutes after the conclusion of this webinar to permit webinar attendees to continue to network.

The next DCoE psychological health webinar topic, Hearing and Vision Impairment from Combat Trauma, is scheduled for 24 July from 1:00 to 2:30 p .m. The next DCoE TBI webinar on the topic of ICD-9 Clinical Modification Coding Guidance for TBI Within the Military Health System is scheduled for 14 August, also from 1:00 to 2:30 p.m.

Again, thank you for attending, and have a wonderful day.

This concludes today's conference. Thank you for your participation. You may now (end audio)