Head Protection: While Equipment Advances, Questions Remain

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As the Army prepares to field an improved combat helmet and develops the next generation of protective headgear, it is also taking stock of what is known and not known about the signature wounds of the conflicts in Iraq and Afghanistan: traumatic brain injury (TBI) and post-traumatic stress disorder (PTSD).

The Advanced Combat Helmet, currently used worldwide, is scheduled to be replaced this fall for deployed and deploying Soldiers with the Enhanced Combat Helmet, which offers even more protection. (U.S. Army photo.)

Scientists, combat developers, health care professionals, and leaders in head protection painted a complex picture of mixed progress at the 27th Army Science Conference from Nov. 29 to Dec. 2, 2010; a Head Protection Summit sponsored by Program Executive Office (PEO) Soldier Feb. 16-17; and the Association of the United States Army (AUSA) Institute of Land Warfare's Winter Symposium and Exposition Feb. 23-25.

Their reports illustrate how far the Army has come since 2008, when Secretary of Defense Robert M. Gates issued his June 26 memorandum, "Caring for Our Wounded Personnel and Their Families," calling for a plan of research and development investments to advance state-of-the-art solutions for world-class medical care for PTSD, TBI, and other conditions afflicting Soldiers as a result of their combat service.

About two-thirds—64 percent—of Soldiers who have returned from fighting in Iraq or Afghanistan have TBI or PTSD, noted GEN Peter W. Chiarelli, Vice Chief of Staff of the Army, at the AUSA Winter Symposium. "The fact remains, these wounds are not well understood," he said.

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Dozens of research and development initiatives are underway to measure the many variables involved in prevention, detection, and treatment of TBI and PTSD, from how best to quantify the effects of blast on Soldiers' helmets and their brains, to how best to treat the injuries, which can have long-term, potentially devastating impacts on day-to-day functioning and quality of life.

"There's been an unprecedented level of investment … in traumatic brain injury, post-traumatic stress, and suicide," said MG James K. Gilman, Commanding General of the U.S. Army Medical Research and Materiel Command (MRMC) and Fort Detrick, MD, at the Army Science Conference. Gilman noted that MRMC is overseeing some 535 active projects representing about $750 million in investment.

The ECH is a joint U.S. Marine Corps/U.S. Army developmental effort that will provide increased protection against ballistic and fragmentation threats. It uses advanced thermoplastic materials that require different manufacturing processes than those associated with resin-impregnated para-aramids. (U.S. Army photo courtesy of PEO Soldier.)

Building a Better Helmet

In the area of Soldier equipment, the Marine Corps and Army are preparing to field the next-generation combat helmet. Meanwhile, the Army is leading an initiative that looks ahead to the succeeding generation of helmets, an integrated headgear system that would protect the skull, face, eyes, and ears.

This fall, deployed and deploying Soldiers can expect to trade the Advanced Combat Helmet (ACH), introduced in 2002, for the Enhanced Combat Helmet (ECH).

The two helmets look nearly identical, but the ECH, a Marine Corps-led program, represents a major improvement in performance. The ECH is a little thicker and weighs 1 to 4 ounces less than the ACH, depending on the size. (The ACH, now in sustainment with more than 1 million fielded, weighs 3.06 pounds in a size medium.)

But there are much more significant differences in protection. "We're about to take a big step with the ECH," said MAJ Jason A. Morneault, PEO Soldier's Assistant Product Manager for head protection systems, at the PEO Soldier-sponsored conference, where head protection experts from medicine, industry, sports, and academia gathered to discuss, collaborate, and coordinate on preventing and mitigating head injuries from ballistic and nonballistic (blast and blunt impact) threats.

The ECH was expected to provide 35 percent greater fragmentation protection than the ACH, but testing showed the improvement to be 50 percent or more, Morneault said. In fact, stronger test guns will be needed to figure out exactly how good the fragmentation protection is. The ECH also provides increased ballistic protection against select small-arms threats.

The improved protection stems from a new material, an ultra high molecular weight polyethylene (UHMWPE) fiber composite. UHMWPE is a class of advanced thermoplastic materials that require different manufacturing processes than those associated with the thermosetting resin-impregnated para-aramid fibers used in the ACH.

The U.S. Army Research Laboratory (ARL) found that some of the technologies that it was developing for other applications had potential use in helmet technology to protect Soldiers from the combat threats in Iraq and Afghanistan. ARL scientists and engineers also pioneered a molding process to pre-form the thermoplastic material, combining layers of the material into lightweight helmet shells. This new methodology, in turn, has transformed the U.S. industrial base for the manufacture of ballistic helmet material.

The Army is working with numerous partners, including the Marine Corps and industry, on the future-generation helmet for mounted and dismounted Soldiers. The system takes a "holistic approach" to protecting the head, face, and neck, said Donald R. Lee II of the Natick Soldier Research, Development, and Engineering Center (NSRDEC) at the Head Protection Summit. NSRDEC is managing the initiative, a four-year effort through FY13.

The Helmet and Electronics and Display System-Upgradeable Protection (HEaDS-UP) Army Technology Objective incorporates ballistic and nonballistic protection with greater fragmentation protection for the lower face, situational awareness, interoperability with night vision equipment, and improved hearing protection.The objective is a well-balanced, modular system that reduces neck fatigue and increases mission performance and situational awareness in all environmental conditions without sacrificing mobility, agility, or weapon compatibility.

The Helmet Sensor Program provides small, lightweight, low-power sensors that mount to Soldiers' combat helmets. The sensors detect, measure, and record impact and blast overpressure associated with IEDs and other events that may cause concussions in an operational environment. (U.S. Army photo courtesy of PEO Soldier.)

Ultimately, HEaDS-UP will yield a package of design options and guidelines based on manufacturing best practices, lessons learned, and mature technology, Lee said.

Gathering Data in Theater

Another element of combat helmet development—the helmet-mounted sensor program—is also undergoing improvements, even as the medical community evaluates the potential and limitations of its early results.

The Generation II Helmet Sensor, to be fielded in August, features upgrades in power management, storage capacity, and data exchange compared with the first-generation sensor, almost 7,000 of which were mounted on helmets in Iraq and Afghanistan to collect data from March 2008 to March 2009.

The sensors measure and record impact and blast overpressure associated with improvised explosive devices (IEDs) and other blast incidents, as well as impact events, that may cause head trauma in combat operations.

The helmet sensor "is not a field diagnostic tool, as some people assume," Morneault cautioned. "It's a data-gathering device for the medical community." The data collected can be used "to better understand what's going on in IEDs and different blasts and blunt impact trauma we're seeing downrange."

While the information gathered has the potential to improve the prevention and mitigation of TBI, the data collected from the first deployment of helmet sensors has unexpected limitations, Gilman

said. Of 250,000 events recorded by the sensors in theater, "only 60,000 of those probably represented some sort of blast or impact," he said. "The sensors were actually very, very sensitive."

MRMC attempted to correlate the sensor recordings to actual injury data or to data found in post-deployment health reassessments, to develop a model of blast injury, and found that "the sensor data correlated very, very poorly," he said.

It will help, Gilman said, that the Generation II sensor will allow for wireless download of data, versus plugging the earlier sensor into a USB port. "I do understand that the job of a young leader is to go downrange and bring Soldiers home, and it's not primarily to collect data from helmet-mounted sensors."

TBI Research Challenges

TBI can be caused by injuries to the head from bullet fragments and shrapnel, blunt impact injuries such as from a collision, or blast events such as the detonation of an IED. Blast, ballistic, and blunt impacts are separate phenomena, with different characteristics. The least understood are blast injuries.

What is known is that blast injuries can result in long-lasting neurologic and psychological problems. Body armor allows the lungs to tolerate blast effects, but the brain is exposed to blast levels in ways that medical experts are still trying to measure.

Experts from the military medical community agree that correctly understanding the biomechanics of blast injuries is vital to the Army's operations, readiness, and health.

"The term itself causes a lot of confusion. … It's a very, very broad spectrum of injury types," said Michael J. Leggieri Jr., Director of DOD's Blast Injury Research Program Coordinating Office within MRMC.

"We have a vast medical TBI research portfolio … focused on knowledge gaps," Leggieri said at the Head Protection Summit: "How do we prevent injury? How do we quickly diagnose that injury? How do we reset? How do we return that person [to active duty]?

"There's a lot we don't know about this injury," he said, although "there are many, many hypotheses about how this injury occurs. If we don't understand the mechanism, there's no way we can develop effective protection strategies."

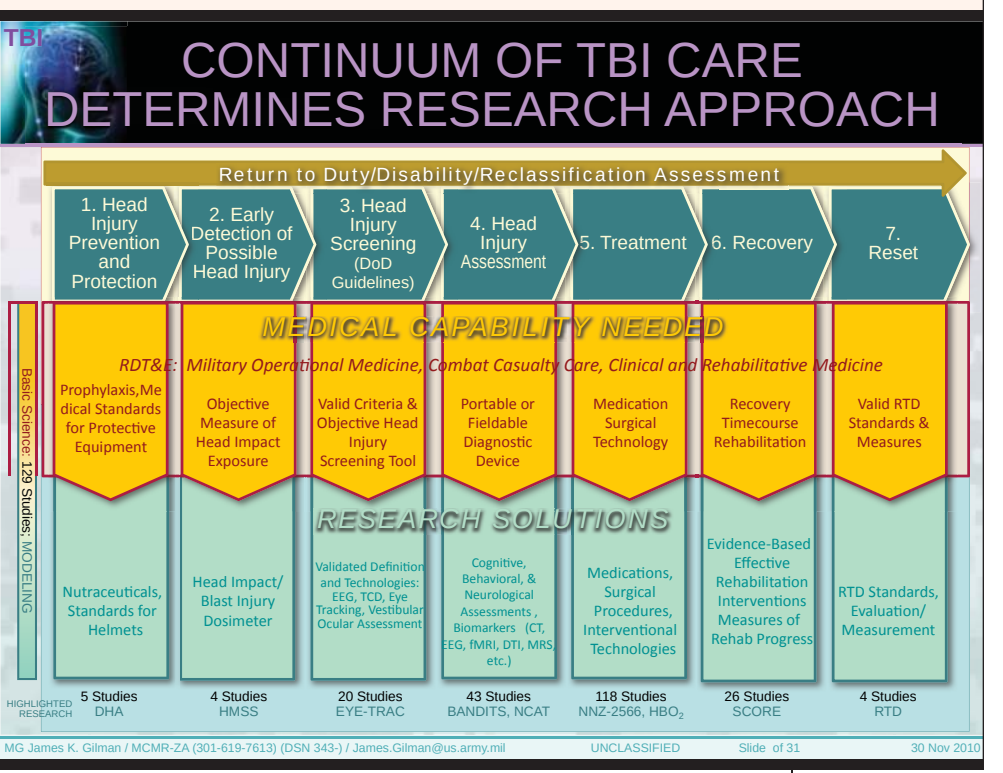
Continuum of Research

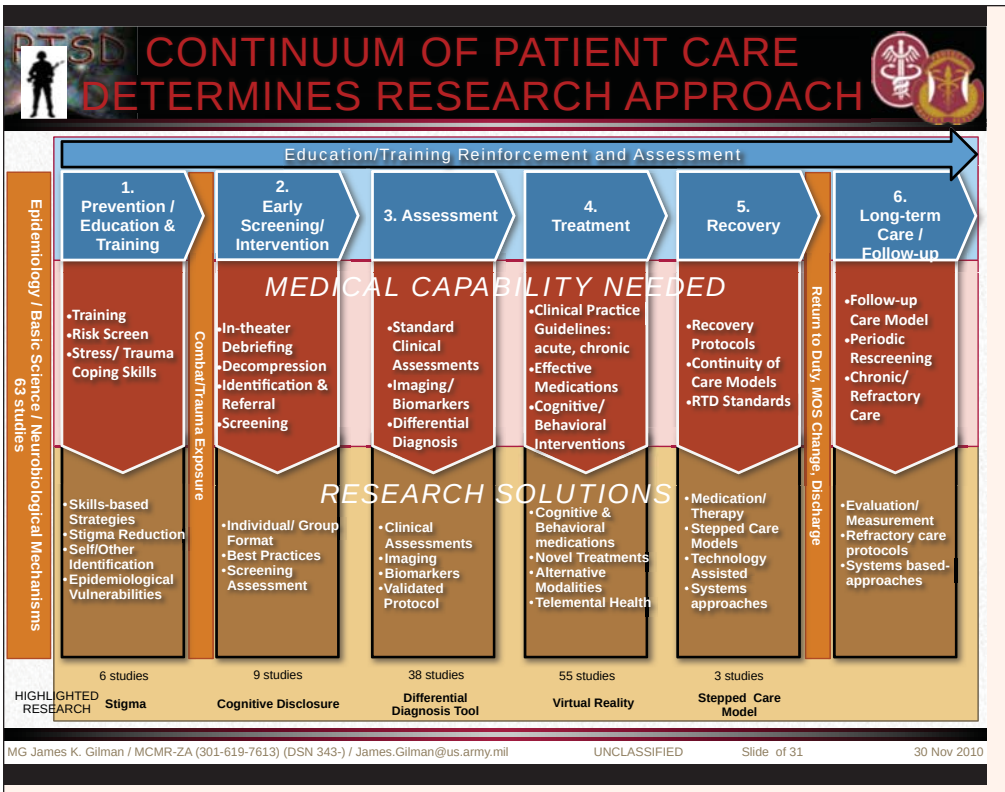
The diverse body of TBI and PTSD research can be organized, as MRMC has done, along a continuum of care for the Soldier or patient, from prevention through assessment and finally, return to duty or long-term care.

TBI in particular "is still a very unique problem in our estimation, because we still don't have a full, clinically well-accepted diagnosis," said Gilman at the Army Science Conference. Instead, a diagnosis of TBI "is based on the subjective report of an exposure to an event, and some reported or estimated proximity thereto, and then some symptom that occurs soon, or immediately after that event. And that symptom can be nothing more than disorientation. So right now we are still struggling to find the gold standard, and this is impacting every one of our efforts in terms of traumatic brain injury."

Following the continuum (see chart below), these efforts include:

- Prevention and Protection—At least three pharmaceutical or nutraceutical products, including the omega-3 fatty acid docosahexaenoic acid (DHA), hold promise for protecting the brain from injury. "If effective, then we can supplement rations with [DHA] and perhaps mitigate or ameliorate the consequences of exposure to blast," said Gilman.
- Early detection—Ultimately, the helmet-mounted sensor may be able to provide this capability, which could improve the outcome of a Soldier's exposure to blast.
- Screening—Deficits in visual tracking performance are one manifestation of diffuse axonal





injury in the brain, a measure of TBI. Eye-tracking devices can measure eye movement as a subject tracks and predicts the movement of an object.

- Assessment—A program called Biomarker Assessment for Neurotrauma Diagnosis and Improved Triage System is exploring objective measures of cellular damage through blood testing of nerve cell proteins, much as cardiologists measure enzymes or proteins as one indicator of cardiac damage. Gilman called the blood test "very promising, because that has probably the earliest hope to get us to an actual objective measure of some exposure to traumatic brain injury." Large-scale clinical trials are planned that hopefully will lead, three or more years from now, to U.S. Food and Drug Administration (FDA) approval of this diagnostic test, which could then be used in fixed medical facilities. The ultimate goal is to develop a hand-held device for use in the field.
- Treatment—For acute or more severe TBI, there is currently no effective pharmaceutical treatment, but multiple drugs have shown promise in pre-clinical tests, including NNZ-2566 from Neuren Pharmaceuticals of New Zealand. It is a molecule that is part of a naturally occurring hormone in the brain with the potential to reduce the effects of a brain injury by preventing further damage.

"The FDA has agreed to an expedited approval process if studies show the positive benefit in humans that was seen in pre-clinical studies," Gilman said. However, it may take up to five years to complete the studies.

For the treatment of milder and moderate TBI, research is focusing on treating chronic symptoms. One possibility is hyperbaric oxygen, the delivery of pure oxygen in a pressurized room. DOD has established a tri-service effort to evaluate hyperbaric oxygen therapy. The problem with treating chronic or mild TBI, Gilman said, is that "over time, the symptoms … tend to improve. And so, if you provide any treatment during the time when improvement is likely to occur, it looks like the treatment worked."

- Recovery—The ongoing Study of Cognitive Rehabilitation Effects seeks to determine, through randomized treatment of military patients who have mild TBI, the effectiveness of methods that ask them to exercise their brains, such as by calculating or remembering, and so to strengthen their cognitive abilities.
- Reset—The Army is developing objective, repeatable assessments that can help determine if a Soldier is ready to return to duty. These assessments look at weapon utilization, physiologic measures, balance, and other factors.

There is evidence that repeated head injuries require special attention. One type of TBI is Chronic Traumatic Encephalopathy (CTE), a progressive degenerative disease found in patients who have been subjected to multiple concussions and other forms of head injury.

Dr. Ann McKee, a neural pathologist from the Center for the Study of Traumatic Encephalopathy at Boston University, told the audience at the PEO Soldier conference that the symptoms of CTE have a slow, insidious onset and tend to develop in midlife. Symptoms include memory loss, "irritability, agitation, and a short fuse." McKee said CTE develops in military veterans and has been described in many different types of mild traumatic injury.

"It's less important how you get the injury," in her view. What's important is the repetitive injury. "This is the challenge, I think, with any discussion about helmet and equipment: How do we protect the brain from the long-term damage we are seeing in these players [athletes] and Soldiers?"

PTSD Challenges

One of the challenges of research into PTSD is that the same roadside IED that causes blast TBI can also cause PTSD, and both can produce the same

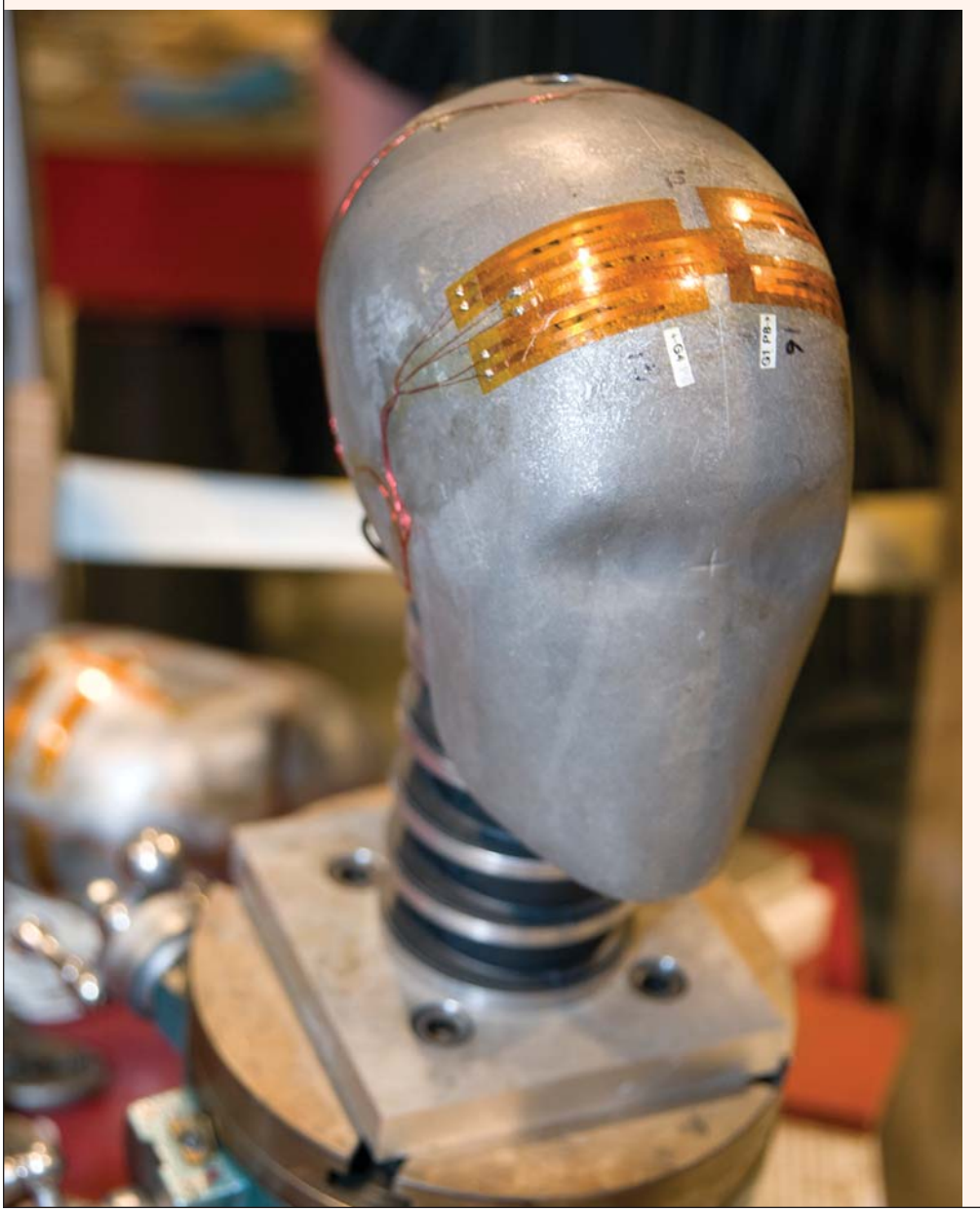
symptoms—irritability, insomnia, impaired attention, and headache, for example. More than a dozen research projects are devoted to distinguishing between mild TBI and PTSD.

With PTSD, too, a complicating element is "co-morbities," simultaneous health problems such as depression, substance abuse, and the prescribed use of strong pain medications. All of these can influence which treatment option to use, Gilman said.

The Army's continuum of PTSD research (see chart on Page 32) includes development of a validated animal model of trauma exposure to evaluate pharmacological treatments for PTSD, as well as:

- Prevention/education and training—The Navy and Army are working together to tackle the stigma associated with seeking help for PTSD or other mental health issues, by developing a media-based stigma reduction program for Soldiers and Marines that targets the factors influencing the decision to seek treatment and identifies barriers to care. As a cultural issue, stigma "will require a period of sustained intervention before we make a dent," Gilman noted. "We can't wait until the stigma is gone before addressing other aspects of PTSD."
- Early screening and intervention—A nearly completed study called Enhanced Resilience Training Through Cognitive Disclosure used emotionally expressive writing as an early intervention for Soldiers who have returned recently from combat. It found this approach to be unsuited to Soldiers with high levels of combat exposure, however.
- Assessment—A multimodal diagnostic approach is needed that distinguishes between TBI and PTSD with adequate sensitivity and specificity. Researchers are seeking the best combination of techniques including imaging, neurophysiological biomarkers, and neuropsychiatric testing. While health care practitioners may not place a high priority on the distinction, it is "a very big deal" in the military's consideration of whether and how to award the Purple Heart to Soldiers with TBI, Gilman said.
- Treatment—The Army is exploring virtual reality (VR) technology and cell phone platforms to assess PTSD treatment options, and the use of VR to administer treatment, particularly for service members located far from medical facilities.
- Recovery—Given that PTSD tends to be chronic and causes recurring problems, a randomized trial is underway to compare management of follow-up behavioral therapy over the telephone and Internet, continuous care management by a nurse supervised by a psychiatrist, and computer-guided care management based on patient preference and the severity of symptoms, all ways to make effective care more accessible and appealing to patients. The results of this research will feed into other initiatives to expand military medical care using cell phones and the Internet, Gilman said.

This instrumented head form is used for helmet testing, which itself is an area with unanswered questions. (U.S. Army photo courtesy of ARL.)



Advances in Helmet Testing

Modeling of blast impact is in itself an area of extensive study. Different headforms are suited to different blast tests in the laboratory. Scientists are working on a matrix of head forms, as scientists elsewhere develop metrics for injury.

"There's not a lot of consensus on what the metrics are that we should be gathering," said Dr. Dixie Hisley of ARL.

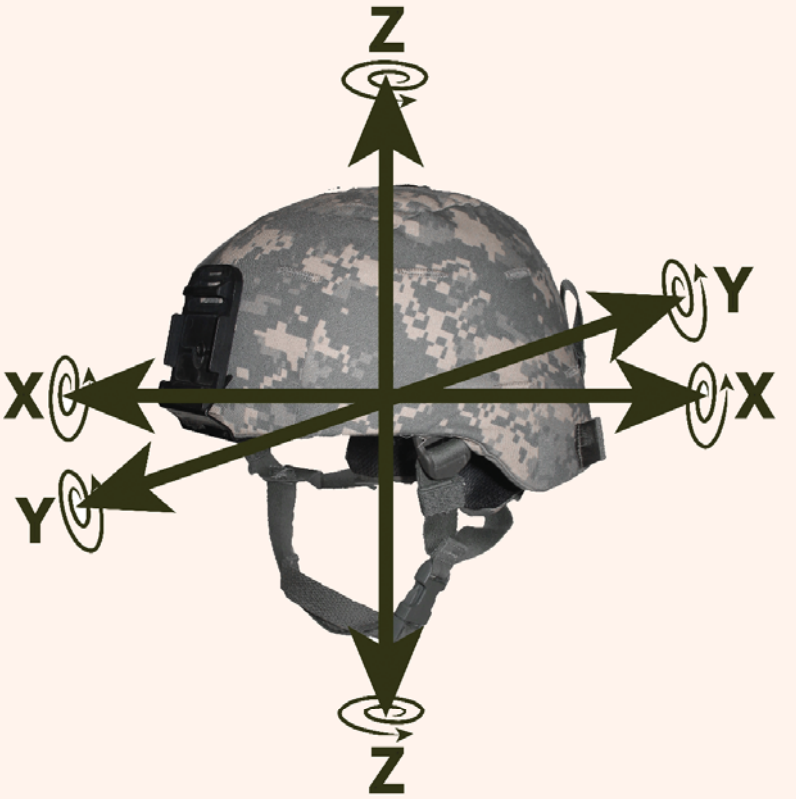
When a projectile hits a Soldier's helmet, it deforms inside as it absorbs the energy, creating "helmet backface deformation." The absorption of energy typically results in a bulge that could grow two to three inches or more toward Soldiers' heads, which equates to "the potential for a pretty good impact on a Soldier's head," Hisley said.

But inside the helmet, there may be 1/2 to 3/4 inch between the helmet and the Soldier's head. "What we at the ARL would like to do is come up with the one to two experimental techniques that would allow us to replicate and measure this phenomenon very accurately," Hisley said.

Ideally, scientists should be able to correlate the velocity of impact, force applied, and the area of contact with the metric for injury, she said, using a method developed at ARL called Digital Image Correlation. "That's the area that we should really be interested in: What available energy is going into the Soldier's head?"

Next Steps

The PEO Soldier Head Protection Summit sought to establish a body of experts from the academic, sports, defense, and medical communities to focus on the prevention and mitigation of head injury from blast, ballistic, and impact threats to the head. The follow-on is an Integrated Concept Team to develop solutions and improve Soldier head protection from threats encountered in combat conditions.



The Generation II Helmet sensor will expand the data gathered in theater by recording both linear and rotational accelerations. (U.S. Army photo courtesy of PEO Soldier.)

"The experts have identified where we need to learn: a valid mathematical model of blast-induced TBI," Leggieri said. "We've got lots and lots of models of traumatic brain injury. We don't have any validated models."

Through the Johns Hopkins University Applied Physics Laboratory, an expert panel is working to develop criteria for valid models, including capabilities, state of the science, validation to date, and availability to the DOD community. Validated models will be independently reviewed and, ultimately, submitted to the Assistant Secretary of Defense for Health Affairs for approval.

"This brings some standardization. It brings some assurance that whatever criteria are being used by DOD, those criteria are the best available," Leggieri said. "We all have the same objective in mind. We want to protect the warfighter."

Leggieri's office, at ***https://blastinjuryresearch.amedd.army.mil****, seeks to be a clearinghouse for blast injury research information. Gilman's presentation at the Army Science Conference is available at* ***http://www.armyscienceconference.com/pdf/Tue/Gilman.pdf****.*

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