# A Simple Way to Better Protect Soldiers against Head Trauma

WHEN Livermore scientists Michael King and William Moss set out to conduct an Army-commissioned study of helmet pad designs, their primary goal was to make a straightforward determination: Could the pads used by the National Football League (NFL) protect against military-relevant impacts better than the current pads in Army combat helmets? Experiments and sophisticated computer simulations showed they would not. But in the process of conducting the study, King and Moss made a more valuable and unexpected finding. The Army helmets could work even better—a lot better, in fact—with only minimal improvement. Adding as little as 3.2 millimeters (one-eighth of an inch) of foam to existing helmet pads could reduce the severity of the impact on the skull by an estimated 24 percent. "It was surprising to us how little it takes to move the injury threshold so dramatically," says King, a mechanical engineer in Livermore's Engineering Directorate.

This finding could significantly improve the military's ability to lessen the severity of traumatic brain injuries (TBIs), a growing concern for soldiers serving in combat zones in Afghanistan and Iraq. Moreover, the understanding gleaned from this analysis of pad behavior could have implications for nonmilitary helmet design, including that of children's helmets and headgear for a variety of sports.

The one-year study was funded by the U.S. Army and the Joint Improvised Explosive Device Defeat Organization. King and Moss, a physicist in the Weapons and Complex Integration Principal Directorate, were selected for the task because of their previously published work on the mechanics of blast-induced brain injuries. (See *S&TR*, March 2010, pp. 14–17.) The goal of this study, however, was to better understand how padding protects against head trauma in impact situations and, in turn, find ways to optimize helmet cushioning for soldiers.

## The Physics of Protection

A helmet does its intended job of absorbing impacts when the foam inside its shell compresses upon hitting an object, absorbing the impact and dissipating the energy quickly and efficiently. This process unfolds over a limited distance—the foam thickness—before the foam densifies as its pores collapse. The now-dense foam becomes very resistant to additional compression, and the force on the head increases dramatically, which can result in injury to the head. How much energy the foam can dissipate before it densifies depends on the speed of impact and the makeup of the pad.

At high speeds, the Livermore study confirmed, harder foam performs better, while at lower speeds, softer foams offer better protection. Because no single foam is optimal for all scenarios, compromises must be made, such as combining hard and soft foam into a bilayer pad like the one in the Army's advanced combat helmet (ACH).

Regardless of the foam used, however, the study found that thicker foams always performed better than thinner foams by absorbing more energy before densifying. This finding by itself may seem like common sense. What is less intuitive is that the added value of increasing foam thickness is not the same for all impact speeds. At low speeds of 3 meters (10 feet) per second or less, adding thickness to the standard Army pad results in only marginal benefits. (See the figure on p. 15.) At speeds above 6 meters (20 feet) per second, the impact can be blunted with extra foam, but the benefit to soldiers is questionable. No helmet designed for military use at this time can prevent serious head trauma at those speeds, considering that the energy on impact increases dramatically with the square of the velocity.

But military-relevant speeds, defined by the Department of Defense as 1.5 to 4.6 meters (5 to 15 feet) per second, fall within that optimal range where adding a small amount of foam can make a huge difference in the helmet's ability to act as an effective cushion. "I've earned my lifetime salary many times over with this finding if the Army implements our recommendation," Moss says.

That small amount, in fact, is all that is needed. Increasing foam thickness by more than 6.3 millimeters (one-quarter of an inch) at these speeds would result in quickly diminishing returns. That is why discovering this window of opportunity for Army helmets was so important. "For the military-relevant range, we have this nice scenario where protection earns its keep," says King. (See movie of a compression test at str.llnl.gov/AprMay12/king.html.)

## Recommendations and Army Response

The simplest and least expensive solution for improving protection is to use one-size-larger helmets to accommodate pads slightly thicker than those used in the current ACH. Going up one size, however, adds extra weight to the approximately 1.6-kilogram (3.5-pound) helmet. That's bad news for soldiers, for whom every extra ounce is a burden considering the heavy loads of equipment they carry onto the battlefield. Larger helmets could also impair mobility and visibility, arguably offsetting the benefits of additional protection. "To make a concrete decision, one must look at the threat envelope and make a risk-and-reward analysis," King says.

Fortunately, the Army is in the process of redesigning the helmet shell—an ideal opportunity, Moss says, to resize the helmet. Each size could be made only slightly larger, thereby allowing for extra padding with only a minimal increase in weight.

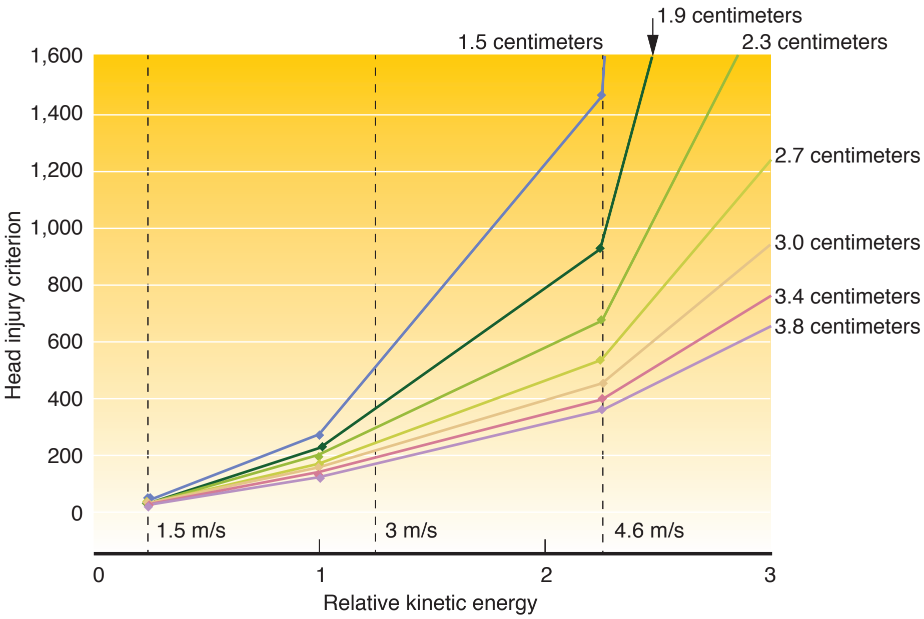
The study recommendation was passed on to the Army, which recently made the first set of implementations. According to Army Colonel R. Todd Dombrowski of the Joint Improvised Explosive Device Defeat Organization, 5 percent of the soldiers were fitted with an extra 3.2 millimeters (one-eighth of an inch) of padding on each side of the temple. The helmets worn by this small group allowed for the extra padding because of a looser fit. For everyone else, the Army decided against immediate implementation because of the extra weight such a change would incur. But with a lighter-weight helmet design now under consideration, the suggested improvement may be implemented on a larger scale soon. "The study gave us valuable information for helmet redesign in the future," Dombrowski says. "Every year, we want to get a better helmet, period."

## Livermore's Unique Capabilities

Moss and King's expertise was a key factor when the Army considered Livermore for this study, as was the Laboratory's role as an unbiased evaluator. But Livermore was ultimately chosen for the task because of its advanced computational simulation capabilities, a result of the institution's core weapons design capabilities. "The billions that have been invested in weapons calculations and the resulting tools that were developed here can be applied to these problems," says Moss, who at one time was responsible for containment calculations for nuclear tests. "We're using the same tools now. They're very robust and can address problems of national interest."

The helmet pad simulations were conducted using the PARADYN software for modeling thermomechanical behavior. The software is an advanced version of the DYNA3D code developed at Livermore in the 1970s and later commercialized worldwide as LS-DYNA.

In addition to the advanced technology, Livermore offers what Moss refers to as a systems approach to solving problems by making use of the wide range of capabilities available onsite. For this study, King and Moss collaborated closely with the Mechanics of Materials Group in the Engineering Technologies Division to design the experimental components of the study. "It's not just doing simulations," Moss says. "It's the all-encompassing approach that keeps the work grounded in reality. We have experts in all the required areas of theoretical, computational, and experimental physics as well as in chemistry and engineering. This is a collective process, something not many places can do."



Foam thickness has a dramatic effect on pad response at high speeds. At a military-relevant speed of 4.6 meters per second (m/s), for example, increasing the current pad thickness in Army helmets (represented by the dark green line) from 1.9 centimeters to 2.3 centimeters reduces the head injury criterion from a high value of 917 to a moderate value of 665. The head injury criterion quantifies the severity of impact.

## Conducting the Study

The Livermore study compared the performance of four pad systems: Team Wendy, currently used by the Army; Oregon Aero, a former Army pad; and two NFL pads, made by Xenith and Riddell. King and Moss performed experiments to characterize the material properties of each foam and then used the material parameters for computer simulations. The team constructed a geometrically accurate model of an ACH using computer tomography scans of an actual helmet shell.

To validate the applicability of simulations to this kind of study, the scientists first simulated a set of experiments performed by the U.S. Army Aeromedical Research Laboratory, in which an inverted ACH with padding was dropped onto an anvil at impact velocities of 1.5 to 6 meters (5 to 20 feet) per second. Using simulations, King and Moss calculated the response of the entire helmet system and compared their results to the data from the Aeromedical Research Laboratory. The two sets matched closely, confirming the accuracy of the simulations.

For the main part of the study, the scientists examined the response of foam compression using a simplified cylinder simulation. This method was designed to compare the performance of pads with different geometries, because football pads are approximately twice as thick as Army pads and could not fit inside the ACH shell. The compression test also served to isolate material response from other factors, such as pad interactions and the geometry and deformation of the helmet shell.

The compression test consisted of a 5-kilogram cylindrical impactor (the approximate weight of a human head) striking identically shaped and sized circular pads from each manufacturer. The scientists ran hundreds of simulations, adjusting the various parameters (such as speed, foam material, pad thickness, and pad area) in numerous configurations. "Simulations allow us to test for a wide variety of impacts that would be too difficult or too costly to re-create experimentally," King says.


Michael King (left) and William Moss perform a compression test on a helmet pad.

## Team Wendy Wins the Day

For comparable thickness and at the specified impact speeds, none of the pads tested outperformed Team Wendy. The stiffer football pads, however, did absorb energy better at high speeds, an important consideration on the football field where the entire body hits the equivalent of a brick wall when players collide. These results suggest that each helmet design needs to be optimized for its intended use and expected type of impact.

King and Moss caution that their findings cannot be used to predict injury rates given the difference between the cylinder test and a full-helmet response, in which the impact is spread over a larger area. The intent of the study was to compare the impact response of different pads, not to give absolute quantitative estimates of injury. Nevertheless, both scientists feel confident that their findings are accurate and fully applicable to real-life scenarios. Since the results were published, Team Wendy performed its own tests and confirmed the finding that thicker pads improve impact mitigation for the helmet and pad system.

Moss notes that if compared with the cost to treat veterans for TBI over the course of their lifetimes, improvements in helmet design that can lower the rate or severity of injury by any amount is money well spent. "It's essentially a no-cost solution," he says about adding extra foam to the helmet. "The return on investment is virtually infinite."

## Noncombat Applications

The fact that certain kinds of foams provide optimal protection when used under different impact conditions has huge implications for a wide range of civilian helmet designs—from sports headgear to children's helmets. Says Moss, pointing to a bulky NFL helmet on the table, "If I take this piece of equipment made for a pro and put it on a kid, that may not be a good thing to do. This pad system may not be tuned for the kind of impact mitigation that a child needs compared with an adult. This study also suggests that the various players on a football team should perhaps be wearing different kinds of helmets, depending on the types of impacts to which they are typically subjected."

More research is needed to determine the optimal helmet design for every situation, civilian or military, and Moss hopes to have the opportunity to follow up in the future. In the meantime, the study he and King conducted for the Army has demonstrated the value of applying advanced simulation techniques, borne out of the Laboratory's historic mission, to helmet design and to the very physics of protecting people who may come in harm's way.

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