

# Solving Football's Concussion Problem

By Dan Polnerow

In recent years, American football has been caught up in controversy about brain damage suffered by players at all levels of the game. The National Football League, facing a class-action lawsuit from hundreds of former players regarding head trauma, is dedicating large amounts of funding to research the problem, and helmet manufacturers are frantically searching for the innovation that will best protect players from the dreaded concussion. In addition, the NFL and NCAA have implemented a number of policy changes (namely, making intentional head-to-head contact and the striking of a defenseless player illegal) in an effort to reduce the number of injuries.

However, for such a prevalent problem in the nation's most popular sport, there is surprisingly little data that could lead to an effective solution. Despite the best efforts of the leagues, the players, and the medical and engineering communities, the incidence of injury at all levels of the game continues to increase. This pattern will likely continue until three crucial changes come about: the effect that different impacts have on players must be quantified, the causes of concussion need to be better understood and more reliably diagnosed by the medical community, and a more complete testing procedure for helmets has to be developed and implemented. Until these issues are addressed, there will not be enough evidence to identify the most effective way to prevent players from concussion.

A number of deceased professional players have had their brains donated to various research institutes for analysis, and medical researchers are finding evidence of Chronic Traumatic Encephalopathy (CTE), a degenerative condition associated with repeated impacts to the head. Researchers see similarities between the brains of former players, elderly Alzheimer's patients, and former boxers with severe dementia; symptoms of CTE include depression, anger, and memory loss, and many attribute the suicides of high-profile former professional players including Junior Seau and Dave Duerson to the disease. Even Chris Henry, an NFL wide receiver who died accidentally in 2009, was found to have signs of CTE in an autopsy – Henry was only 26.

In theory, the football helmet should protect the player from injury. Since the 1970s, helmets have been constructed with a rigid, polycarbonate shell, a steel facemask, and padding (typically a combination of foam and inflatable air bladders) on the inside. Modern helmets may use more advanced materials and more analyzed and engineered designs, but the basic concept remains largely unchanged. Riddell, the largest helmet manufacturer and maker of the official helmet of the NFL, produces the Revolution Speed helmet system, which utilizes high density vinyl nitrile foam, a facemask designed to absorb some of the energy of the impact, and a larger shell to fit more padding. Schutt, the second-largest helmet manufacturer, produces multiple helmets that use a complex 3-dimensional engineered structure made of thermoplastic as the primary protection mechanism.

The concussion epidemic has led to the rise of a number of startup helmet manufacturers, each with a unique solution to the problem. One of the most successful startups is Xenith, a company

headed by former Harvard University quarterback Vin Ferrara. Xenith helmets use a system of venting air bladders, which compress varying amounts depending on how severe the impact is, and are used by a number of professional players in addition to their growing following among collegiate and high school athletes.

Every helmet must pass a test administered by the National Operating Committee for Standards in Athletic Equipment (NOCSAE) to be approved for use. NOCSAE drops each helmet (without a facemask) on six different locations from a height of 1.52 meters. All impacts are centered, and result in large linear accelerations. The test, which is primarily designed to check for protection against skull fracture, has remained largely unchanged since its implementation in 1973. The incidence of skull fracture and other catastrophic head injuries in football has dropped off dramatically since that time, but the NOCSAE standard does little to test helmets for their effectiveness in preventing brain injuries like concussions.

How can it be that the National Football League, an organization worth billions of dollars, cannot protect their players from serious short-term and long-term injury to the most valuable organ in the body? In short, policy makers and helmet manufacturers are attempting to protect players against an affliction with a disputed cause, which cannot be reliably diagnosed, and can only be detected in an autopsy.

One of the most significant areas of study has been the effort to quantify head impacts by magnitude and location. To do this, many researchers use the Head Impact Telemetry System, developed by Simbex LLC in Lebanon, New Hampshire in 2004. The system is made up of six single-axis accelerometers that measure and record peak accelerations, impact duration, and location of the impact. Simbex LLC has partnered with Riddell, a leading helmet manufacturer, to offer the system in many of Riddell's helmets. Most studies that have been conducted analyzing head impacts in football have done so using the HIT System, and impacts at the professional, collegiate, and interscholastic levels of play have all been analyzed.

It has been determined that impacts are not uniform for every position in football – athletes experience different hits based on the positions they play. Crisco, Wilcox, Beckwith, Chu, Duhaime, Rowson, Duma, Maerlender, McAllister, and Greenwald (2011) investigated 314 Division I NCAA athletes from Dartmouth College, Brown University, and Virginia Polytechnic Institute (Virginia Tech) in order to quantify head impacts in terms of magnitude, location, and frequency, and differentiate collisions by position. Using the Simbex HIT System, the researchers calculated peak and median linear acceleration, rotational acceleration, impact location, and frequency for each position, and were able to distinguish certain impact characteristics by position. Peak rotational acceleration, measured in  $\text{rad/s}^2$ , was calculated by multiplying the vector product of peak linear acceleration and a point of rotation 10 centimeters below the center of gravity of the head (a location validated by previous research). Consistent with previous data, Crisco et al (2011) found that offensive lineman, defensive lineman, and linebackers experienced the lowest magnitude impacts but the highest frequency of collisions over a season, more than twice any other position. Running backs received the greatest magnitude impacts, while quarterbacks sustained the greatest magnitude and most frequent hits to the back of the head. The study provided valuable data in quantifying head impacts and did

succeed in differentiating impacts by position, but did not examine the relationships between head impact exposure and diagnosis of concussion.

There is concern that data collected about collegiate and professional athletes does not compare to lower levels of the game. High school football players are generally not as fully developed and are more likely to be playing with improper form, potentially increasing the risk of injury. A study similar to the collegiate study carried out by Crisco et al (2011) was conducted on players at a central Illinois high school by Broglio, Sosnoff, Shin, He, Alcaraz, and Zimmerman (2009). The Simbex HIT System was used to measure values of head acceleration. It was found that high school athletes tended to experience greater post-impact acceleration than collegiate players – Broglio et al (2009) speculated the cause to be a less-developed muscle structure in high school athletes that was not as effective in controlling the head after impact. Additionally, the mean peak linear acceleration across all sessions (practices and games) was calculated to be approximately 2.5 G higher in high school athletes than in college players, compared with values determined by a similar study conducted at the collegiate level (2007). This information supports the theory that despite the attention given to professional and college players, high school athletes are potentially at a greater risk for injury and long-term damage.

Broglio et al (2009) did not find the HIT System to be useful as a diagnostic tool, citing the lack of complete understanding about the biomechanical components of a concussion. Broglio et al (2009) reported 349 impacts that exceeded 70 G of linear acceleration but only 5 concussive injuries that were diagnosed, despite a prior estimate that an acceleration of 70-75 G was necessary to induce a concussion in professional football players (Pellman et al, 2003). Until further data could be gathered and a better understanding of the concussion was reached, Broglio et al (2009) did not recommend the use of the HIT System for anything more than a research tool.

In addition to the concerns voiced by Broglio et al (2009), critics of the HIT System argue that there is no way to validate the data from it. There is no comparable system, so the HIT System is used in almost every study quantifying head impacts. If there were some error in the algorithm used to calculate acceleration, or if a helmet were to deform under impact and skew the data, there would be no way to tell. Researchers may use the data drawn from HIT analysis, but there is nothing to confirm that data.

Not only do these studies fail to draw conclusions about the correlation between acceleration and concussion, but medical researchers cannot say with certainty what causes a concussion in the first place. In a recent *Popular Science* article, Tom Foster interviewed a number of researchers involved in the study of brain trauma in professional athletes and received two significantly different answers (2013). Currently, there are two main theories about what causes a concussion: linear acceleration and rotational acceleration. At this point, it is still unclear if the two are related to one another, even slightly. Linear accelerations are strong, mostly centered impacts, as experienced by a helmet in the NOCSAE drop test, whereas rotational accelerations are caused by any off-axis impact, causing the brain to rotate within the skull around the center of gravity of the head (and are far more common in an actual football practice or game). Stefan Duma, founder of Virginia Tech's Center for Injury Biomechanics, believes there is a strong correlation

between linear and rotational acceleration after analyzing almost 2 million impacts sustained by Virginia Tech's football team (using the HIT System).

However, if this were true, the solution for preventing linear accelerations and concussions caused by them would be simple: add more padding. Many researchers do not believe the answer to the concussion problem to be that simple. Among others, Robert Cantu of Boston University and Blaine Hoshizaki of the University of Ottawa believe rotational acceleration does the most damage to the brain, and point out that current helmets do little to prevent it. In 2012, Hoshizaki Post, Oeur, and Gilchrist, researchers from the University of Ottawa and the University College Dublin, used the University College Dublin Brain Trauma Model to calculate brain deformation metrics associated with varying levels of linear and rotational acceleration. They found that rotational impacts tended to be more associated with brain deformation impacts thought to be related to concussions, but recommended that additional research be carried out to confirm this data.

Manufacturers are left essentially on their own to protect players from a serious injury that cannot be easily diagnosed. A lot of recent information is beginning to point to rotational acceleration as the primary cause of concussion, but that does not mean that a strong linear force would not cause harm. As it currently stands, NOCSAE only tests for protection against strong linear impact, and it would be difficult and expensive to design a helmet that works against rotational acceleration. Why would a company acting on unconfirmed data choose this route?

As more former players are diagnosed with brain damage, NOCSAE has received heavy criticism. Many believe their drop test method is archaic and does not accurately represent how the helmets will perform against more complicated injuries like concussions. In 2006, NOCSAE proposed a test using a linear impactor in place of the drop test. Gwin, Chu, Diamond, Halstead, Crisco, and Greenwald (2010) compared both the drop test and the proposed linear impactor test to in vivo, or live, impacts sustained by players on the Dartmouth College football team by using the HIT System developed by Simbex. Gwin et al (2010) found that in vivo collisions occurred 37% more frequently in locations tested by the linear impactor test as opposed to the drop test and found the linear impactor test to be more practical in recreating high-speed collisions. The methodology for the linear impactor test includes a facemask attached to the helmet while the current drop test does not, a main factor in the recreation of in vivo impacts. Additionally, to simulate the highest values of the Gadd Severity Index ( $G_{SI}$ , where  $a$  = resultant linear head acceleration and  $T$  = the duration of the impact, used to calculate magnitude of acceleration in this study and approximately measure the injury potential of an impact) recorded in vivo, a helmet would have to be dropped from a height greater than 6 meters, which is not practical for testing. Gwin et al (2010) recommended further research into the effects of rotational acceleration in causing injury, as this study did not take rotational acceleration into account.

Since the NOCSAE standard does not test against rotational forces, no commercially available helmet works against it. Hoshizaki et al (2012) compared brain deformation metrics associated with centric and non-centric impact on three different commercially available helmets. The researchers stated that although the helmet using vinyl nitrile performed best in linear impact testing, the helmets which used engineered three-dimensional layers performed better when using brain deformation metrics as an indication of performance. Since the current NOCSAE

testing procedure only accounts for linear acceleration, it was expected that vinyl nitrile (used in the most popular helmet of the three) would perform well in this category. However, the researchers stated that vinyl nitrile was limited in its ability to absorb energy by thickness and density, whereas the engineered materials had more potential in their ability to reduce injury.

It is important to note that every single study done in relation to brain damage in football has recommended that additional research be conducted. The medical community cannot definitively say what causes a concussion, nor can they determine the long-term and short-term effects of concussive versus sub-concussive impact. Proposed thresholds of acceleration required to cause a concussion are tentative, and while the effort to quantify impacts has yielded results, researchers are almost entirely relying on a largely unconfirmed system.

Until the causes of concussion are better understood, it will be difficult to determine thresholds that can be measured using the HIT System or a similar future system. If thresholds cannot be determined, it will be impossible for NOCSAE to subject helmets on the market to accurate tests and definitively conclude what systems more effectively protect against concussion. Hundreds of thousands of players, from youths to professional athletes, remain at risk in the meantime. As it stands, there is not enough evidence to identify the best method to prevent damaging head impact in American football – additional diagnostic tools must be developed and more focused research must be continued at all levels of the game.

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