Measuring Head Impact Exposure and Mild Traumatic Brain Injury in Humans

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ABSTRACT

Helmeted sports such as football offer a unique opportunity to study head injury biomechanics in live human subjects. Impact reconstruction using game videos and real-time measurements of head kinematics in football provide a method of quantifying the head impact exposure athletes experience. A total of 58 impacts from NFL games have been reconstructed using Hybrid III crash test dummies, including 25 concussive impacts. Roughly 2 million impacts have been recorded using helmet-mounted accelerometer devices, with 105 concussive impacts. Similar values have been found for peak linear acceleration, one of the best predictors of concussion, using the two methods. From the NFL impact reconstructions, researchers found a peak linear acceleration value of 98 ± 28 g which is not substantially different from the value of 105 ± 27 g from the helmet-mounted sensor data. Both methods provide valuable head impact biomechanics data which are used to quantify impact exposure in football and assess injury risk due to head impact. Helmet mounted accelerometers have the added benefit of collecting every impact a player sustains while wearing the sensors, giving more detailed impact frequency data and many more data points. Future research will focus on expanding the head impact data set, especially at the youth level. The expanded data set will lead to improved injury risk curves which will guide future safety standards in sports as well as other areas, including the automotive industry and military, where head injury is a concern.

Key Words: Concussion, sports, head, helmet, HITS

PRESENTATION SUMMARY

Globally, at least 10 million Traumatic Brain Injuries (TBI) resulting in death or hospitalization occur each year, with many more cases treated without hospitalization or untreated altogether [1]. The majority of TBI cases are classified as mild Traumatic Brain Injury (mTBI). Sports and recreation account for an estimated 1.6 to 3.8 million cases of mTBI annually [2]. By quantifying head impact exposure in sports, researchers hope to improve understanding of the injury mechanism, establish reliable injury risk functions, and ultimately reduce the prevalence of head injury in sports and elsewhere. Football offers a unique opportunity to study head injury biomechanics in live human subjects; players willingly expose themselves to potentially injurious head impacts which can be monitored using helmet-mounted sensors.

A number of studies have investigated head impact exposure and injury prevalence in the National Football League (NFL) by reconstructing in-game impacts from video recordings [3-9]. In total, 58 severe impacts were reproduced in a lab setting using helmeted Hybrid III crash test dummies, including 25 concussions. Impact velocities and locations as well as head kinematics were determined using multiple video angles for each reconstructed case. Accelerometers located inside the Hybrid III headforms measured linear and rotational head acceleration throughout each test for both the struck and striking dummies.

Pellman et al. [5] found the relative impact velocities to be 9.3 ± 1.9 m/s for the concussive incidences while the change in head velocity for the injured players were found to be 7.2 ± 1.8 m/s. The dummies in the concussed cases experienced greater peak linear head accelerations, with an average of 98 ± 28 g, compared to 60 ± 24 g for the non-injury cases. Viano et al. [9] found similar results for linear acceleration, with concussed players experiencing a peak linear acceleration of 94.3 ± 27.5 g and compared to 67.9 ± 14.5 g for non-concussed players. The typical impact duration was approximately 15 ms. While these head impact reconstructions lend insight to head injury biomechanics, only a limited number of cases can be studied.

Over the last decade, on-field head impacts have been collected from football players using the Head Impact Telemetry (HIT) System (Figure 1) [10]. The HIT System is a commercially available device that utilizes a 6-accelerometer array mounted between the pads of a football helmet to measure the player’s linear head acceleration during an impact and approximate peak rotational acceleration [11]. A second custom-built six degree of freedom system (6-DOF) has also been used to measure head accelerations of football players during live play [12,13]. Like the HIT System, the 6-DOF uses an accelerometer array mounted between the pads of a football helmet to measure head acceleration. The accelerometer orientation in the 6-DOF allows for direct measurement of rotational acceleration in addition to linear acceleration, however. Though the 6-DOF offers a more accurate rotational acceleration measurement than the HIT System, its prohibitive cost makes widespread implementation of the system impractical [14]. The accelerometers in both systems are designed to remain in contact with the players head during an impact, in order to measure head acceleration rather than helmet acceleration. A study by Manoogian et al. [15] found that the HIT System acceleration was similar to that measured inside a Hybrid III headform, while helmet acceleration was roughly 10 times greater (Figure 2). A separate study by Beckwith et al. [16] compared HIT System acceleration measurements to Hybrid III acceleration measurements and found that the HIT System produced reliable acceleration measurements.

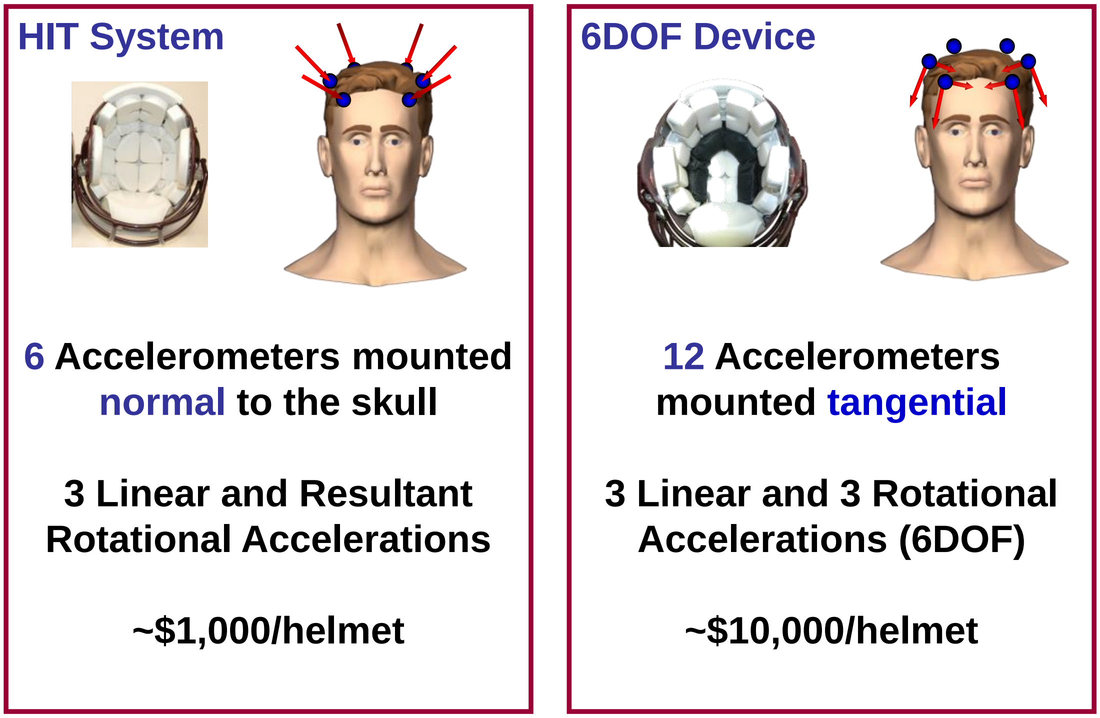

Figure 1: The two helmet mounted accelerometer devices used to collect head acceleration data from football players at the youth, high school, and collegiate levels.

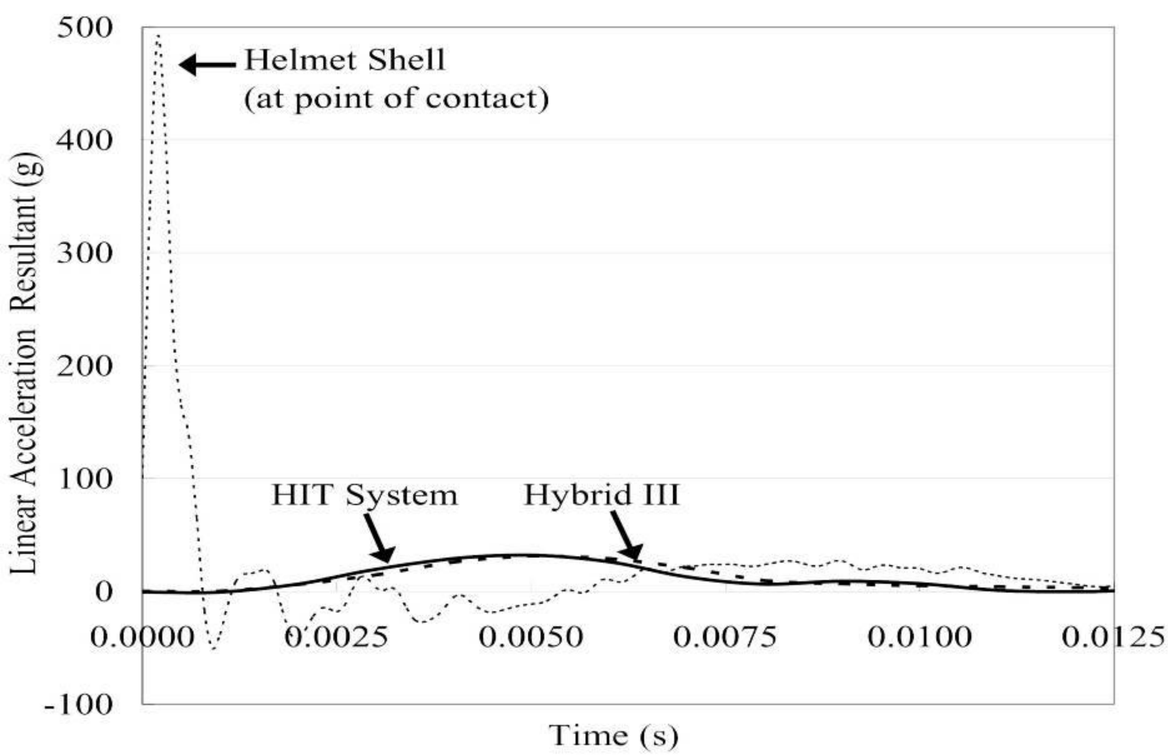

Figure 2: Comparison of linear acceleration vs. time for an accelerometer mounted on the shell of a football helmet, the HIT System, and a Hybrid III headform.

The HIT System has been used to record head impacts from football players since 2003, first at the collegiate level and later at the high school and youth levels [10,17-33]. The majority head impact data collected with the HIT System has been from college and high school football players. On average, college football players sustain 1000 impacts per season with an average linear and rotational 95th percentile magnitude of 68 g and 2975 rad/s^2 [21,30,34]. High school players average 565 impacts per season with 95th percentile acceleration magnitudes of 56 g and 2527 rad/s^2 [21,27]. A total of 105 concussive impacts have been recorded using the system, with an average linear acceleration of 105 ± 27 g [13,22,27,35]. Figure 3 shows the number of head accelerations measured using the HIT System at Virginia Tech and teams using the system by year from 2003 to 2012.

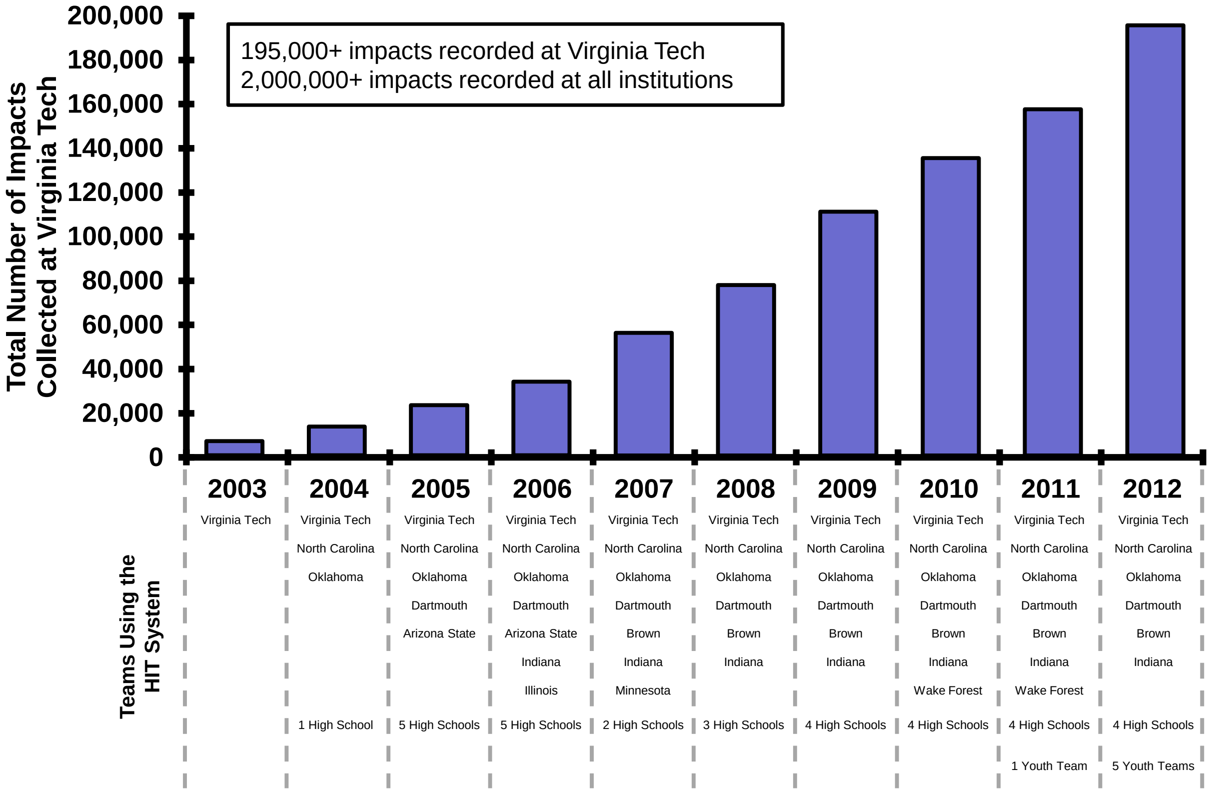

Figure 3: List of schools using the HIT System to collect head impact data in football players by year from 2003 to 2012

Over the last two seasons, the HIT System and 6-DOF have been used to collect exposure data from youth football players as well. The initial youth football study, by Daneil et al. [36], collected measured 748 impacts from 7 players, age 7 to 8, using the 6-DOF. In that study, the authors found that players sustained an average of 107 impacts during the season, with linear and rotational 95th percentile magnitudes of 40 g and 2347 rad/s^2. No concessions were observed in this initial study. In the second year of the youth study, more than 100 players from 5 teams, ages 6 to 18, were instrumented during practices and games for the entire season. The second year data will provide, for the first time, impact frequencies and acceleration magnitudes for all youth football age groups.

The NFL studies utilizing crash dummy reconstructions and helmet mounted accelerometer studies have yielded remarkably similar results in terms of linear and rotational acceleration for concussive data points. Peak linear acceleration is particularly important to the study of head injuries, as it has been shown to be a good predictor of concussion [14]. The NFL reconstructions resulted in an average peak linear acceleration of 98 ± 28 g [5] and 94 ± 28 g [9] for concussive impacts and the volunteer data has an average value of 105 ± 27 g [34]. In terms of rotational acceleration and velocity, the two methods also match quite well (Figure 4).

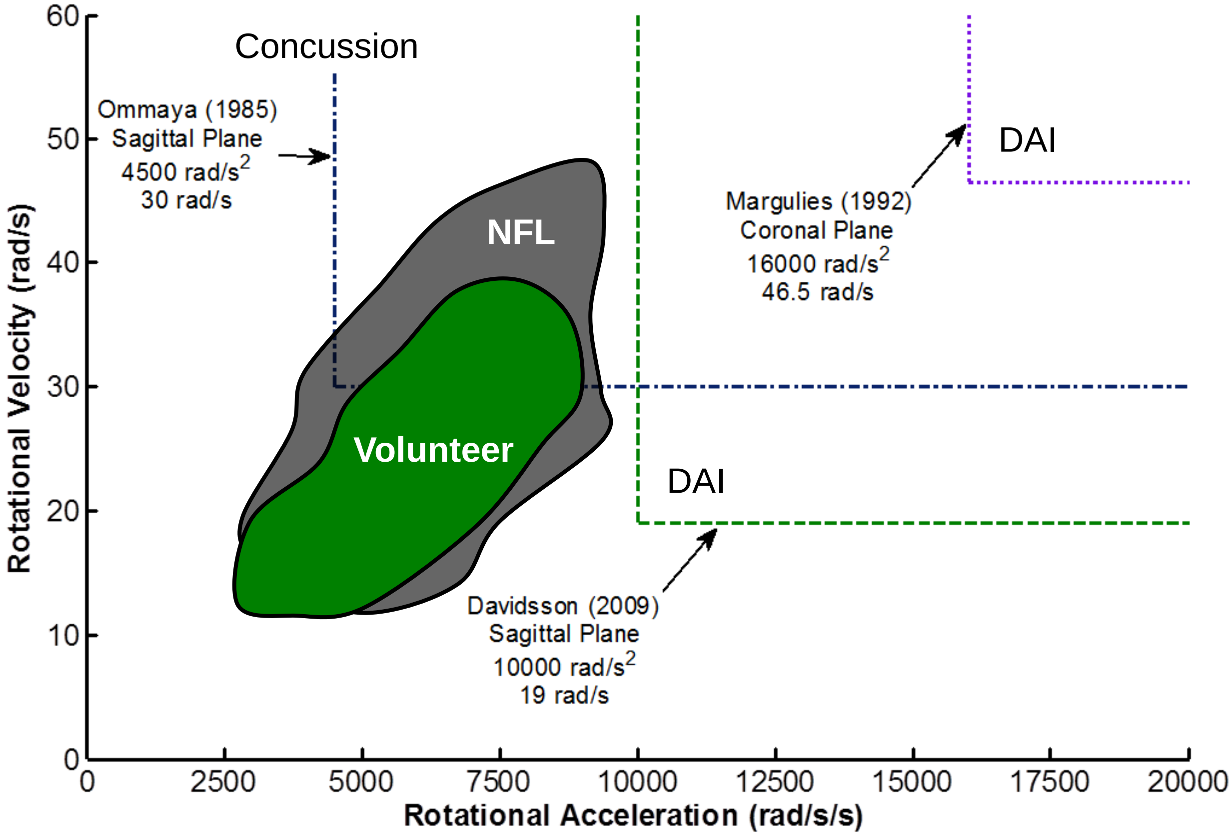

Figure 4: Rotational velocity vs. rotational acceleration for concussive impacts from NFL and volunteer data relative to previous studies on concussion and diffuse axonal injury (DAI).

To date, approximately 2 million data points have been collected using the HIT System and the number continues to rise each year. As the impact data set continues to grow, we will gain more insight into the level of exposure football players at all levels experience during a season and over their playing career. Furthermore, as we collect more concussive data points, we will be able to develop better risk functions for mTBI, leading to better safety equipment in sports [37,38]. These results may also have applications beyond football, in areas such as other sports, motor vehicle crashes, and the military, where mTBI is a concern.

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