

## MEASUREMENT OF HEAD IMPACTS IN COLLEGIATE FOOTBALL PLAYERS: AN INVESTIGATION OF POSITIONAL AND EVENT-TYPE DIFFERENCES

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**OBJECTIVE:** There exists a need to better understand the biomechanical forces associated with head impacts in American football. The purpose of this study was to investigate whether or not differences in head accelerations existed between different player positions and different event types in collegiate football. We also sought to identify whether or not any associations existed between high-magnitude impacts and location of head impacts.

**METHODS:** We conducted a prospective field study in which accelerometers were embedded in the football helmets of 72 collegiate football players. Linear accelerations of all head impacts sustained over the course of the 2005 and 2006 National Collegiate Athletic Association football seasons were collected. One-way analyses of variance and  $\chi^2$  tests of association assessed positional, event type, and location of head impact differences.

**RESULTS:** Football players consistently sustained head impacts between 21 and 23 g. Positional differences were identified within our sample. Impacts sustained during helmets-only practices were greater than those sustained in games or scrimmages. There was an association between position and high-magnitude impacts, as well as between high-magnitude impacts and location of head impact, with the likelihood of impacts to the top of the head much higher than those to the front, back, left, and right sides.

**CONCLUSION:** Less than 0.35% of impacts exceeding theoretical injury thresholds resulted in concussion. More injury data are required before any theoretical thresholds for injury can be confirmed. Coaches and sports medicine professionals should recognize that head impacts sustained in helmets-only practices are as severe as games or scrimmages; there seem to be no "light" days for football players.

**KEY WORDS:** Biomechanics, Concussion, Helmet, Injury threshold, Mild traumatic brain injury

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Concussion remains an area of great interest among sports medicine professionals. As part of their daily interaction with athletes, certified athletic trainers have the advantage of better observing the progression and eventual recovery of athletes sustaining mild traumatic brain injury (MTBI). An estimated 500,000 hospital visits occur annually without hospitalization after MTBI, whereas 200,000 cases require hospitalization (1). Because 90% of head injuries are mild and typically manifest in minor headaches and other symptoms, medical help for these injuries are often not sought in the general community. Previous reports have suggested

that the number of MTBIs may be as high as twice the number of patients who report for medical follow-up (7). American football has long been associated with a relatively high prevalence of MTBI, with previous reports suggesting that as many as 20% of football players will sustain a MTBI over the course of any given season (4). Given that there are over 1.5 million participants in American football each year, the incidence of MTBI presents an increasing burden on our healthcare system. There is a need to better understand potential contributors to the high prevalence of head injuries in football. These include measuring the magnitude of head impacts

and other biomechanical factors, ultimately benefitting improved equipment design with the goal of improving the safety of our football players.

The biomechanics of head impacts have been investigated in a variety of laboratory settings dating back to the mid-1940s. Pudenz and Sheldon (16) replaced the top halves of monkey skulls with clear, transparent domes; impacts were imparted on the monkeys and high-speed videography recorded the movement of the brain. Ommaya and Gennarelli (13) continued the animal studies and were among the first to describe in detail linear and rotational accelerative mechanisms of injury. More recently, the National Football League commissioned an investigation of sports-related concussions. One of these studies performed laboratory reconstructions of video-recorded concussions using helmeted Hybrid III dummies (15), and it was suggested that an injury threshold of 70 to 75 g existed for sustaining concussion based on the translational (linear) acceleration of a football player's head.

Recent technological developments have purported the measurement of head impacts in real-time and in more natural settings. In recent work, Duma et al. (3) published descriptive information regarding the peak linear accelerations of head impacts in a small sample of Division I football players. This study reported a mean peak linear acceleration of the head of 32 g. A follow-up study included data from a second season of measuring head impacts and found, in a limited sample, that a lower magnitude of head acceleration may actually cause MTBI (2).

As sports medicine professionals, we need to better understand the nature of head impacts football players sustain on a daily basis. Therefore, the purpose of this study was to investigate whether or not differences in head accelerations existed between different player positions in collegiate football and to identify which playing positions were more likely to sustain high-magnitude impacts. We also aimed to identify whether or not differences in head accelerations existed between different event types (game or scrimmage, full-contact practice, and helmets-only practices) and location of head impact (back, front, left, right, and top). Finally, we sought to identify whether or not there were any associations between high-magnitude impacts and location of head impacts.

## PATIENTS AND METHODS

Seventy-two Division I collegiate football players (age at start of enrollment,  $19.58 \pm 1.60$  yr) from one school participated in this study, which sought to measure real-time head impacts over the course of the 2005 and 2006 National Collegiate Athletic Association football seasons. In 2005, our sample included 22 freshmen, 11 sophomores, 10 juniors, and nine seniors; during the 2006 season, 23 freshmen, 10 sophomores, eight juniors, and nine seniors were studied. Additionally, our sample was representative of many playing positions, including 22 offensive linemen, 13 defensive linemen, 12 defensive backs (including cornerbacks and safeties), nine linebackers, 12 offensive backs (including fullbacks, running backs, and tailbacks), and five wide receivers. Because quarterbacks do not typically sustain contact during practices and our two starting quarterbacks were not instrumented, three quar-

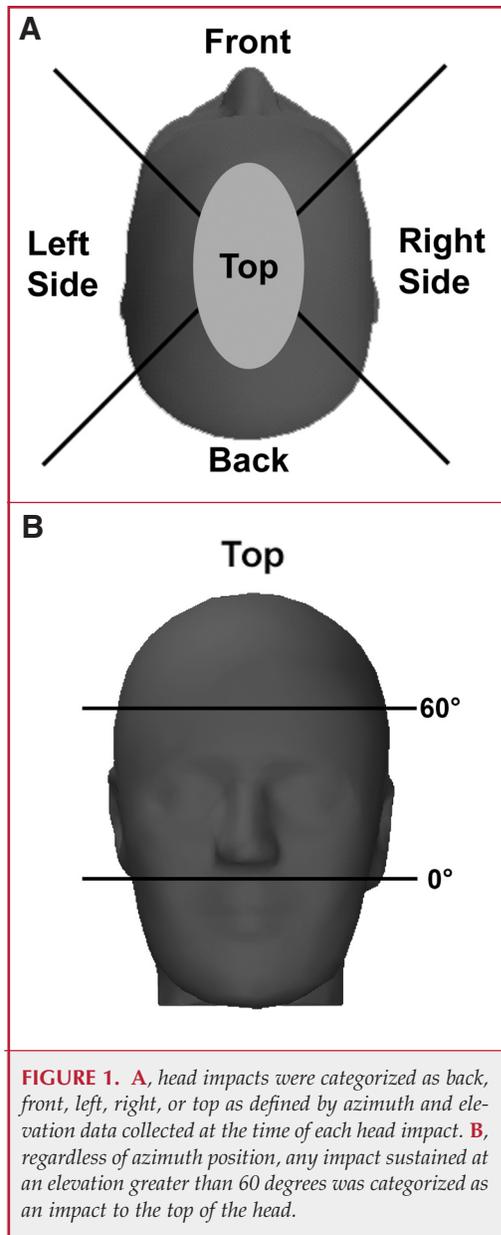
terbacks were excluded from our sample. Four participants changed playing position from the 2005 to the 2006 football seasons. A detailed explanation of the study was provided for all the athletes. Informed consent documents were approved by the university's Institutional Review Board and were signed by each player before the athlete's helmet was instrumented.

## Instrumentation

This study used Head Impact Telemetry System technology (Simbex, Lebanon, NH) incorporated within the Sideline Response System (Riddell Corp., Elyria, OH). A major component of the Head Impact Telemetry System is a unit comprised of six spring-loaded single-axis accelerometers that are inserted into Riddell VSR-4 (large- or extra large-sized) or Revolution (medium- or large-sized) football helmets (Riddell Corp.). For head acceleration data to be recorded, the acceleration of any individual accelerometer must exceed a desired threshold; this threshold was set at 10 g for this study. Once this occurs, information from the six accelerometers is collected at 1 kHz for a period of 40 ms; 8 ms are recorded before the data collection trigger and 32 ms of data are collected after the threshold trigger. Information from 100 separate head impacts can then be stored in nonvolatile memory built into the accelerometer device (i.e., resides in the helmet proper). The collected data undergo resident filtering to remove any direct current offsets from the accelerometer signals. The data are time-stamped on the accelerometer player unit, then encoded, and transmitted to a Sideline Controller through a radiofrequency telemetry link. Standard measures of head acceleration such as linear acceleration, Gadd Severity Index, and Head Injury Criterion are analyzed and stored at this time. The user interfaces with the Sideline Response System through the Head Impact Telemetry Impact Analyzer software on the laptop. The telemetry system is capable of transmitting accelerometer data from as many as 64 players over a distance well in excess of the length of a standard American football field.

## Data Reduction

The raw head impact data were exported from the Sideline Response System into Matlab 7 (The Mathworks, Inc., Natick, MA), where data were reduced to include only those impacts that were sustained during practices, scrimmages, and games; only impacts registering a linear acceleration greater than 10 g were included for the purposes of our analyses. Impacts less than 10 g are considered negligible with respect to impact biomechanics and their relationship to head trauma. Because each impact was linked to a player enrolled in our study by unique identifiers, we were able to easily associate impacts that belonged to a particular player and categorize those impacts based on positional information we had collected at the start of the season. Linear acceleration was the outcome measure of interest and was retained for the purpose of further analysis. Because head impact data are highly skewed in favor of low-magnitude impacts, our data were transformed using a natural logarithmic function to meet the assumptions of normality for the proposed parametric analyses described subsequently. All of our findings were then reverted back to their original scale for purposes of presentation. Azimuth and elevation data collected from the accelerometer player units were used to categorize the location of head impacts as depicted in *Figure 1*. Any impact sustained at an angle greater than 60 degrees in elevation was categorized as an impact to the top of the head. Front head impacts were defined as those occurring within 45 degrees from either side of the sagittal midline. Similarly, impacts within 45 degrees of either side of the sagittal midline posterior to the head were categorized as an impact to the back of the head. Impacts sustained within 45 degrees of the frontal plane were accordingly categorized as right or left, depending on which side of the head they were struck.



### Data Analysis

To assess our primary research objective, descriptive analyses (means and standard deviations) were calculated on the linear acceleration of measured head impacts. A one-way analysis of variance (ANOVA) was performed to assess whether or not differences in linear acceleration of head impacts existed between positions. A second one-way ANOVA was performed to evaluate whether or not differences in the linear acceleration of head impacts existed between helmets-only practices, full-contact practices, and games or scrimmages. A third one-way ANOVA was performed to identify differences in linear acceleration of head impacts and where impacts were imparted to the head (back, front, left, right, or top). In the event of a significant group difference, post hoc analyses using the Tukey Honestly Significant Difference were performed on the data to correct for

multiple comparisons. Impacts were then divided into one of three categories: impacts greater than 80 g (high), impacts ranging between 30 and 80 g (moderate), and impacts registering no higher than 30 g (low). A  $\chi^2$  test of independence was performed to identify whether or not there was an association between high-magnitude impacts (i.e., greater than 80 g) and player position. A second  $\chi^2$  test of independence was performed to identify whether or not an association existed between high-magnitude impacts and location of head impact; locations were identified as back, front, left, right, and top. All statistical analyses were performed using SPSS 13.0 for Windows (SPSS Inc., Chicago, IL) and the level of significance was set at a  $P$  value of less than 0.05 a priori.

## RESULTS

Over the course of the 2005 and 2006 National Collegiate Athletic Association Division I football seasons, we collected 82,026 head impacts, of which 57,024 exceeded our study threshold of 10 g and were retained for the purposes of data analyses. Descriptive data for these impacts are presented by player position (Table 1), event type (Table 2), and impact location (Table 3).

### Player Position Differences

A statistically significant difference was found among the positions ( $F_{5,57018} = 38.35$ ;  $P < 0.001$ ). The Tukey Honestly Significant Difference analysis revealed that offensive linemen ( $22.89 \pm 1.79$  g) sustained higher accelerative head impacts compared with defensive linemen ( $21.56 \pm 1.76$  g) and defensive backs ( $21.02 \pm 1.78$  g). Offensive backs ( $22.93 \pm 1.83$  g) and linebackers ( $22.67 \pm 1.81$  g) also sustained statistically higher magnitude impacts compared with defensive linemen and defensive backs. Defensive linemen and wide receivers ( $22.19 \pm 1.83$  g) sustained higher magnitude impacts than defensive backs. No other positional differences were observed. A strong association between high-magnitude head impacts and player position was also observed ( $\chi^2 [10] = 146.61$ ,  $P < 0.001$ ). Further analyses revealed that offensive backs were 1.52, 1.41, 1.24, 1.17, and 1.03 times more likely to sustain an impact of greater than 80 g than defensive linemen, defensive backs, offensive linemen, linebackers, and wide receivers, respectively.

**TABLE 1. Frequency (number) of head impacts sustained by position in the 2005 and 2006 football seasons<sup>a</sup>**

Position	Frequency of recorded impacts	Mean ( $\pm$ standard deviation) linear acceleration (g) of recorded head impacts
Offensive linemen	20,256 (35.52%)	22.89 $\pm$ 1.79
Offensive backs	7066 (12.39%)	22.93 $\pm$ 1.83
Defensive linemen	12,540 (21.99%)	21.56 $\pm$ 1.76
Defensive backs	8767 (15.37%)	21.02 $\pm$ 1.78
Linebackers	5892 (10.33%)	22.67 $\pm$ 1.81
Wide receivers	2503 (4.39%)	22.19 $\pm$ 1.83
Total	57,024	22.25 $\pm$ 1.79

<sup>a</sup> Percentages represent the percentage of total sample and add up to 99.99% as a result of rounding.

**TABLE 2. Frequency (number) of head impacts sustained by event type in the 2005 and 2006 football seasons<sup>a</sup>**

Event type	Frequency of recorded impacts	Mean (± standard deviation) linear acceleration (g) of recorded head impacts
Helmets-only practice	15,541 (27.25%)	22.47 ± 1.81
Full-contact practice	28,610 (50.17%)	22.65 ± 1.80
Games/scrimmages	12,873 (22.57%)	21.12 ± 1.73
Total	57,024	22.25 ± 1.79

<sup>a</sup> Percentages represent the percentage of total sample and add up to 99.99% as a result of rounding.

**TABLE 3. Frequency (number) of head impacts sustained by impact location in 2005 and 2006 football seasons<sup>a</sup>**

Location of head impact	Frequency of recorded impacts	Mean (± standard deviation) linear acceleration (g) of recorded head impacts
Top	10,728 (18.81%)	29.22 (1.95)
Front	20,450 (35.86%)	20.84 (1.68)
Back	17,617 (30.89%)	21.71 (1.79)
Left	4303 (7.55%)	19.74 (1.67)
Right	3926 (6.88%)	18.85 (1.64)
Total	57,024	22.25 (1.79)

<sup>a</sup> Percentages represent the percentage of total sample and add up to 99.99% as a result of rounding.

### Event-type Differences

A statistically significant difference was found when comparing the linear acceleration of head impacts of football players across three different event types ( $F_{2,57021} = 67.51$ ;  $P < 0.001$ ). Post hoc analyses identified head impacts sustained in helmets-only ( $22.47 \pm 1.81$  g) and full-contact practices ( $22.65 \pm 1.80$  g) were significantly higher than those sustained in games or scrimmages ( $21.12 \pm 1.73$  g). No differences in impact magnitudes were observed between helmets-only and full-contact practices.

### Location of Head Impact Differences

A statistically significant difference was found when comparing the linear acceleration of head impacts of football players across five different impact locations ( $F_{4,57019} = 826.20$ ;  $P < 0.001$ ). Post hoc analyses identified that head impacts sustained to the top of the head ( $29.22 \pm 1.95$  g) were significantly higher than those sustained to the back ( $21.71 \pm 1.79$  g), front ( $20.84 \pm 1.68$  g), left ( $19.74 \pm 1.67$  g), or right ( $18.85 \pm 1.64$  g) sides. A strong association between high-magnitude head impacts and location of head impact was also observed ( $\chi^2 [8] = 2847.27$ ,  $P < 0.001$ ). Football players in our sample were 8.5 and 6.54 times

more likely to sustain an impact greater than 80 g to the top of the head than on the right and left sides, respectively. Furthermore, they were 7.08 and 2.43 times more likely to sustain higher impacts to the top of the head than to the front and back, respectively.

## DISCUSSION

Our understanding of the biomechanical factors relating to MTBI has previously been confined to the laboratory setting. Although Duma et al. (3) and Broolinson et al. (2) have previously provided important data regarding head impacts in collegiate football, their studies were strictly descriptive in nature and did not attempt to identify positional or event-type differences. These are questions of high interest for many clinicians who are mandated with the care of football players at all levels of competition. To our knowledge, the current study is the first to investigate these research questions in a large cohort of Division I collegiate football players.

Our results suggest that, on average, head impacts sustained in Division I collegiate football typically range between 21 and 23 g, depending on playing position. No concussions were recorded in this range for our sample. Duma et al. (3) reported the magnitude of head impacts to be  $32 \pm 25$  g. A number of possibilities can explain these differences. First, Duma et al. (3) calculated the mean and standard deviation of their impacts without controlling for the highly skewed distribution of their data; this also explains the large variability in linear acceleration reported from their sample. To take into account the highly skewed nature of linear acceleration of head impacts, we performed a natural logarithmic transformation of the acceleration data. By doing this, we were able to perform parametric analyses (i.e., one-way ANOVA) because our log-transformed data now met the assumption of a normal distribution. Another reason for this discrepancy may have been that Duma et al. (3) alternated eight accelerometer units among their sample, selectively targeting players throughout the course of the season. Our study attempted to measure all the head impacts sustained by each player in every practice and game throughout the season. These important preliminary findings in the field of modern concussion biomechanics can be combined with those of earlier research to better understand the impact load demands between playing levels. Naunheim et al. (9) sought to investigate the acceleration forces to the head in high school football players. It was reported that peak accelerations inside the helmet for football players in their sample averaged 29.2 g. Our data do not support the notion that average magnitudes are of this higher value. For one, Naunheim et al. (9) only investigated linear acceleration of head impacts in two high school football players, one offensive lineman and one defensive lineman. Given that Naunheim et al. (9) included data on only two high school players, it is possible that the head accelerations in their report are inflated. We contend that a more recent report, including a larger sample of high school and Division I collegiate football players, suggests the high school player

typically sustains head impacts lower than the values we report in our study (18).

Although statistically significant differences across playing positions were observed in our study, we acknowledge that these differences have little clinical meaning. Notwithstanding, our positional analyses complement epidemiology studies that identified offensive linemen and linebackers as those players most likely to sustain a concussion in collegiate football (5). Previous reports (8) suggested that offensive backs experience the highest frequency of head impacts and that defensive backs sustained the lowest magnitude of head accelerations. This previous work was limited by a small player sample size ( $n = 16$ ), although similar trends were consistent with data in this study. The positional trends are further emphasized by significant associations observed in this study. We found that offensive backs were 1.52, 1.41, 1.24, 1.17, and 1.03 times more likely to sustain an impact of greater than 80 g than defensive linemen, defensive backs, offensive linemen, linebackers, and wide receivers, respectively. These data differ slightly from what we expected based on previously reported concussion injury rates (5). Guskiewicz et al. (5) reported the lowest concussion injury rates in running backs and wide receivers compared with linebackers, offensive linemen, defensive backs, and defensive linemen. However, our data suggest that offensive backs and wide receivers are more likely to sustain a high-magnitude impact than the other positions in our study. This is an interesting finding given that we would expect the likelihood of sustaining high-magnitude impacts to be related to an increase in concussion injury rates. Based on our findings, it is plausible that a cumulative effect of repeated low-magnitude head impacts might explain the increased injury rates previously observed in the other playing positions. Future studies should seek the answer to this important research question. Furthermore, in a recent report in this journal by Schnebel et al. (18), it was reported that skill players (i.e., quarterbacks, running backs, wide receivers, cornerbacks, and safeties) sustained fewer impacts than linemen; however, skill players were more likely to sustain higher magnitude impacts than linemen. Our study provides more elaborate positional information by offering a sufficient sample of a wide variety of positions. One limitation to our study, however, is the exclusion of quarterbacks from our sample. Future work should study the quarterback position because these players, as a result of their playing role, are often vulnerable to blindside hits and are unable to protect themselves from collisions.

Based on previous reconstruction data, it has been suggested that concussions in padded (i.e., helmeted) impacts are more likely to occur between 70 and 75 g (15). We collected acceleration data on 1858 impacts greater than 80 g; only seven resulted in concussion. Although the initial work by Pellman et al. (15) represented the most sophisticated method of analyzing concussive injuries in professional football players at the time, it was lacking real-time head acceleration data. One must also question the limitation that only 31 cases out of 182 reviewed were reconstructed in a laboratory setting. It should be noted that the injury threshold reported by Pellman et al. (15) was the

result of reconstructing concussions sustained in the National Football League and may not be representative of the collegiate or high school football player. This notion may be supported in part by previously published work in this journal reporting different recovery times of neuropsychological performance between National Football League and high school players after concussion (14). Our data were collected on collegiate football players, and less than 0.35% of impacts greater than 80 g resulted in concussion in our sample. We speculate that the lower threshold reported by Pellman et al. (15) might be suggestive of the potential cumulative effects of recurrent head impacts sustained by players in the National Football League. Understanding the cumulative nature of repeated head impacts is an area for future study.

Another interesting finding is that head impacts sustained during helmets-only practices and full-contact practices are statistically significantly higher than those sustained in games and scrimmages. Although we acknowledge that a claimed difference may be an artifact of many impacts, our data are still suggestive that impacts sustained in games are not greater than those sustained in regular and even light practices. This is surprising given that most concussive injuries have been shown to occur in games. It has been previously reported that 51.9% (68 out of 131) of concussions sustained in Division I collegiate football occurred during games (5). However, this trend is not the same in Division II and Division III collegiate football. It was reported that 46.2 and 38.5% of all concussions were sustained during games in Division II and Division III football, respectively. Although the absolute number of game-related head injuries appears to decrease along with competitive level, reported injury rates illustrate that as many as 3.70, 3.21, and 5.26 concussions occur per 1000 athlete-exposures during games in Divisions I, II, and III, respectively. These contrast the values for practice-related concussions, in which injury rates have been reported to be as low as 0.39, 0.44, and 1.07 per 1000 athlete-exposures in Divisions I, II, and III, respectively (5). Many sports medicine professionals and coaches often regard helmets-only practices as those that pose lower risks of injury to the athlete, but our findings may be reason for caution.

Our investigation pertaining to the location of head impact is interesting. As rule changes attempt to reduce the incidence of cervical spine injury in football players, we have observed that 18.81% of all head impacts are still imparted by or to the top of the head. The implications of these findings with respect to cervical spine injury are worth discussing. Axial loading has long been a mechanism of injury associated with football. Between 1971 and 1975, 39% of nonquadriplegic neck injuries and 52% of permanent quadriplegia in football resulted from axial loading mechanisms (19). It has been reported that 200 head-down impacts occurred during one team's season in 1990 (6). Heck (6) did not provide a comparative assessment of impacts occurring to other areas of the head; however, our data suggest that many more impacts are occurring to the top of head than previously thought. Our findings and how they relate to the potential compressive loading of the cervical spine are equally interesting. In previous work by Nightingale et al.

(10–12), compressive load limits of the cervical spine have previously been reported to range between 3340 and 4450 N. Given that we have measured linear accelerations exceeding  $784.8 \text{ m/s}^{-2}$  ( $80 \text{ g} \times 9.81 \text{ m/s}^{-2}/1 \text{ g}$ ), simple Newtonian calculations suggest that a head mass as light as 5.67 kg accelerating at this rate is capable of producing 4450 N of force. Given that the head mass of a 100-kg (220 lbs) football player is approximately 8.1 kg, a head acceleration of 80 g would far exceed the upper proposed compressive load limit of 4450 N. Fortunately, neck compressive forces are generated by the bony architecture, and the ligamentous and muscular support, of the cervical region that assist in reducing the compressive load after an axial compression; these were not included in the estimates. It should also be noted that these calculations are based on standardized Dempster anthropometric data (20), and these estimates do not include the mass of the helmet itself. Although the implications of these findings are important to sports medicine professionals from the context of cervical spine injury, there is evidence to suggest that concern should exist with respect to the implication of sports-related concussion. Of the seven concussions we recorded over the course of these seasons, four resulted from impacts to the top of the head. We acknowledge that we are limited with a small sample of injuries at this point, but we feel that this is an interesting area worthy of future research. Preliminary evidence is also suggestive that increased neuropsychological deficits exist after impacts to the crown of the head. In a study of 97 concussed athletes, it was found that those who sustained an impact to the crown of the head exhibited increased neuropsychological deficits compared with those who received impacts to the other areas of the head (17). The mean age of the athletes in a study by Schnakenberg-Ott et al. (17) was 16.3 years. Although their data are preliminary, it appears there is value in investigating the relationships between location of head impact and concussion severity. Future research should describe these relationships as they relate to high school athletes because they typically account for the largest number of football players in the United States.

Less than 0.35% of impacts greater than 80 g resulted in concussion based on athlete self-report of symptoms. It may be possible that a greater number of athletes sustained a concussion and experienced symptoms associated with the injury but did not report this to the medical personnel (i.e., certified athletic trainer or team physician). One way to help identify these cases might be the implementation of real-time data collection of head impact accelerations. We should investigate whether a real-time head impact greater than a theoretically proposed injury threshold results in a decline in objective clinical measures of concussion. Furthermore, it will be interesting to see how neuroimaging, neuropsychological, and balance test performance will relate to both magnitude and location of head impacts.

## CONCLUSIONS

In summary, our data have identified positional and event-type differences regarding head impact severity. Furthermore,

it was found that an association exists between player position and the likelihood of sustaining an impact with a linear acceleration in excess of 80 g. Of all the impacts that exceeded theoretical thresholds of injury previously reported, less than 0.35% resulted in self-reported symptoms that were later diagnosed as concussive. Any proposed theoretical injury threshold should be interpreted with caution because all are limited by very small sample sizes. Concussion remains an area of high interest for sports medicine professionals. Although we continue to learn more about the injury, it remains one of the most difficult injuries to manage in our field. Continued real-time data collection procedures in the sports arena should provide clinicians with valuable information pertaining to sports-related concussion.

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## COMMENTS

Mihalik et al. studied head impacts by using accelerometers embedded in the helmets of 76 collegiate football players during a 2-year period. Their findings are interesting and add to our knowledge of the biomechanics in this contact sport. They showed that head impact measurements were consistently between 21 and 23 *g*, and that this range did not produce concussion, that impacts to the top of the head tended to be the largest, and that practice sessions unexpectedly involved high acceleration values.

Their results lend increasing credibility to the theory that linemen, in fact, experience repeated head impacts that are lower in magnitude but higher in number, and thus have a greater than expected concussion risk due to the cumulative effects of these impacts. The authors also offer the interesting speculation that lower threshold values for mild traumatic brain injury in the National Football League may represent the cumulative effects of numerous impacts.

Studies such as this expand our knowledge of mild traumatic brain injury in sports by moving the focus out of the laboratory to an on-field setting. An understanding of concussion thresholds will undoubtedly involve additional factors besides acceleration. Additional research with larger sample sizes will help us to continue to advance our knowl-

edge, and acceleration data may one day be used in real time to identify, during a contest, who is at greatest risk.

**Julian E. Bailes**  
*Morgantown, West Virginia*

Mihalik et al. used accelerometers implanted in the helmets of college football players to measure the accelerations associated with all head impacts, both in practice and during games, during two football seasons. More than 82,000 impacts were recorded. The average magnitude of impacts did not differ much between the various positions played. Curiously, impacts sustained during practices were of greater magnitude than those sustained during games. Another interesting result is that although this group's previous work suggested that running backs and wide receivers have the lowest rates of concussion, the present work suggests that offensive backs and receivers are more likely to sustain high-magnitude impacts. Mihalik et al. speculate that the cumulative effect of repeated, low-magnitude impact may explain the paradox of higher concussion rates in players who are least likely to sustain high-magnitude impacts. Future studies will determine whether this provocative idea withstands the test of time.

**Alex B. Valadka**  
*Houston, Texas*

This article reports the results of a study designed to measure head impact in collegiate football players. The study uses a relatively new technology (the Head Impact Telemetry system) and provides interesting data on the biomechanical characteristics of blows to different parts of the helmet. The most important aspect of this study is its reliance on real-time data collected telemetrically at the time of collision. This technology represents a relatively new development and allows for the collection of data on each instrumented athlete with almost immediate transmission of this information to a computer for storage and later analysis. The study does not seek to evaluate velocities that are associated with concussive injuries. The limitation of the study is the relatively low number of subjects in each of the position groups; therefore, the results should be considered preliminary. However, Mihalik et al. have provided us with this initial study. We hope that the ongoing collection of data will lead to continued exploration of this technology as a research tool.

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