[Primary Care]

Inadequate Helmet Fit Increases Concussion Severity in American High School Football Players

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Background: There is limited information on the relationship between football helmet fit and concussion severity.

Hypothesis: Poor helmet fit may predispose football players to a more severe concussion.

Study Design: Descriptive epidemiology study.

Level of Evidence: Level 3.

Methods: Data from concussion injury reports were obtained from the National High School Sports-Related Injury Surveillance System over a 9-year period. Symptoms, duration, and helmet parameters (fit, interior padding) were analyzed for all first-time concussions.

Results: Data from 4580 concussions were analyzed. Patients who suffered concussions with a helmet that did not fit properly (3.22%), as determined by an athletic trainer, had higher rates of drowsiness (RR, 1.46; $P = 0.005$), hyperexcitability (RR, 2.38; $P = 0.047$), and sensitivity to noise (RR, 1.88; $P < 0.001$); had more symptoms (5.34 vs 4.54, $P = 0.004$); and had longer symptom duration ($P = 0.04$). Athletes with helmets lined with an air bladder had greater rates of sensitivity to light (RR, 1.13; $P = 0.02$), sensitivity to noise (RR, 1.25; $P = 0.009$), and longer symptom duration ($P = 0.004$) compared with foam or gel liners.

Conclusion: An improperly fitted football helmet is a risk factor for a concussion with more symptoms and of longer duration. Concussions of longer duration are also more common in players with an air bladder–lined helmet. Current high school football rules should mandate supervision and maintenance of helmet fit throughout the season, prior to impact.

Clinical Relevance: Team physicians, athletic trainers, coaches, and high school officials should ensure proper oversight of helmet fit in high school athletes to decrease concussion severity and duration.

Keywords: concussion; football helmets; athletic trainer

Over the past 2 decades, the rate of concussion in American high school football demonstrated an alarming upward trend. In 1 study, rates of concussion doubled per 1000 high school athlete-exposures between 2005 and 2012.[20] Data from a national high school registry in 2012 revealed that concussions comprised 13.2% of all reported high school sport injuries.[16] This statistic increased from 5.5% in 1999 to 8.9% in 2007.[16] Concussions have been referred to as a "silent epidemic."[7] While associated problems are often not visible, they may lead to profound consequences, including long-term mental, physical, or occupational sequelae. Accordingly, reported frequencies are likely underestimated because of unrecognized or unreported injuries.[17] Numerous risk factors for concussion have been proposed, including helmet technology,

sex, coaching staff expertise, prior concussion, and increased sport-related contact.[6,13,16,23]

Since the advent of football in 1869, helmets with various engineering standards have evolved in an attempt to protect the head. When the rate of brain-related fatalities associated with football peaked in the late 1950s, Gadd[9] developed a severity index (GSI) that determined the likelihood of skull fracture during impact. The National Operating Committee on Standards for Athletic Equipment (NOCSAE) utilized the GSI in efforts to establish new helmet standards. While the number of skull fractures in football has dramatically declined with modern helmet design,[2] concussions have persisted at concerning rates.

The effect of proper helmet fit or type of helmet lining on concussion characteristics has not been fully investigated. Several recent studies have assessed whether modern helmet technology is protective against concussion, but none of them specifically investigated helmet fit.[6,8,21,24] Therefore, the purpose of this study was to assess the potential relationship between helmet fit and concussion severity or symptom duration in high school football.

Starting with the 2012-2013 high school football season, the National Federation of State High School Associations (NFHS) instituted a new rule whereby players with a completely dislodged helmet are required to sit out 1 play to adjust their helmet for a more proper fit. The goal of this rule was to protect at-risk players and encourage the wearing of properly fitted helmets. Therefore, this study additionally analyzed changes in concussion severity and duration after the NFHS instituted this new helmet rule.

METHODS

The National High School Sports–Related Injury Surveillance system (HS RIO) has had institutional review board approval from Nationwide Children's Hospital since its inception in 2005. Data regarding first-time concussions sustained during participation in high school football during 9 seasons from 2005-2006 through 2013-2014 were retrospectively obtained from HS RIO, a prospective surveillance study that collected computerized reporting information online from a large national population of high schools. Briefly, eligible high schools with 1 or more National Athletic Trainers' Association (NATA)–affiliated certified athletic trainer (AT) with a valid email address were sent annual invitations to participate in the HS RIO. High schools that responded were categorized into 8 strata based on school population (enrollment ≤1000 or >1000) and United States census geographic region. Twelve or 13 schools were randomly selected from each strata to compose the nationally representative 100-school sample. If a school dropped out of the study during the academic year, a replacement from the same stratum was randomly chosen to maintain the 100-school study population. ATs from participating high schools logged onto the study Web site weekly during the academic year to report injury incidence and athlete exposure information. An

athlete exposure was defined as 1 high school athlete participating in 1 school-sanctioned practice or competition. Reportable injuries (1) occurred as a result of participation in an organized high school practice or competition, (2) required medical attention by an AT or physician, and (3) restricted the athlete's participation in the sport for >1 day or resulted in any fracture, concussion, or dental injury even if it did not result in restriction of participation. This study is restricted to football concussion data. Each concussion report documented concussion symptoms and helmet characteristics, including whether the AT believed the helmet fit correctly at the time of injury and type of inner helmet liner. Assessment of equipment fit is a required educational competency for all ATs certified by the Commission on Accreditation of Athletic Training Education. Data were analyzed using SPSS 22.0 software. Duration of symptoms were categorized into 4 groups: ≤15 minutes, between 15 minutes and 24 hours, between 24 hours and 1 week, and >1 week. Student t tests and analyses of variance were utilized to compare means of continuous variables. Chi-square tests were performed for all categorical analyses. P values less than 0.05 were considered significant. In this study, a concussion was defined as more severe if it was associated with more symptoms.

RESULTS

Data from 4580 concussions sustained over 9 seasons were analyzed. Anthropometric data showed: mean age, 15.6 ± 1.25 years (range, 13-19 years); mean height, 69.3 ± 3.41 inches (range, 50-81 inches); and mean weight, 174 ± 37.0 pounds (range, 85-372 pounds). Concussion injury reports showed a mean 4.43 ± 2.33 symptoms (range, 0-14) (Table 1). Durations of symptoms (Table 2) were reported in 4311 reports (94.1%). Concussions with more symptoms were associated with statistically longer durations to resolution (Figure 1). When separated into groups above or below mean values, there was no difference in number of symptoms according to age (P = 0.603) or weight (P = 0.0913). Players taller than 70 inches had more severe concussions than shorter players (4.49 ± 2.35 vs 1.33 ± 2.26 symptoms, P = 0.0369).

Helmet Fit

Data regarding helmet fit were included in 3172 reports. Athletic trainers reported that 102 helmets did not fit properly and 3070 helmets did. Athletes with helmets that did not fit properly had greater rates of drowsiness (RR, 1.5; P = 0.0037), hyperexcitability (RR, 2.4; P = 0.0329), and sensitivity to noise (RR, 1.9; P < 0.001) (Table 1). Athletes with poorly fitted helmets also averaged more symptoms (5.34 vs 4.54, P = 0.004). Symptom duration was recorded in 3003 (94.7%) reports for players with data on helmet fit. Athletes with poorly fitted helmets experienced symptoms for longer than 1 week more often than athletes with properly fitted helmets (37.0% vs 30.8%, P = 0.04).

Table 1. Symptom distribution[a]

	No. of Players With Symptom (%)	Did Helmet Fit? (yes vs no), P value	Helmet Liner (air bladder vs other), P value
Amnesia	982 (21.4)	0.550	0.095
Concentration difficulty	2616 (57.1)	0.204	0.768
Confusion/disorientation	2178 (47.5)	0.608	0.220
Dizziness/unsteadiness	3332 (72.8)	0.909	0.515
Drowsiness	1302 (28.4)	0.0037 (RR = 1.5)	0.0285 (RR = 0.9)
Headache	4190 (91.5)	0.910	0.447
Hyperexcitability	111 (2.4)	0.0329 (RR = 2.4)	0.319
Irritability	476 (10.4)	0.163	0.216
Loss of consciousness	146 (3.2)	0.409	0.0396 (RR = 0.6)
Nausea	1383 (30.2)	0.0839	0.0907
Tinnitus	461 (10.1)	0.418	0.117
Sensitive to light/visual disturbance	1762 (38.5)	0.058	0.0223 (RR = 1.1)
Sensitive to noise	943 (20.6)	< 0.0001 (RR = 1.9)	0.0087 (RR = 1.2)

RR, relative risk.
[a]N = 4580, 9 seasons.

Table 2. Durations of symptoms[a]

Duration	No. of Players (%)	Before 2012 Rule Change, n (%)[b]	After 2012 Rule Change, n (%)[b]	Air, n (%)[c]	Foam or Gel, n (%)[c]
≤15 min	138 (3.20)	120 (4.55)	18 (1.07)	55 (2.2)	28 (4.5)
>15 min and ≤24 h	767 (17.8)	559 (21.2)	208 (12.4)	420 (16.5)	107 (17.1)
>24 h and ≤1 wk	2141 (49.7)	1362 (51.7)	779 (46.5)	1277 (50.3)	285 (45.5)
>1 wk	1265 (29.3)	594 (22.5)	671 (40.0)	786 (31.0)	206 (32.9)

[a]Data presented as number of players (%). Percentages are proportions of concussions according to the column title categorized by duration.
[b]Chi-square, 195.8; $P < 0.0001$.
[c]Chi-square, 13.2; $P = 0.004$.

Helmet Liner

Data regarding helmet liners were included in 3352 reports. There were 2690 helmets with an interior air bladder lining and 662 helmets lined with either a foam (n = 534) or gel (n = 128) liner. Athletes who sustained a concussion while wearing helmets with an air bladder had significantly greater rates of sensitivity to light (RR, 1.1; $P = 0.0223$) and sensitivity to noise (RR, 1.2; $P = 0.00870$) (Table 1). Athletes with a gel or foam helmet liner had significantly greater rates of loss of consciousness (RR, 1.6; $P = 0.0396$) and drowsiness (RR, 1.1; $P = 0.0285$) (Table 1). Liner type was not associated with number of symptoms ($P = 0.378$). Symptom duration was recorded in 3164 (94.4%) reports for players with data on helmet liner. Air bladders were associated with fewer concussions lasting less than 15 minutes (2.17% vs 4.47%) and more concussions lasting between 24 hours to 1 week (50.3% vs 45.5%) (Table 2). However, there was no significant change in the remaining 2 duration categories (Table 2). There was no
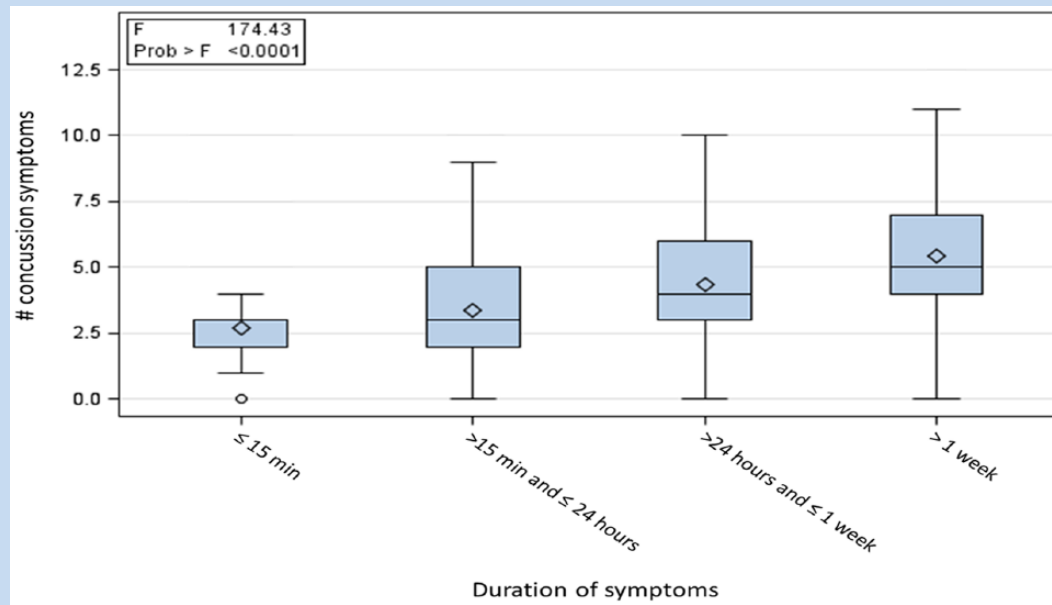
Figure 1. Comparison of number of concussion symptoms with durations of symptoms.

significant difference in the proportion of helmets that fit when comparing air bladders versus alternate liners ($P = 0.944$).

2012 NFHS Helmet Rule

After the 2012 helmet rule was instituted, there was no change in the proportion of helmets that fit improperly at the time of injury (3.79% vs 2.79%, $P = 0.158$). However, concussions were associated with more symptoms after the rule change (4.65 ± 2.27) compared with before the rule change (4.29 ± 2.37, $P = 0.04$), and the percentage of concussions that lasted longer than 1 week increased ($P < 0.0001$, Table 2).

DISCUSSION

This study suggests that there is an increased risk of concussion severity and duration if the high school football player's helmet fits improperly. Recent studies have implied that football helmet fit may have an important role in concussion prevention. A minimum of 7% of helmets worn by athletes who sustained catastrophic intracranial injuries are incorrectly fit or defective.[1] A prospective study that utilized neurocognitive test results as endpoints concluded that modern helmet technology decreases the risk of concussion in high school football.[5] These modern helmets have additional thick padding over the zygoma and mandible regions that improves helmet fit. A more recent study collected head impact exposure data using helmet-mounted accelerometers in 1833 college football players and revealed that helmet design is a risk factor for concussion. The newer helmet model associated with fewer concussions in that study had interior padding that was 40% thicker than a standard helmet worn by the comparison group.[21]

One possible explanation for the more severe concussions in the group with a poorly fitted helmet is that the cervical muscles play an important role in absorbing impact forces as the helmet and head function as a single unit.[22] If the helmet is not secured properly to the head and acts as a separate unit, the cervical muscles may not be able to dampen the forces, especially rotational forces, which are then transmitted from the helmet to the brain. A loose helmet also may delay the cervical muscle contraction response to an impact since the direction of the force to resist may not be detected until it reaches the head. The lack of correlation between biomechanical data on impact forces and a clinical concussion threshold may be partially due to the fit of the helmet.[8]

Maintaining a properly fitted helmet throughout the season is challenging because of mismatches between helmet size and the athlete's head. Helmet fit can also vary when athletes sweat or play in rainy conditions. Additionally, high school athletes may dramatically alter their hair styles (eg, shaving their heads) or what they wear under a helmet (eg, adding internal layers of clothing for warmth) over the course of a season. Last, air bladder systems may leak, resulting in insufficient inflation.

According to rules published by the NFHS, no supervising individual is specifically responsible for ensuring proper helmet fit prior to athlete participation.[4] Prior to each game, coaches are required to verify that all athletes are wearing a helmet that meets NOCSAE standards and that all helmets have an exterior warning label. This warning label mentions avoidable causes and risks of head and neck injuries but does not mention helmet fit. Football helmet manufacturers make recommendations on how to achieve and maintain a proper fit. However, data on enforcement of these recommendations are lacking. It is often the responsibility of the athlete to recheck

helmet fit, inflate a loose air bladder during the season, or bring problems with helmet fit to the attention of team officials.[10]

This study found no difference in the proportion of properly fitting helmets at the time of injury before or after the 2012 NFHS rule change. That rule mandated that any player with a helmet completely dislodged must leave the game for 1 play and adjust their helmet. Unfortunately, concussions were of greater severity after the 2012 rule change, and the frequency with which symptoms lasted more than 1 week increased. Although this study does not establish causality between this rule change and reported outcomes, these findings are concerning. The NFHS helmet rule does not force athletes to adjust their helmets until after they have sustained a potentially major impact. Thus, supervisors of high school football teams should mandate that coaches, ATs, or equipment managers verify adequate helmet fit among all players prior to and throughout the football season.

These findings suggest that helmets lined with air-bladders are at increased risk for concussions with sensitivity to light, sensitivity to noise, and concussions of longer duration. However, there was no association between helmet liner type and concussion prevalence or severity. In addition, helmets lined with gel or foam liners had higher risks of loss of consciousness and drowsiness. Loss of consciousness is an infrequent finding but is also more concerning than sensitivity to light or noise.[12,14] Different helmet liners may offer varying protection against specific symptoms, but the preliminary findings that concussions of longer duration are associated with helmets with air bladder liners requires further biomechanical and clinical research.

There are several important limitations regarding the interpretation of our data. First, the number of symptoms was used as a measure of concussion severity. Although several methods have been utilized to measure concussion severity, there is no single accepted method.[11,12,14] The number of initial symptoms and concussion duration may be related, but not always congruent. A greater number of symptoms within the first week after a concussion may be a risk factor for more severe postconcussion symptoms.[19] Additionally, individuals with a high early symptom load may be at risk for developing persistent complaints.[15] However, we reported symptom duration separate from total number of symptoms because certain studies have refuted the belief that a greater number of concussion symptoms at initial presentation is associated with overall increased symptom duration.[3,11]

Second, a relatively small proportion (5.3%) of all concussion reports with data on helmet fit did not contain answers regarding symptom duration. Given the large remaining sample size, it is unlikely that this deficit affected the results. Third, ATs reported that helmets did fit in the majority of athletes. Nonetheless, sample sizes among the group of athletes with poorly fitting helmets were still large enough to draw conclusions with statistical power.

Most important, this study lacked a uniform method with which to measure helmet fit, and there is no comparison group. The retrospective nature of this study exposes this analysis to inherent confounders. With regard to helmet technology and data collection, several studies involving football helmets are subject to equipment bias and underreporting.[18] However, because this study identified a relationship between an AT's assessment of helmet fit with concussion severity, this suggests an easily modifiable risk factor that can be addressed on the field. In reality, simply ensuring time for repeat helmet fit assessments throughout the season is a reasonable method in which helmet fit can be enhanced and implemented. This study also analyzed helmet fit as an isolated risk factor for concussion, although there are many other risk factors and causes for severe concussion, including style of play, playing position, time to recovery, prior concussion, and genetic factors. Despite these limitations, this study identifies an important new potential intervention that may reduce concussion severity and possibly even concussion incidence.

CONCLUSION

This study suggests that concussions in high school football players wearing an improperly fitted helmet may be of greater severity and longer duration than concussions in athletes with a properly fitted helmet. The 2012 NFHS helmet rules encourage properly fitting helmets but may not adequately address this problem. These data also suggest that helmets lined with air bladders are associated with concussions of longer duration, which may be related to air leakage. Team physicians, athletic directors, coaches, athletes, and ATs should be aware of the potentially deleterious effect of an improperly fitted helmet. Governing bodies as well as high schools should ensure proper adult oversight of football helmet fit throughout each season.

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