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Protective Equipment and Player Characteristics Associated With the Incidence of Sport-Related Concussion in High School Football Players:

A Multifactorial Prospective Study

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Abstract

Background—The incidence of sport-related concussion (SRC) in high school football is well documented. However, limited prospective data are available regarding how player characteristics and protective equipment affect the incidence of SRC.

Purpose—To determine whether the type of protective equipment (helmet and mouth guard) and player characteristics affect the incidence of SRC in high school football players.

Design—Cohort study; Level of evidence, 2.

Methods—Certified athletic trainers (ATs) at each high school recorded the type of helmet worn (brand, model, purchase year, and recondition status) by each player as well as information regarding players' demographics, type of mouth guard used, and history of SRC. The ATs also recorded the incidence and days lost from participation for each SRC. Incidence of SRC was compared for various helmets, type of mouth guard, history of SRC, and player demographics.

Results—A total of 2081 players (grades 9–12) enrolled during the 2012 and/or 2013 football seasons (2287 player-seasons) and participated in 134,437 football (practice or competition) exposures. Of these players, 206 (9%) sustained a total of 211 SRCs (1.56/1000 exposures). There was no difference in the incidence of SRC (number of helmets, % SRC [95% CI]) for players wearing Riddell (1171, 9.1% [7.6%–11.0%]), Schutt (680, 8.7% [6.7%–11.1%]), or Xenith (436, 9.2% [6.7%–12.4%]) helmets. Helmet age and recondition status did not affect the incidence of SRC. The rate of SRC (hazard ratio [HR]) was higher in players who wore a custom mouth guard (HR = 1.69 [95% CI, 1.20–2.37], $P < .001$) than in players who wore a generic mouth guard. The rate of SRC was also higher (HR = 1.96 [95% CI, 1.40–2.73], $P < .001$) in players who had

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sustained an SRC within the previous 12 months (15.1% of the 259 players [95% CI, 11.0%–20.1%]) than in players without a previous SRC (8.2% of the 2028 players [95% CI, 7.1%–9.5%]).

Conclusion—Incidence of SRC was similar regardless of the helmet brand (manufacturer) worn by high school football players. Players who had sustained an SRC within the previous 12 months were more likely to sustain an SRC than were players without a history of SRC. Sports medicine providers who work with high school football players need to realize that factors other than the type of protective equipment worn affect the risk of SRC in high school players.

Keywords

football helmet; concussion; high school

Sport related-concussion (SRC) is a growing concern in the United States, and an estimated 300,000 SRCs occur annually.^{6,11,17} Football is the most popular high school sport in the United States, with 1.1 million participants during the 2012 school year.²⁴ Almost half of the SRCs sustained during high school sports take place in football,^{18,28} and many are treated in emergency departments.²³ While the incidence of concussion in high school athletes is relatively well established, the specific risk factors for this injury in high school football^{1,3,6,16,28} are less well understood. Possible risk factors for concussion in football include the history of concussion, characteristics unique to the individual (age, competition level, body mass index [BMI]), and type of protective equipment worn by the player.^{1,2,15,21,22,26,32}

The football helmet is the primary piece of equipment used to protect a player from head-related injury and in recent years has been identified as a device that may reduce a player's risk of sustaining a concussion.^{5,31} Football helmets have evolved a great deal over the past 50 years.³⁷ Current football helmets are heavier and larger and are designed to absorb and dissipate impact forces to a greater extent than earlier models.³⁷ The most popular helmet brands used by high school football players in the United States are manufactured by a limited number of companies. The helmets currently in use are similar, with slight differences noted in exterior shell designs, interior padding, and fitting methods.^{30,33,42} These manufacturers do state that their helmets cannot prevent concussions or eliminate the risk for serious injury. However, in recent years the manufacturers have modified existing helmets and introduced new helmets with claims from laboratory testing that their helmets are the best and offer the maximum protection.^{30,33,40} In addition, manufacturers recommend that coaches and schools purchase newer helmets as opposed to using helmets that are several years old that have not been reconditioned recently. Reconditioning a helmet consists of removing the face mask and exterior hardware, inspecting the shell for cracks, removing and replacing any worn interior components, disinfecting and painting the helmet, and testing the helmet with drop tests. However, few prospective data are available on the incidence of SRC in football players actually wearing different makes and models of helmets.^{2,7,12} In addition, laboratory-based studies have suggested that mouth guards may attenuate the forces applied to the head from specific impact locations.^{34,38,39} As with football helmets, there is limited evidence from prospective clinical studies supporting the claim that any specific type of mouth guard will reduce the incidence of SRC in high school football players.^{8,9,12,20}

Experts have stated that concussion susceptibility in various sport settings is often multifactorial.^{3,39} Previous research has not been able to fully account for or quantify the role of specific player variables in regard to concussion susceptibility.^{1,15,19,21} This issue is paramount since concussions are being reported with increasing frequency in high school athletes.^{17,19} To date, limited prospective research has been conducted in actual sport settings to examine the role of protective equipment in reducing the risk of SRC.^{6,8,21} The primary specific aim of this study was to determine whether the brand, age, or recondition status of the helmet worn by high school football players affects the incidence of SRC. The secondary aim was to determine whether other factors such as type of mouth guard worn and the player's age, grade (year) in school, BMI, previous tackle football playing experience, competition level, or history of concussion are associated with risk of SRC.

MATERIALS AND METHODS

The study was approved by the University of Wisconsin's Health Sciences Institutional Review Board. Before the start of the study, instructions for player recruitment, enrollment, and data collection were provided to ensure that all of the athletic trainers (ATs) at participating schools used standardized data collection and reporting methods. Special attention was paid to accurately identify and record the characteristics of various helmet brands (Riddell, Schutt, and Xenith) and models as well as the type of mouth guard (generic, that is, provided by the school; specialized, sold individually and marketed to provide more protection than generic mouth guards; or custom fitted, fitted specifically for the athlete by a dental professional or company) All ATs had to undergo institutional research training and certification before taking part in any research-related activities.

Data were collected in Wisconsin during the 2012 (34 schools) and 2013 (18 schools) seasons. The sample size was calculated based on (1) the incidence of SRC from pilot data obtained in high schools during the 2011 football season and (2) the expected number of each specific brand of helmet at participating schools. Based on these assumptions, the goal was to enroll a minimum of 1500 subjects (500 each who wore helmets by Riddell Inc, Schutt Inc, and Xenith Inc) to detect significant differences, with $\beta = .80$ and $P < .05$. While this sample size would allow us to detect differences between helmet brands, it was assumed that we would not be able to detect differences in SRC rates for each of specific helmet model produced by each manufacturer.

To be included in the study, each player had to be on the roster of the interscholastic football team for one of the participating schools (freshman, junior varsity, or varsity) and able to fully participate (no disabling injuries) in team activities on the first day of practice.

Data Collection

Before the start of the season, demographic information was collected from each player regarding his grade in school, level of competition (freshman, junior varsity, or varsity), expected offensive and defensive playing positions, number of years playing full-contact tackle football, and history of SRC that he and his parents could recall. The ATs at each school administered the Concussion Symptom Index (CSI)²⁹ before the start of the season.

The ATs recorded the helmet brand (Riddell, Schutt, or Xenith) as well as the specific model, purchase year, and recondition year (if available) worn by each subject. In newer helmets, this information is readily available on the back of the helmet. In older helmet models, this information is located inside the shell underneath the interior padding. If the purchase year or recondition year was not visible on the helmet, the information was recorded as unknown. ATs checked each player's helmet during the first 3 days of practice (no contact allowed) to ensure that the helmet was properly fitted per the manufacturer's instructions. Mouth guards were classified as being generic (moldable plastic provided by the school), specialized (sold online and in sporting goods stores with marketing that emphasizes the ability to reduce impact forces to the brain), or custom fitted (fitted specifically for the player by a dental professional or through an online service).

During the season, the ATs and coaches kept daily attendance logs to record all football-related practice and competition exposures. Practice exposures were classified as being full contact or no contact. During the season, if a player changed his helmet or mouth guard, this information was recorded and all subsequent exposure data reflected this change.

Definition of Sport-Related Concussion

A sport-related concussion was defined according to the American Academy of Neurology guideline for diagnosis and management of sport-related concussion as "an injury resulting from a blow to the head or other applied forces (linear or rotational) causing an alteration in mental status and 1 or more of the following symptoms: headache, nausea, vomiting, dizziness/balance problems, fatigue, difficulty sleeping, drowsiness, sensitivity to light/noise, blurred vision, memory difficulty, and difficulty concentrating."²⁷(p582) This definition was used as part of other clinical research studies being conducted by the authors concurrent with this study.

Assessment of Sport-Related Concussion

Wisconsin state law requires that any athlete suspected of sustaining an SRC be removed from practice or competition immediately and not be allowed to return to sport activities until examined and cleared by a credentialed medical professional (physician or licensed athletic trainer).⁴¹ An AT administered the CSI instrument as soon as an SRC was suspected or reported by the player. Additional data were recorded for each SRC, including the type of exposure, playing surface, mechanism of injury (eg, tackled, tackling, blocking), duration of symptoms (days), referral to other medical providers, and use of post-injury assessments.

Each player with an SRC was allowed to return to football activities only under the direct supervision of his school AT and/or primary care provider (physician) by use of a statewide mandated stepwise protocol with provisions for delayed return to play based on the return of any signs or symptoms.⁴⁰ Concussion severity was determined by summing the days lost from the first day after injury until the player returned to unrestricted football practice and or competition.

Data Analyses

All regression models accounted for school as a cluster random effect. Approximately 9% of players were reenrolled in 2013 after participating in 2012. To assess the effect of this repeated data on estimated regression coefficients, we analyzed the data in 3 ways: (1) treating repeated players as independent data, (2) eliminating repeated data by randomly selecting 2012 or 2013 as the only year included in the analysis for each repeated player, and (3) treating repeated players as dependent data and having player as a random effect. All methods produced very similar coefficients, 95% CIs, and statistical results. To ultimately have the most player-seasons reported and to have the most generalizable data to any 1 year of football for a player, we reported all data as if the repeated player's 2 years of data were independent of each other.

Baseline player and equipment characteristics were compared between players who sustained an SRC and those who did not by use of *t* tests and logistic regression. Concussion rates and 95% CIs were calculated by cluster adjusted Poisson regression, with number of exposures as an offset. All injury rates are reported per 1000 exposures.

The time to first SRC was compared based on player and equipment characteristics by use of a univariate, cluster adjusted Cox proportional hazards (Cox PH) model. A multivariate cluster adjusted Cox PH was used to examine the relationships between player and equipment characteristics while controlling for several variables (age, BMI, football experience, previous SRC, mouth guard type, helmet brand, and helmet recondition status). The assumption of proportionality of the hazards was verified as sufficient for most of the models. For those models in which the assumption was violated, a time-dependent Cox PH model with an interaction term between the violating variable and time was fit. The results from the models with and without an interaction term were quantitatively similar. Therefore, the simpler model with proportional hazards violation is reported for ease of interpretation.

RESULTS

A summary of player demographic and equipment information is found in Table 1. A total of 2081 players enrolled in the study. Of these players, 206 (9%) enrolled in both the 2012 and 2013 seasons for a total of 2287 player-seasons during the study period. Players participated in 134,437 football exposures, including 21,525 in competition and 112,912 in practice (17% no contact allowed, 83% full contact allowed). The distribution of players by grade in school was similar, although almost half participated in varsity-level competition. Fifty-two (2.3%) of the subjects were participating in their first year of tackle (full contact) football, while 351 (15.4%) had previously played tackle football for 7 or more years. Overall, 438 players (19.2%) reported a history of SRC, including 259 (11.3%) players who had sustained an SRC within the previous 12 months.

More players wore helmets by Riddell ($n = 1171$, 51%) compared with those by Schutt ($n = 680$, 30%) or Xenith ($n = 436$, 19%). The most commonly worn helmet models by brand were the Riddell Revolution Speed ($n = 617$), Schutt DNA Pro+ ($n = 420$), and Xenith X1 ($n = 272$). Four hundred sixty-five (26%) of the helmets were being used during their initial purchase year, while 745 (33%) helmets had been in service for 5 or more years. A total of

1592 helmets had been in use for multiple seasons, but 330 (14.4%) of these helmets were reconditioned and used in the same years as the current study. Additional helmet data (brand, model, purchase year, recondition year) are provided in the appendix (available online at <http://ajsm.sagepub.com/supplemental>). Almost two-thirds of the players wore a generic mouth guard provided by their school.

A total of 206 players (9%) sustained 211 sport-related concussions (1.56/1000 athlete exposures) playing high school football (Table 2). Five subjects (2.4%) sustained 2 concussions within the same season, while 1 subject sustained a concussion in both the 2012 and 2013 seasons. Change in the CSI score from baseline to the date the SRC was reported (mean $\pm$ SD, 17.7 ± 10.2). The majority (60%) of concussions were sustained in competition. The SRC rate for competition was significantly higher ($P < .001$) than in practice (competition = 5.81, practice = 0.76). The most common mechanism of injury was tackling ($n = 48$, 23%), followed by contact with an opponent ($n = 42$, 20%) and being tackled ($n = 30$, 14%). In addition to being evaluated by the team AT, 105 concussed players (50%) were referred to a primary care physician while 15 (6%) were referred to an MD specialist (sports medicine physician or neuropsychologist) in addition to the primary care provider for additional evaluation. The most commonly used postinjury concussion assessment tool was computerized neurocognitive testing ($n = 123$, 58.2%). Eighteen (8.5%) subjects had their symptoms resolve in less than a day; 118 (56%) reported that their symptoms resolved in 1 to 7 days; 60 (28%) had symptoms for more than 7 days; and 14 (7%) remained symptomatic after the season (7%). Subjects missed an average of 15.5 ± 10.3 days for each SRC.

There was no difference in the rate of SRC across helmet brands, helmet age (determined by purchase year), or helmet recondition status (Table 3). Players who wore a custom-fitted mouth guard had a 60% increased risk of concussion compared with those wearing generic mouth guards. Players who reported sustaining an SRC within the previous 12 months were almost twice as likely to sustain an SRC compared with players without a history of concussion. No other player characteristics (age, BMI, grade in school, competition level, or previous tackle football experience) were associated with an increased risk for SRC.

There was no difference ($P = .265$) in the days lost (median [interquartile range, 25th–75th percentile]) due to SRC in players wearing Riddell (13.0 [10.0–19.0]), Schutt (13.0 [3.0–22.0]), or Xenith (15.0 [12.0–19.0]) helmets or any difference ($P = .423$) in the median days lost from SRC in players wearing custom (14.0 [10.5–20.5]), generic (14.0 [11.0–20.0]), or specialized (13.0 [10.0–19.0]) mouth guards.

DISCUSSION

This study demonstrated that helmet brand, age, and recondition status were not associated with a lower risk of SRC in high school football players. Further, the use of a generic mouth guard was associated with lower risk of SRC in this population. This is the largest prospective study to have reported the brand of helmets worn by high school football players in the United States. All football helmets are designed to limit the force of impact on the head by dispersing and attenuating the blow, which reduces transmission of the force to the

skull and brain tissue and subsequently reduces the risk of skull fracture and intracranial hemorrhage.^{36,37} All football helmets currently in use in high school football must meet the National Operating Committee on Standards in Athletic Equipment (NOCSAE) helmet standard and pass a threshold of standard performance criteria from multiple impact tests.²⁵ Our results show that no particular helmet brand provides superior protection against sustaining an SRC compared with other helmet brand or models.

Our results are in contrast with a study in high school players by Collins et al⁵ in 2006, which reported that new Riddell Revolution helmets reduced the risk of SRC by 31% compared with other “standard” helmets. This study was limited, however, by fact that the age of the other helmets was not reported and, more important, the exposure data for each player were not recorded. More recent research³⁸ has reported that certain helmet brands and models perform better on specific laboratory-based impact testing, leading the authors to conclude that these helmets provide greater protection against concussion. Expanding on this research, Rowson et al³¹ reported that the incidence of SRC was lower in Riddell Revolution helmets compared with Riddell VSR-4 helmets in a study that recorded the incidence of SRC and subconcussive head impacts with a helmet-mounted accelerometer. The difference in our findings from the previous research may be due to several factors. First, we conducted a prospective epidemiologic study on the performance of helmets in a large sample of high school players actually participating in football rather than a laboratory study that documented helmet dynamics to determine how protective a helmet might be. Further, we recorded data from a much larger variety of new and older helmets currently being used in high school settings. Finally, we controlled for multiple variables in our analyses, including history of concussion, which has been widely reported as a significant risk factor for concussion in athletic populations.^{1,3,15} These previous studies compared a small number of specific helmet models, while our study grouped all models by their manufacturer (brand). We thought it was most appropriate to group the helmets by their manufacturer since each manufacturer often used similar exterior shell designs and interior padding systems for helmets produced in the same year. Furthermore, comparing the incidence of SRC across every specific model would be difficult due to the small numbers for some models; the newest helmet models (Riddell 360, Schutt Vengeance, and Xenith X2) were worn by less than 10% of players in our study.

While it is widely reported that newer helmets perform better on laboratory tests than older helmets no longer sold, less well studied is whether the age of newer helmets (less than 3–4 years old) affects the incidence of SRC. This is important because helmet manufacturers stress that helmets should be replaced on a regular schedule and that coaches should purchase a number of new helmets each season. Older helmets should be used only if they have been reconditioned and certified to meet the same NOCSAE impact standards as new helmets.²⁵ It is less expensive to recondition a helmet than purchase a new helmet; the manufacturers we contacted stated that the costs to recondition a helmet can be as low as US \$30 to \$40 or as high as one-third the purchase price for a new helmet. For this reason we examined whether helmet age or recondition status was associated with incidence of SRC. In our sample, 66% of the helmets were purchased within the previous 4 years, and we found that the incidence of SRC in newly purchased helmets was similar to that in older helmets that had already been in service multiple seasons. Previously, specific guidelines by

manufacturers regarding helmet reconditioning were limited, although it was widely accepted that helmets should be reconditioned every several years or when recommended by a helmet manufacturer representative. In 2013, however, manufacturers began recommending that helmets be reconditioned yearly. We found that the risk of SRC was similar regardless of whether the helmet was new, used in the same year it was reconditioned, or reconditioned in previous years.

Our finding that the incidence of SRC was lower for players wearing a generic mouth guard than subjects wearing a custom fitted mouth guard was unexpected. The ability of a mouth guard to reduce the risk of dental injury is well established. Further evidence that a mouth guard can reduce risk of concussion remains inconsistent.^{7,9,20} Proponents of using mouth guards to reduce the incidence of SRC cite potential protective mechanisms that include absorbing the force of a blow to the jaw, increasing separation of the head of the condyle and mandibular fossa, and limiting muscle activation of the neck musculature.^{34,35} While previous laboratory studies have shown that mouth guards can dissipate impact forces sustained to the mandible, well-controlled prospective studies in athlete populations have not shown that this translates into a decreased risk of SRC.^{8,20} One explanation for our finding is that we did not assess the type of impact (blow to the head vs struck on the chin or jaw) that resulted in the SRC. A second explanation may be that players wearing custom mouth guards might have had additional player characteristics and risk factors we did not assess. In addition, the increase in the rate of SRC may be due to the fact that players with custom mouth guards feel they have greater protection against an SCR and play with less regard or fear for sustaining an injury. Only 9% of the players in our sample wore these custom mouth guards, and the difference in concussion rate may have occurred by chance or may have not been found if the sample of these players had been larger.

Intrinsic factors may play a greater role in SRC susceptibility than the type of protective equipment worn by the player.^{9,19} Limited retrospective data suggest that the risk of SRC increases in older players who are competing at a high level.^{1,8} It has been suggested that older players competing at the varsity level are more likely to sustain an SRC than younger players competing at lower levels (freshmen or junior varsity team) because of the impact forces they sustain with body-to-body contact on the football field. We did not find a relationship between the player's age, size, or competition level and the incidence of SRC.

Interestingly, the number of years of tackle football experience was not associated with an increased or decreased risk of SRC. To our knowledge, this is the first study to examine players' tackle football experience and the risk of SRC in older (high school) players. Previous research has shown that the risk of concussion in youth sports is significant and also is affected by the league parameters related to the amount of contact that is allowed. Emery et al¹⁰ noted that Canadian youth playing in hockey leagues that allowed full body checking had a 70% increased risk for concussion compared with players in leagues without body checking. Further, Guskiewicz and Valovich McLeod¹⁴ reported that players who participate in sports at a younger age have a longer window of vulnerability and are more likely to sustain multiple concussions during their sport career.

Our finding that players with a history of sport-related concussion were at higher risk of sustaining another concussion is consistent with previous studies of high school athletes.^{13,32} What is novel about our results is that this increased risk exists even when controlling for the players' use of protective equipment, years of football experience, and player characteristics such as their grade in school and competition level. This further highlights the need for medical providers to document a history of SRC in young football players. In addition, players, parents, and coaches need to be educated about the increased concussion risk in these individuals.

The type of exposure (practice vs competition) had a substantial effect on the incidence of SRC in this study. The rate of SRC was nearly 7 times higher during competition than practice and 4 times higher during full-contact practice sessions than sessions where no contact was allowed. Broglio et al⁴ recently reported that head impact magnitude was significantly higher during competitions and that limiting contact during practice sessions could reduce the number of impacts up to 39% over the course of the season. Our data may support these findings that limiting the number of full-contact practices may be an effective method to reduce the overall incidence of SRC in high school football.

Limitations

Several limitations should be acknowledged with regard to our findings. First, this is not a randomized controlled study but rather a cohort study with data obtained from a convenience sample of schools that agreed to take part in the study. As such, it is susceptible to the effect of the unknown or unmeasured confounders. Schools in Wisconsin without access to a full-time AT throughout the season (38%) were not recruited to take part. Thus, despite the large size of our sample, the participating coaches and medical staff may not be representative of the football programs in Wisconsin or schools throughout the United States. In addition, all players and ATs who participated in the study were not blinded and may have reporting bias. Unfortunately, truly randomized and blinded research studies in high school settings are not feasible due to the requirements of obtaining administrative school approval, informed consent for minors, and the data reporting required by onsite ATs. To minimize this bias, our sample included both public and private schools and a broad range of small, medium, and large student enrollments, located in urban, suburban, and rural settings. In addition, a large cohort study such as this requires that sports injury diagnoses, reporting, and treatment be dependent upon multiple medical providers in numerous communities and schools rather than a single medical provider. We also recognize that proper helmet fit may play a role in SRC susceptibility. While we provided helmet fitting instructions for each helmet brand and instructed each school AT to check each helmet during the first week of practice, we did not measure the helmet fit (and how it may have changed) throughout the season. Finally, as in nearly all prospective studies of SRC, our methods relied on reporting of athlete exposures to calculate the incidence of SRC and assess the performance of various helmets. Using force accelerometers in each helmet to measure head impact exposure, as has been done in collegiate and high school settings, may be a more sensitive method to understand the protective characteristics of different helmets. However, the costs and staffing to use instrumented helmets in a large high school cohort were prohibitive in our situation.

CONCLUSION

In the current study, different types of football helmets (brand, age, recondition status) worn by high school football players offered similar protection against SRC regardless of player age, grade in school, or competition level. The rate of SRC was higher for players with a history of SRC as well as for players who wore custom-fitted mouth guards compared with generic mouth guards. A significant proportion of concussions occurred during full-contact practices, suggesting that limiting the number of full-contact practice sessions may have the potential to reduce the incidence of SRC in high school football settings.

The relationship of the type of protective equipment and incidence of SRC warrants further study, especially in actual athlete populations. Future researchers may want to evaluate the incidence of SRC in a large sample of high school players who wear different helmet brands, using models instrumented to measure head impact data while controlling for various player characteristics. In addition, to further study the role of mouth guards and SRC, researchers could look at the incidence of SRC for athletes who wear different types of mouth guards but have sustained blows only to the chin and jaw that resulted in SRC.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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TABLE 1

High School Football Player Demographics, Helmet or Mouth Guard Worn, Tackle Football Experience, and Concussion History^a

Player Characteristics		
Player-seasons, No.	2287	
Age, y	15.9 ± 1.2	
Height, in.	70.3 ± 3.2	
Weight, in.	172.2 ± 36.3	
BMI, lb/in. ²	24.3 ± 4.4	
Baseline CSI score	1.0 ± 1.2	
Player Variables	No. of Subjects	%
Helmet brand worn		
Riddell	1171	51.2
Schutt	680	29.7
Xenith	436	19.1
Helmet age, y ^b		
1–2	695	30.4
3–4	830	36.3
5–6	399	17.4
7+	348	15.2
Helmet condition		
New	463	20.2
Reconditioned same year of the study	330	14.4
All other helmets ^c	1477	64.5
Mouth guard type		
Generic	1386	60.6
Custom	199	8.7
Specialized	702	30.7
Grade (year) in school		
9th	625	27.3
10th	598	26.1
11th	544	23.8
12th	512	22.4
Competition level		
Freshman	567	24.8
Junior varsity	627	27.4
Varsity	1093	47.8
Previous tackle football experience, y		
0–1	256	11.2
2–3	406	17.8
4–5	856	37.4

Player Characteristics		
6+	767	33.5
Previous SRC (within 12 mo)		
No	1928	84.3
Yes	259	11.3
Previous SRC (ever)		
No	1849	80.8
Yes	438	19.2

^aBMI, body mass index; CSI, Concussion Symptom Index; SRC, sport related-concussion.

^bHelmet age determined by year helmet was purchased.

^cNever reconditioned or reconditioned more than 1 year before the study year.

TABLE 2

Football Exposures and Rate of Sport-Related Concussion, Mechanism of Injury, Postinjury Assessment, and Days Lost From Sport^a

	No. of Exposures	SRC	SRC Rate, % (95% CI) ^b	P Value
Football session				
Competition	21,525	125	5.81 (4.86–6.94)	
Practice: full contact	94,022	82	0.87 (0.61–0.95)	<.001
Practice: no contact	18,890	4	0.21 (0.07–0.58)	<.001
Mechanism of injury, No. (%)				
Tackling	48 (22.7)			
Contact with opponent	42 (19.9)			
Being tackled	30 (14.2)			
Contact with ground	22 (10.4)			
Blocking	17 (8.1)			
Contact with teammate	14 (6.6)			
Being blocked	13 (6.2)			
Unknown	25 (11.8)			
Postinjury concussion assessment tool used, No. (%)				
Computerized neurocognitive testing	123 (58.3)			
CSI	94 (44.5)			
SCAT2/SCAT3	65 (30.8)			
SAC	33 (15.6)			
BESS	26 (12.3)			
Days lost due to SRC, median (IQR) ^c	13 (10.0–18.3)			

^a BESS, Balance Error Scoring System; IQR, interquartile range; SAC, Standardized Assessment of Concussion; SCAT, Sport Concussion Assessment Tool; SRC, sport related-concussion.

^b Percentages may total more than 100 because some subjects had more than 1 assessment.

^c 25th–75th percentile.

TABLE 3

Sport-Related Concussion Injury Rates, Odds Ratios, and Cox Proportional Hazard Ratios for Player Demographics and Helmet and Mouth Guard Characteristics^a

Characteristic	No SRC (n = 2081)	SRC (n = 206)	Univariate Analysis				Multivariate Analysis ^b			
			P Value	Odds Ratio ^c (95% CI)	P Value	SRC Rate ^d (95% CI)	Hazard Ratio ^e (95% CI)	P Value	Cox Hazard Ratio ^e (95% CI)	
Player age, y, mean ± SD	15.9 ± 1.2	15.8 ± 1.2	.090	—	—	—	0.88 (0.76–1.03)	.120	0.90 (0.76–1.06)	.190
BMI, lb/in. ² , mean ± SD	24.4 ± 4.5	24.2 ± 4.3	.700	—	—	—	1.00 (0.96–1.03)	.770	1.00 (0.97–1.03)	.810
No.		SRC	% SRC							
Grade (year) in school										
9th	625	61	9.8	Reference	—	1.78 (1.30–2.44)	Reference	—	Reference	—
10th	598	55	9.2	0.94 (0.63–1.40)	.770	1.51 (1.05–2.18)	0.87 (0.57–1.32)	.520	0.98 (0.66–1.48)	.940
11th	546	52	9.5	0.97 (0.65–1.46)	.920	1.48 (1.02–2.15)	0.91 (0.62–1.34)	.630	1.00 (0.69–1.46)	>.999
12th	518	38	7.3	0.73 (0.47–1.14)	.170	1.20 (0.80–1.79)	0.67 (0.38–1.19)	.180	0.78 (0.45–1.35)	.380
Competition level										
Freshman	567	55	9.7	Reference	—	1.79 (1.29–2.49)	Reference	—	Reference	—
Junior varsity	627	60	9.6	0.99 (0.66–1.48)	>.999	1.58 (1.09–2.28)	0.92 (0.61–1.37)	.670	0.98 (0.65–1.46)	.910
Varsity	1093	91	8.3	0.85 (0.59–1.23)	.360	1.32 (0.94–1.85)	0.79 (0.51–1.21)	.280	0.86 (0.55–1.33)	.490
Previous tackle football experience, y										
0–1	256	24	9.4	Reference	—	1.55 (0.99–2.43)	Reference	—	Reference	—
2–3	406	30	7.4	0.77 (0.42–1.42)	.380	1.37 (0.80–2.36)	0.80 (0.43–1.49)	.480	0.81 (0.44–1.52)	.520
4–5	858	91	10.6	1.15 (0.71–1.93)	.640	1.74 (1.10–2.76)	1.12 (0.64–1.98)	.690	1.13 (0.64–1.97)	.680
6+	767	61	8.0	0.84 (0.50–1.43)	.510	1.27 (0.78–2.06)	0.79 (0.42–1.48)	.460	0.85 (0.46–1.59)	.620
Previous SRC (within 12 mo)										
No	2028	167	8.2	Reference	—	1.38 (1.08–1.75)	Reference	—	Reference	—
Yes	259	39	15.1	1.97 (1.32–2.90)	<.001	2.47 (1.73–3.53)	1.97 (1.37–2.83)	<.001	1.96 (1.40–2.73)	<.001
Mouth guard type										
Generic	1386	107	7.7	Reference	—	1.29 (0.98–1.69)	Reference	—	Reference	—
Custom	199	26	13.1	1.80 (1.09–2.87)	.020	2.33 (1.49–3.66)	1.66 (1.14–2.41)	.010	1.69 (1.20–2.37)	<.001
Specialized	702	73	10.4	1.39 (1.00–1.92)	.050	1.70 (1.24–2.33)	1.35 (0.89–2.05)	.160	1.34 (0.90–1.99)	.150

Characteristic	Univariate Analysis					Multivariate Analysis ^b		
	No SRC (n = 2081)	SRC (n = 206)	P Value	Odds Ratio ^c (95% CI)	P Value	SRC Rate ^d (95% CI)	Hazard Ratio ^e (95% CI)	P Value
Helmet brand								
Riddell	1171	107	9.1	Reference	—	1.38 (1.03–1.86)	Reference	—
Schutt	680	59	8.7	0.94 (0.67–1.33)	.800	1.57 (1.01–2.44)	0.93 (0.61–1.43)	.920
Xenith	436	40	9.2	1.00 (0.67–1.49)	> .999	1.73 (1.09–2.75)	0.99 (0.63–1.56)	.980
Helmet age, y ^f								
1–2	695	72	10.4	Reference	—	1.62 (1.19–2.22)	Reference	—
3–4	830	65	7.8	0.74 (0.51–1.06)	.090	1.25 (0.88–1.78)	0.75 (0.52–1.08)	.140
5–6	397	33	8.3	0.78 (0.49–1.23)	.290	1.51 (0.98–2.31)	0.88 (0.58–1.32)	.540
7+	348	35	10.1	0.97 (0.61–1.51)	.910	1.82 (1.18–2.81)	1.03 (0.62–1.71)	.850
Helmet condition								
New helmet	463	47	10.2	Reference	—	1.64 (1.15–2.35)	Reference	—
Reconditioned same year	330	28	8.5	0.82 (0.48–1.37)	.460	1.27 (0.77–2.09)	0.81 (0.44–1.50)	.580
All other helmets ^g	1451	130	8.8	0.85 (0.60–1.24)	.410	1.50 (1.05–2.14)	0.88 (0.61–1.26)	.500

^aBMI, body mass index; SRC, sport related-concussion.

^bAge, BMI, tackle football experience, previous SRC, mouth guard type, helmet brand, and helmet recondition status were used as covariates. Grade in school and level of competition were both correlated with age ($p > .085$); therefore, age was removed as a covariate in the multivariate model when ratios were estimated for grade and level.

^cUsing the Fisher method.

^dPer 1000 exposures.

^eFrom Cox proportional hazards regression: All regressions have school as a random effect.

^fDetermined by year helmet was purchased; helmets with an unknown purchase year were excluded from this analysis.

^gNever reconditioned or reconditioned > 1 year before the study year. Helmets with an unknown recondition year were excluded from this analysis.