Incidence and Risk Factors for Concussion in High School Athletes, North Carolina, 1996–1999

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Schulz, M. R., Marshall, S. W. , Yang, J., Mueller, F. O. , Weaver, N. L. , Kalsbeek, W. D., Bowling, J. M., (2004). Incidence and risk factors for concussion in high school athletes, NC, 1996-1999. *American Journal of Epidemiology, 160 (10)*, 937-944.

Abstract:
A prospective cohort study was used to quantify risk factors for sports concussions. Analysis was based on a stratified cluster sample of North Carolina high school athletes followed during 1996–1999. Clustering was by school and sport, and the sample included 15,802 athletes with 1–8 seasons of follow-up per athlete. Concussion rates were estimated for 12 sports, and risk factors were quantified using generalized Poisson regression. Concussion rates ranged from 9.36 (95% confidence interval: 1.93, 16.80) per 100,000 athlete-exposures in cheerleading to 33.09 (95% confidence interval: 24.74, 41.44) per 100,000 athlete-exposures in football, where "athlete-exposure" is one athlete participating in one practice or game. The overall rate of concussion was 17.15 (95% confidence interval: 13.30, 21.00) per 100,000 athlete-exposures. Cheerleading was the only sport for which the practice rate was greater than the game rate. Almost two thirds of cheerleading concussions involved two-level pyramids. Concussion rates were elevated for athletes with a history of concussion, and they increased with the increasing level of body contact permitted in the sport. After adjustment for sport, body mass index, and year in school, history of concussion(s) remained a moderately strong risk factor for concussion (rate ratio = 2.28, 95% confidence interval: 1.24, 4.19). The fact that concussion history is an important predictor of concussion incidence, even in this young population, underscores the importance of primary prevention efforts, timely identification, and careful clinical management of these injuries.
Key Words: athletic injuries; brain concussion; Poisson distribution; risk factors; sports; students
Abbreviations: NCHSAA, North Carolina High School Athletic Association; NCHSAIS, North Carolina High School Athletic Injury Study.

Article:

Because participation in sports involves the potential for impact to the head, athletes are at particular risk for concussion. Permanent brain damage and even death can result if sports-related concussions are not diagnosed and treated properly. Second-impact syndrome, a condition with a mortality rate of nearly 50 percent, may occur when an athlete who has sustained even a mild concussion sustains a second concussion before symptoms associated with the first have resolved (1). High school athletes, who numbered nearly 7 million in 2000–2001, are the largest group of athletes at risk of concussion (2).

An estimate of the annual number of sports- and physical-activity-related concussions is derived from data collected in the Injury Supplement to the 1991 National Health Interview Survey. Using data from this survey, Sosin et al. (3) estimated a total of 1.54 million traumatic brain injuries that involved loss of consciousness in the year prior to the interview. Of these injuries, 306,000 (95 percent confidence interval: 262,000, 354,000) were attributed to sports or physical activity. A key limitation of these national surveillance data is that data on concussions not resulting in loss of consciousness were not available (4). Many more sports-related concussions would likely be identified if the estimates produced from the National Health Interview Survey data were supplemented by data on concussions not resulting in loss of consciousness. A survey of 242 certified athletic trainers employed by high schools and colleges reported that 90 percent of their football-related concussions did not involve loss of consciousness (5).

Much of the attention that concussion has received (5–10) has focused on concussions in football. Recent studies have estimated concussion rates in other collision sports, such as hockey (11) and rugby (12), and two large, national studies have documented how concussion rates vary by sport and exposure type (games vs. practices) (13, 14). Still, for some sports, such as women's track and competitive cheerleading, no published concussion rates are available.

Several of the football studies have indicated a strong association between concussion history and incident concussion (5, 9). However, this association has not been demonstrated in any other sport, and no studies have been published that examined how the relation between concussion history and the concussion rate is affected by covariates. Several variables such as age, body size and type, access to proper facilities, and education of coaches have been postulated as determinants of athletic injuries (15–19), but these variables have not been explored empirically as determinants of concussion in sports.

The purpose of this study was to examine the incidence rate of sports-related concussions by sport and to estimate the association between history of previous concussion(s) and concussion rate, adjusted for variables that have been postulated to affect the concussion rate.

MATERIALS AND METHODS

Sample selection

Data were collected as part of the North Carolina High School Athletic Injury Study (NCHSAIS), a prospective cohort study of the injury experience of North Carolina high school athletes (20). Weaver et al. (21) described the selection of the study population in detail. The study population was selected using a stratified two-stage cluster-sampling design. In the first stage, 100 schools were selected from among the 324 high schools that are members of the North Carolina High School Athletic Association (NCHSAA). In the second stage at each participating school, six teams were randomly selected for follow-up from the 12 sports (football, cheerleading, wrestling, volleyball, baseball, softball, boys' and girls' basketball, boys' and girls' soccer, and boys' and girls' track) included in the study. The sampling process attempted to ensure that all NCHSAA athletes had the same selection probability. The sampling probabilities and data on nonresponse at the first and second levels were used to construct sampling weights for the purpose of estimating incidence for the population of all NCHSAA athletes.

Data collection

The selected varsity teams were followed for 3 years, and one contact person at each school, either an athletic trainer or athletic director, had ultimate responsibility for ensuring the timely and accurate completion of data forms. Varsity athletes were enrolled in the NCHSAIS 1 day after they received a consent letter to share with their parents. Besides informing parents of what their child's participation would entail, the letter offered parents a toll-free number to contact the project staff (if parents had questions or declined participation in the study). Because there was little risk to the athletes and given the extreme logistic challenges, written consent was not required. The consent letter and the protocol of the NCHSAIS were approved by the Institutional Review Board of the University of North Carolina School of Public Health.

Each varsity athlete participating in a selected sport completed a demographic form at the beginning of each season. The form requested information regarding sport, grade in school, sex, weight, height, and history of previous concussions regardless of the cause of concussion. Each head coach also completed a demographic form that asked for information about educational attainment.

To document the number of players who participated in each game or practice during the preseason and regular season, participation forms similar to attendance sheets were completed weekly for each team. If an athlete participated in any part of a game or practice, he or she was considered to have participated, and information was not collected on the degree of participation. An injury report form requested information on injury event circumstances (whether the injury occurred during a game or practice and whether the injury occurred during preseason, regular season, or post-season) and nature of the injury (type of injury and body part injured). A reportable injury was defined as one that occurred as a result of participation in varsity high school sports and that either limited the student's full participation in the sport the day following the injury or required medical attention by a health professional. In addition, all brain concussions were defined as reportable injuries. Multiple injuries were reported for any given injury event with a separate injury form being completed for each separate injury.

Ascertainment of concussions

Although there is no generally agreed upon definition of concussion, a commonly referenced definition is a "clinical syndrome characterized by immediate and transient post-traumatic impairment of neural functions, such as alteration of consciousness, disturbance of vision, equilibrium, etc., due to brain stem involvement" (22, p. 388). For this study, incident concussion was operationalized with two questions. First, concussion was one of 16 possible responses that school contacts could use to describe the type of injury. The second question elicited information about signs and symptoms consistent with concussion, such as the length of disorientation/ confusion, the absence or presence of short-term memory loss, and the duration of lost consciousness associated with the injury. The exact wording of the questions appears in figure 1.

1. Type of injury (check one only):

[1] O Abrasion/Scrape	[9] O Stress fracture
[2] O Contusion/Bruise	[10] O Heat exhaustion
[3] O Laceration/Cut	[11] O Heatstroke
[4] O Puncture wound	[12] O Infection
[5] O Sprain (ligament)	[13] O Hemorrhage
[6] O Strain (muscle)	[14] O Blisters
[7] O Dislocation	[15] O Concussion
[8] O Fracture	[16] O Other:_______________

2. This athlete (check one only):

[1] O Was disoriented/confused for **less** than 15 minutes.

[2] O Was disoriented/confused for **more** than 15 minutes.

[3] O Was disoriented/confused **and** had a loss of short-term memory.

[4] O Unconscious (duration:____________minutes).

[5] O None of the above.

[6] O Other.

FIGURE 1. Exact wording of questions used to identify concussions among 19,903 high school athletes who competed during the preseason and regular season, North Carolina, 1996–1999.

If an injury was designated as a concussion in response to question 1, the injury was counted as a concussion. If an injury type other than concussion was designated on an injury form but signs and symptoms consistent with a concussion were reported in response to the second question, the entire injury form was reviewed by one of the authors (M. S.), with special focus on responses to the questions about the nature of the injury event. After review of the injury form, the same author (M. S.) determined whether the concussion-related signs and symptoms were most likely due to a sport-related concussion or another injury or health condition, such as heat stress. Injuries determined to be concussions after the review were combined with the injuries designated as concussions in the first question. Finally, as mentioned above, retrospective self-reported lifetime history of concussion was obtained at the beginning of each season, when each individual athlete completed the athlete demo-graphic form. The question used simply asked the athlete whether or not he or she had ever experienced a concussion. We did not ask about the severity of past concussions.

Data analysis

Because the study was a 3-year prospective cohort study, many of the high school athletes participated for more than one “athlete-season” (one athlete participating for one season), and therefore there were multiple observations for many athletes. The resulting data structure was a longitudinal data set comprising between one and eight observations for each athlete. Because of difficulties in collecting complete postseason participation data, all concussion rate estimates and models were limited to preseason and regular season data.

To compare concussion incidence between sports, sport-specific concussion incidence density rates per “athlete-game” (one athlete in one game), per “athlete-practice” (one athlete in one practice), and per “athlete-exposure” (one athlete participating in one practice or game) were estimated as follows:

Game rate (r_g) = weighted sum of game concussions ($\sum_i wn_g$)/weighted sum of athlete-games ($\sum_i we_g$).

Practice rate (r_p) = weighted sum of practice concussions ($\sum_i wn_p$)/weighted sum of athlete-practices ($\sum_i we_p$).

Overall rate (r) = weighted sum of concussions ($\sum_i wn_a$)/ weighted sum of athlete-exposures ($\sum_i we_a$),

where athlete-exposures (e_a) = the sum of athlete-games (e_g) and athlete-practices (e_p), total concussions (n_a) = the sum of game concussions (n_g) and practice concussions (n_p), and $\sum_i$ = the sum over all atheletes.

The 95 percent confidence intervals of the rates were calculated using the formula, 95 percent confidence interval of rate = rate ± 1.96 × (variance of the rate)$^{1/2}$ (23).

The weights in the equations above account for complex survey design and differential nonresponse at different levels of the survey design, and they serve to estimate results for all NCHSAA athletes on the basis of the athletes included in the study (21).

For the purposes of multivariate adjustment of the association between previous concussion and concussion rate, a Poisson regression model was developed that included several athlete-level covariates (sport, body mass index, year in school), calendar time, school size (as a proxy for access to facilities and resources), and highest educational attainment by head coach. Sports were grouped as contact (football and wrestling), limited contact (basketball, soccer, baseball/softball), and noncontact (track, cheerleading, and volleyball) and as collision (football) versus noncollision (all other study sports). Grade in school, highest educational attainment by coach, and body mass index were categorized in several different ways in bivariate analyses to determine the shape of their relations to the concussion rate before inclusion in the multivariate model.

Since the objective of the Poisson model was to describe the concussion rate as a function of the covariates while accounting for the complex sample survey used to collect the data, SUDAAN, version 8.0 (24), software was used to fit the Poisson regression model. Generalized Poisson models account for the correlation of teams within schools and athletes within teams that is expected in data clustered by school and team when they were collected (25).

TABLE 1. Rate of concussion by sport among 19,903 high school athletes who competed during the preseason and regular season, North Carolina, 1996–1999

	Actual no. of concussions	Annual weighted no. of concussions*	Annual weighted no. of athlete-exposures† (× 10^5)	Rate/100,000 athlete-exposures	95% confidence interval	Rate/100,000 athlete-games†	95% confidence interval	Rate/100,000 athlete-practices†	95% confidence interval	$IRR_{g/p}$‡	95% confidence interval
Sport											
Football	75	280	8.48	33.09	24.74, 41.44	148.84	102.82, 194.87	8.47	3.90, 13.04	17.57	8.87, 34.83
Boys' soccer	24	69	2.95	23.31	8.40, 38.22	59.34	18.10, 100.58	2.67	0, 6.39	22.23	4.41, 111.98
Girls' soccer	6	18	1.38	13.21	0, 27.30	19.91	0.43, 39.39	7.94	0, 19.84	2.51	0.86, 7.35
Boys' basketball	12	33	3.21	10.25	4.20, 16.29	25.92	10.05, 41.78	1.89	0, 4.53	13.75	3.15, 59.95
Girls' basketball	10	52	2.97	17.49	0.80, 34.18	46.66	0, 94.19	1.74	0, 5.08	26.78	2.65, 270.81
Baseball	9	30	2.49	11.98	3.10, 20.86	16.99	3.00, 30.97	8.37	0, 19.72	2.03	0.40, 10.18
Softball	6	21	2.04	10.14	1.48, 18.80	19.99	0, 41.90	4.09	0, 9.48	4.88	0.79, 30.36
Wrestling	13	29	3.05	9.36	0, 19.21	15.96	0, 34.00	7.08	0, 15.21	2.25	0.92, 5.58
Cheerleading	7	21	2.27	9.36	1.93, 16.80	3.38	0, 9.99	11.32	1.84, 20.81	0.30	0.04, 2.51
Boys' track	4	25	2.48	10.14	0, 25.16	48.66	0, 122.08	0			
Girls' track	2	29	2.03	14.34	0, 43.23	59.30	0, 181.18	0			
Total	168	607	35.40	17.15	13.30, 21.00	46.22	33.90, 58.55	5.20	3.22, 7.17	8.90	5.67, 13.96
Gender											
Males	137	466	22.60	20.61	15.31, 25.91	61.50	42.00, 80.99	5.81	3.30, 8.31	10.59	6.28, 17.86
Females	31	141	12.80	11.04	4.30, 17.78	24.92	4.78, 45.06	4.01	1.25, 6.77	6.22	1.97, 19.64

* Annual statewide incidence in North Carolina High School Athletic Association high schools.

† "Athlete-exposure" is one athlete participating in one practice or game; "athlete-game" is one athlete in one game; "athlete-practice" is one athlete in one practice.

‡ $IRR_{g/p}$, injury rate ratio where the practice rate is the referent.

RESULTS

Of the 2,750 reported injuries in the NCHSAIS, 206 were ascertained to be concussions. Only 8 percent of the concussions resulted in a loss of consciousness. Eighty-two concussions were ascertained by the school contacts responsible for ensuring the completion of the injury forms. An additional 124 concussions were ascertained by one of the study authors (M. S.) through a review of the injury event circumstances surrounding 135 injuries for which concussion signs and symptoms were reported on injury forms but the injury type was not designated as concussion. Of the total concussions, 168 occurred during the 1,024,636 regular and preseason athlete-exposures. These data were weighted, and the number of concussions and concussion rates per 100,000 athlete-exposures for specific sports and all sports combined are reported in table 1.

Sport- and sex-specific injury rates

Football had the highest overall and game concussion rate (table 1). In contrast, the football practice rate was exceeded by the practice rate in cheerleading. The injury rate ratio comparing the game rate with the practice rate was greater than one for both sexes and for all sports except cheer-leading. Besides being substantially less than one, the confidence interval of the game/practice rate ratio for cheerleading did not overlap with those of half the other sports (table 1).

Poisson regression models of the concussion rate

Unadjusted estimates indicated that having a history of one or more previous concussions was a moderately strong predictor of the concussion rate (table 2). Almost 4.5 percent of the athletes had a history of previous concussions. Likewise, participation in contact sports was a moderately strong predictor of the concussion rate (table 2). Being a ninth grader or having a body mass index in the bottom quintile of the study athletes was a moderately strong protective predictor of the concussion rate. Although being a ninth grader appeared to be protective, the concussion rate did not increase monotonically with grade in school. Likewise, the concussion rate did not increase monotonically with quintiles of athlete body mass index. Neither school size nor the highest educational level achieved by the head coach appeared to have a predictive influence on the concussion rate, but concussion rates were noticeably higher in the second year of the study compared with either year 1 or 3.

TABLE 2. Rate ratios and 95% confidence intervals for concussion among 19,903 high school athletes who competed during the preseason and regular season, North Carolina, 1996–1999

Exposure	Unadjusted rate ratio	95% confidence interval	Multivariate-adjusted rate ratio (full model)	95% confidence interval	Adjusted rate ratio (parsimonious model)	95% confidence interval
Athlete-level variables						
Concussion history						
No history of concussion(s)	1.00	Referent	1.00	Referent	1.00	Referent
History of concussion(s)	2.95	1.67, 5.24	2.25	1.14, 4.44	2.28	1.24, 4.19
Degree of contact						
Participation in noncontact sports	1.00	Referent	1.00	Referent	1.00	Referent
Limited contact sports	1.73	0.67, 4.48	1.89	0.68, 5.25	2.01	0.70, 5.73
Full contact sports	3.13	1.18, 8.29	3.28	1.26, 8.58	3.84	1.42, 10.40
Body mass index						
Athletes with highest 80% of body mass indexes	1.00	Referent	1.00	Referent	1.00	Referent
Athletes with lowest 20% of body mass indexes	0.26	0.12, 0.59	0.44	0.20, 0.99	0.40	0.18, 0.90
≤13.3–<19.6 (bottom quintile)	1.00	Referent				
19.6–<21.0 (second quintile)	2.78	1.18, 6.48				
21.0–<22.6 (third quintile)	4.21	1.86, 9.57				
22.6–<25.1 (fourth quintile)	3.59	1.36, 9.44				
25.1–<52.0 (top quintile)	4.47	1.79, 11.17				
Grade						
Sophomores to seniors	1.00	Referent	1.00	Referent	1.00	Referent
Ninth graders	0.45	0.22, 0.91	0.61	0.29, 1.27	0.60	0.30, 1.20
Seniors	1.00	Reference				
Juniors	0.70	0.40, 1.23				
Sophomores	0.75	0.42, 1.36				
Ninth graders	0.37	0.17, 0.81				
Calendar time						
1998–1999	1.00	Referent	1.00	Referent		
1997–1998	2.53	1.49, 4.29	2.32	1.24, 4.32		
1996–1997	1.19	0.67, 2.13	1.41	0.82, 2.44		
School level						
Class 4A (1,314–2,600 students)	1.00	Referent	1.00	Referent		
Class 3A (967–1,308 students)	0.63	0.36, 1.12	0.97	0.51, 1.84		
Class 2A (668–957 students)	1.10	0.61, 1.99	1.58	0.75, 3.31		
Class 1A (<668 students)	0.74	0.39, 1.40	1.26	0.62, 2.58		
Head coach qualifications						
Master's degree	1.00	Referent	1.00	Referent		
No master's degree	0.74	0.48, 1.13	0.94	0.60, 1.49		

TABLE 3. Concussion incidence comparing athletes with and without a history of previous concussion(s) among 19,903 high school athletes who competed during the preseason and regular season, North Carolina, 1996–1999*

Sport	One or more previous concussions			No previous concussion			Rate ratio†	95% confidence interval
	No. of incident concussions‡	No. of athlete-exposures§	Incidence rate/10,000 athlete-exposures	No. of incident concussions	No. of athlete-exposures	Incidence rate/10,000 athlete-exposures		
Football¶,#	151	126,542	11.92	691	2,416,272	2.86	4.17	1.70, 10.23
Nonfootball	50	300,689	1.66	930	7,775,166	1.20	1.38	0.56, 3.44
All sports	201	427,231	4.70	1,621	10,191,439	1.59	2.95	1.67, 5.24

* Weighted data.
† Not adjusted for any other variables.
‡ Athletes sustaining one or more concussions within a season.
§ An "athlete-exposure" is one athlete participating in one practice or game.
¶ The rate ratio for those athletes participating in football with no history of previous concussion(s) relative to those not participating in football with no history of previous concussion(s) was 2.4 (95% confidence interval: 1.5, 3.8).
\# The rate ratio for those athletes participating in football with a history of previous concussion(s) relative to the referent group of those not participating in football with no history of previous concussion(s) was 10.0 (95% confidence interval: 4.22, 23.55).

When all these variables—history of concussion, sport by contact level, body mass index (top 80 percent vs. bottom 20 percent), grade in school (12th grade vs. 9th–11th grades), calendar year, school size, highest educational degree completed by head coach—were included in a model, history of previous concussion(s) was still associated with a greater than twofold elevation of the concussion rate, and the association of the other variables with the concussion rate changed little (table 2). Besides history of concussion(s), participation in contact sports, being in the bottom quintile of study athlete body mass indexes, and year 2 of the study appeared to be the strongest predictors of the concussion rate.

Because the association between concussion history and incident concussion was of interest, further modeling focused on obtaining a parsimonious estimate of this association. The confounding effect of each variable was deter-mined by removing variables from the model on a one-by-one basis; a variable was retained in the model if its removal changed the rate ratio for history of concussion by more than 10 percent. The final model included only a three-level term for sport (contact, limited contact, noncontact), a dichotomous term for body mass index (lowest quintile vs. top four quintiles), and a dichotomous term for grade in school (ninth grader vs. all others) as important confounders of the relation between previous concussion(s) and the concussion rate (table 2). The parsimonious, adjusted estimate of the concussion rate ratio of those with a history of concussion(s), compared with those with no reported history, was nearly identical to the rate ratio estimated for the full model (table 2). Participation in football, the only collision sport in the study, was a biologically plausible effect measure modifier of the association between history of concussion(s) and the concussion rate (table 3). In unadjusted analysis, in a comparison of the concussion rate of those with a history of concussion(s) with the rate of those with no reported history, the rate ratio was greater than 4 among football players and only slightly greater than 1 among all other study athletes. Data were too sparse to permit an assessment of other covariates as modifiers.

DISCUSSION

Multiple concussions

Risk of concussion was elevated more than twofold among athletes with a history of concussion(s) relative to athletes without a history of concussion(s) even after adjusting for sport, body mass index, and grade in school. This is the first prospective study to identify history of concussion(s) as a potential risk factor for future concussions. History of concussion(s) was also observed to be a potential risk factor for subsequent concussions by Gerberich et al. (9) and more recently by Guskiewicz et al. (5) in their studies of football players.

Several aspects of the current study lend weight to the identification of retrospective history of concussion as a risk factor for subsequent incident concussion. First, both incident concussions and exposure time were assessed prospectively, reducing the probability of recall bias; second, the regression models used account for individual exposure differences at the level of athlete-exposure; and third, important potential confounders, sport, body mass index, and grade in school, were considered and eliminated as alternative explanations of the observed association.

Two explanations can be considered for why a retrospective history of concussion is associated with elevated risk of prospective incident concussion. First, it is possible that the ability of the brain to respond to traumatic insults may be compromised in previously concussed athletes, making them more susceptible to another concussion. This scenario is the chronic analog to second-impact syndrome, except that the second injury in second-impact syndrome is not a concussion but rather a serious traumatic brain injury that can result in death (1). This compromised state of the brain, if present, is not easily detected by current methods. Collins et al. (8) found some evidence of long-term cognitive deficits among football players with two or more concussions compared with those with none, but Macciocchi et al. (10) did not find similar deficits among football players with two concussions compared with those with one concussion. Likewise, Guskiewicz et al. (26) reported no association between chronic cognitive impairment and a history of mild concussions among collegiate soccer players.

Alternatively, it may be that the risk of concussion is greater among those with a history of concussion for environmental and behavioral reasons. Some athletes are exposed to more athletic activity because they play more minutes within games or practices, and some athletes are exposed to more intense athletic activity (in terms of the number and force of the collisions that athletes experience) because of their individual or team style of play. These same athletes may continue to be exposed to more minutes or more intense athletic activity for the same reasons, even after having the first concussion. The current study lends some support to this argument. It indicates that the effect estimate for history of concussion within the football strata is much stronger than the effect estimate for history of concussion for the other sports, and football players would appear to be exposed to more collisions and more forceful collisions than athletes in the other study sports.

Significance

Because the study was based on a stratified two-stage cluster sample and examined 12 sports (including six girls' sports), the current study broadens the understanding of sports concussions. Most of the concussion literature has focused on football; for girls' track and cheerleading, concussion rates have not previously been reported in the literature. Interestingly, cheerleading was the only sport for which the concussion rate ratio comparing the game rate with the practice rate was less than one. One possible explanation for this finding is that cheerleadering teams in competition are judged on the basis of both the difficulty and the form of their routines; this scoring method could influence cheerleader behavior so as to reduce risk in games relative to practices. Another possible explanation would be that more and stronger spotters (individuals assigned to spot and catch falling performers) are available for competitions than for practice (27).

Several investigators (28, 29) have highlighted the importance of collecting specific and accurate exposure data to measure time at risk of injury for populations of athletes. For injury rates to be comparable between studies, comparable measures of time at risk, as well as comparable definitions of injury and comparable methods of injury ascertainment, must be utilized. The measure of time at risk used in this study, the athlete-exposure (i.e., one athlete participating in one practice or game), is a detailed measure of time at risk that can be collected (albeit with a good deal of work) at this level. Obviously, since each athlete-game and each athlete-practice are associated with different activities and varying minutes of activity, it would be ideal to capture a more precise estimate of the minutes of each athlete (athlete-minutes) spent on each type of sport-specific activity (e.g., offense, defense, running, tackling, sideline cheering, partner stunts, and so on). However, this level of detail was beyond the scope of the study. The approach taken in this study may underestimate game concussion rates per athlete-minute for sports in which many athletes participate for brief periods of time relative to sports in which fewer players participate for longer time periods.

The current study used athletic trainers where they were available to document injuries, which was in only 33 percent of the schools. The choice of data collector was mainly driven by the fact that the majority of high schools do not have certified athletic trainers. Consequently, some concussions may have gone uncounted. This limitation was in part remedied by including a brief question about head injury symptoms, which allowed the concussions, not originally identified by our data collectors, to be identified in the analysis.

Calendar year of the concussion remained an important predictor of the overall concussion rate in the full model, but it did not affect the relation between history of concussion and the concussion rate. Since no other covariate appeared to confound the association between calendar year and the overall concussion rate, it may be that concussion ascertainment was more complete for the second year of the study (1997–1998) compared with either the first or third year. This explanation is bolstered by the fact that the injury rate for athletic injuries of all types was elevated for year 2 relative to the other years in the NCHSAIS (20).

Ascertainment of concussion history and possibility of bias in effect estimate

Recall decay regarding events in the more distant past may have led to an underestimation of the number of previous concussions suffered by athletes in this study. Harel et al. (30) described how the injury rates of children and adolescents based on information provided by their mothers declined as the recall period that mothers were reporting became more distant in time. In the current study, the athlete reported his or her own injury history so we are concerned with the recall of the athlete rather than that of a proxy.

The primary interest of this study was to estimate the association between a history of previous concussions and the current concussion rate. This effect estimate would only have been biased by the athletes' recall decay if their recall decay was associated with the ascertainment of concussions during the study period (3 1). Since concussion ascertainment was done by school contacts who were unaware of the athlete's responses regarding history of previous concussions, it is unlikely that the recall decay of the athletes regarding their previous concussions would be associated with the ascertainment of incident concussions. However, as Gerberich et al. (9) suggested, athletes who recalled a past concussion were more vigorous in reporting concussion symptoms than those with no recall of past concussion, perhaps because the former were more aware of concussion symptoms and the attendant dangers.

To help quantify the extent to which underreporting of concussions in those with a negative concussion history could have introduced a bias, we conducted a small sensitivity analysis using simple deterministic methods (3 1). The working assumption for the sensitivity analysis was that specificity was 100 percent (i.e., all recorded concussions represented true concussions). If the difference in underreporting between those with and without a history of concussion was up to 10 percent, only a modest degree of bias was present. Under this scenario, the corrected rate ratio (for the unadjusted rate ratio of 2.96) ranged from 2.70 to 3.29 for history of concussion. Even if the difference in underreporting was up to 20 percent, the range of the corrected rate ratio expanded to only 2.37–3.70. This suggests that under-reporting of concussions is not a major threat to the validity of this finding as long as it is nondifferential or moderately differential with respect to history of concussion.

Conclusion

The results of this study broaden the knowledge base regarding concussion in high school athletes, especially with respect to cheerleading and girls' track. Cheerleading appears to be exceptional in that it is the only sport in which the risk of concussion is greater in practice than it is in competition, pointing to a need to focus cheerleading concussion prevention efforts on practices. In multivariate regression models, the relation between history of concussion and the concussion rate remained strong after adjustment for several covariates in the multivariate model, but when sports were categorized as collision sports (football) versus noncollision sports (the 11 other sports), the association of history of concussion with the concussion rate was found to be much stronger for the collision sport (football) than for the noncollision sports.

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