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*Am J Sports Med* 2012 40: 747 originally published online January 27, 2012  
DOI: 10.1177/0363546511435626

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# Epidemiology of Concussions Among United States High School Athletes in 20 Sports

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*Investigation performed at The Research Institute at Nationwide Children's Hospital, Columbus, Ohio*

**Background:** In the United States (US), an estimated 300,000 sports-related concussions occur annually. Among individuals 15 to 24 years of age, sports are second only to motor vehicle crashes as the leading cause of concussions.

**Purpose:** To investigate the epidemiology of concussions in high school athletes by comparing rates and patterns of concussion among 20 sports.

**Study Design:** Descriptive epidemiology study.

**Methods:** Using an Internet-based data collection tool, RIO, certified athletic trainers from a large, nationally dispersed sample of US high schools reported athlete exposure and injury data for 20 sports during the 2008-2010 academic years.

**Results:** During the study period, 1936 concussions were reported during 7,780,064 athlete-exposures (AEs) for an overall injury rate of 2.5 per 10,000 AEs. The injury rate was higher in competition (6.4) than practice (1.1) (rate ratio [RR], 5.7; 95% confidence interval [CI], 5.2-6.3). The majority of concussions resulted from participation in football (47.1%, n = 912), followed by girls' soccer (8.2%, n = 159), boys' wrestling (5.8%, n = 112), and girls' basketball (5.5%, n = 107). Football had the highest concussion rate (6.4), followed by boys' ice hockey (5.4) and boys' lacrosse (4.0). Concussions represented a greater proportion of total injuries among boys' ice hockey (22.2%) than all other sports studied (13.0%) (injury proportion ratio [IPR], 1.7; 95% CI, 1.4-2.1;  $P < .01$ ). In gender-comparable sports, girls had a higher concussion rate (1.7) than boys (1.0) (RR, 1.7; 95% CI, 1.4-2.0). The most common mechanisms of injury were player-player contact (70.3%) and player-playing surface contact (17.2%). In more than 40% of athletes in sports other than girls' swimming and girls' track, concussion symptoms resolved in 3 days or less. Athletes most commonly returned to play in 1 to 3 weeks (55.3%), with 22.8% returning in less than 1 week and 2.0% returning in less than 1 day.

**Conclusion:** Although interest in sports-related concussions is usually focused on full-contact sports like football and ice hockey, concussions occur across a wide variety of high school sports. Concussion rates vary by sport, gender, and type of exposure. An understanding of concussion rates, patterns of injury, and risk factors can drive targeted preventive measures and help reduce the risk for concussion among high school athletes in all sports.

**Keywords:** concussion; high school; injury; surveillance

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One or more of the authors has declared the following potential conflict of interest or source of funding: The content of this report was funded in part by the Centers for Disease Control and Prevention (CDC) grants #R49/CE000674-01 and #R49/CE001172-01. The authors also acknowledge the generous research funding contributions of the National Federation of State High School Associations (NFHS) and DonJoy Orthotics.

In the United States (US), concussions are a common injury among athletes, with an estimated 300,000 sports-related concussions occurring annually.<sup>10,20,22</sup> Concussion has been broadly defined as a trauma-induced alteration in mental status that may involve a loss of consciousness.<sup>13,24</sup> However, many concussions go undiagnosed because athletes often fail to report concussive symptoms or are not accurately identified as having concussive symptoms.<sup>2,17</sup> Recent research shows that young athletes are more susceptible to concussions than older athletes, and because of the ongoing neurocognitive development that occurs throughout adolescence, concussions can have severe acute and long-term complications in young athletes.<sup>5,21,22</sup> These findings have serious implications because participation in high school athletics has increased for years, with more than half of all high school students, over 3.1 million girls and 4.2 million boys, participating in sports during the 2009-2010 school year.<sup>19</sup> Reduction

of concussion incidence in high school athletics is a major public health concern.

Despite the serious potential public health implications, few studies have been conducted on concussion rates in a broad spectrum of high school sports.<sup>10,23,26</sup> Most studies investigating adolescent concussions have focused predominantly on football, with other collision sports such as lacrosse and ice hockey being relatively unstudied at the high school level.<sup>8,12,15</sup> Previous investigations involving a range of high school sports show that concussion rates are higher in competition than in practice.<sup>10,23,26</sup> However, few authors have compared rates of concussion between gender-comparable sports or among sports played only by girls at the high school level. This gap in the literature is crucial, as more recent investigation highlights the disparity between genders and shows that in sports played by both genders, girls sustain higher concussion rates.<sup>10</sup> Some evidence further suggests a discrepancy between male and female athletes in reported symptoms, concussion recovery times, and postconcussion outcomes on neuropsychological testing.<sup>4,6,7,9</sup> A more complete understanding of concussions in high school athletes is needed, as research indicates younger athletes are more prone to second-impact syndrome, which often has catastrophic consequences.<sup>5</sup> Moreover, many studies have emphasized the importance of proper assessment and management of sports-related concussions as well as adherence to the currently accepted return-to-play guidelines.<sup>8,11,15-17,28</sup>

The objective of this study was to update and expand upon prior studies by investigating the epidemiology of concussions across a collection of 20 high school sports in a large, nationally disperse sample. To achieve this, concussion rates are compared by sport, gender, and exposure type. Furthermore, this investigation describes concussion injury patterns by sport in terms of severity (as determined by time loss), mechanisms, activities, symptoms, and symptom resolution time. The long-term goal was to provide a more comprehensive understanding of the epidemiology of concussions among high school athletes.

## MATERIALS AND METHODS

### Data Collection

We evaluated data from the National High School Sports-Related Injury Surveillance System, High School RIO (Reporting Information Online), an Internet-based sports injury surveillance system. The methodology of this surveillance study has been reported previously.<sup>25</sup> In brief, high schools with one or more National Athletic Trainers' Association-affiliated certified athletic trainers (ATs) with a valid e-mail address are invited to participate. Willing participants are categorized into 8 strata based on school population (enrollment  $\leq 1000$  or  $> 1000$ ) and US Census geographic location.<sup>27</sup> From these 8 strata, 100 high schools are randomly selected to participate in the nationally representative sample. Those schools not selected to participate and that offered any of the more rare sports (ie, girls' gymnastics, field hockey, and lacrosse and boys' ice hockey, volleyball, and

lacrosse) were included in the expansion of the National High School Sports-Related Injury Surveillance convenience sample. A sample of schools not selected for the nationally representative study or that offered the remaining rare 9 sports of interest in the expansion High School RIO (boys' and girls' track and field, swimming and diving, and cheerleading) were selected in an attempt to ensure at least 100 schools were reporting for each of the 20 sports of interest. This sampling methodology resulted in a large, nationally disperse convenience sample of US high schools. Certified ATs from participating high schools logged onto the High School RIO Web site weekly throughout the academic year to report injury incidence and athlete exposure (AE) for 20 sports: boys' football, soccer, volleyball, basketball, wrestling, baseball, ice hockey, lacrosse, swimming/diving, track/field, and cheerleading and girls' soccer, basketball, volleyball, softball, gymnastics, field hockey, lacrosse, swimming/diving, track/field, and cheerleading. Boys' volleyball and cheerleading had 1 year of data analyzed in this study because of their addition to the survey during the 2009-2010 school year. All other sports had 2 years of data analyzed.

### Definition of Injury and Exposure

An AE was 1 athlete participating in 1 athletic practice or competition. Cases where injury occurred during "other training" (ie, weight training, etc) were excluded ( $n = 21$ ). A reportable injury was one that (1) occurred as a result of participation in an organized practice or competition, (2) required medical attention by an AT or a physician, and (3) resulted in a restriction of the athlete's participation for  $\geq 1$  day or (4) resulted in any fracture, concussion, or dental injury regardless of whether it resulted in a restriction of the student-athlete's participation. For each injury, the AT completed a detailed injury report on the injured athlete (age, height, weight, etc), the injury (site, diagnosis, severity, etc), and the injury event (activity, mechanism, etc). Throughout the study, reporters were able to view previously submitted information and update reports as needed.

### Statistical Analysis

We analyzed data using SPSS software, version 19.0 (SPSS, Chicago, Illinois). Overall rates were calculated by dividing concussion incidence by AE using raw case counts. Additionally, rates were calculated by sport for each type of athlete exposure (practice vs completion) as well as overall by using the number of injuries as the numerator (total number of concussions, number of practice-related concussions, and number of competition-related concussions) and the number of AEs as the denominator (total number of AEs, practice AEs, and competition AEs). We calculated rate ratios (RRs) and injury proportion ratios (IPRs) with  $P$  values and 95% confidence intervals (CIs). We considered CIs not including 1.00 and  $P$  values  $< .05$  to be statistically significant. An IPR  $> 1.00$  suggests a risk association, while an IPR  $< 1.00$  suggests a protective association. As an example, RRs and IPRs were calculated as follows:

$$RR = \frac{(\text{total \# girls' soccer concussions} / \text{total \# girls' soccer AEs}) \times 10,000}{(\text{total \# boys' soccer concussions} / \text{total \# boys' soccer AEs}) \times 10,000}$$

IPR =

$$\frac{(\text{\# boys' lacrosse player - contact concussions} / \text{total \# boys' lacrosse concussions})}{(\text{\# girls' lacrosse player - contact concussions} / \text{total \# girls' lacrosse concussions})}$$

This study was approved by the Institutional Review Board at Nationwide Children's Hospital.

## RESULTS

### Incidence and Rates

In the 20 sports studied over the course of the 2008-2010 school years, 14,635 injuries were reported, 1936 (13.2%) of which were concussions. This included 1289 concussions (66.6%) that occurred in competition and 647 (33.4%) that occurred during practice. These injuries were sustained during the course of 7,780,064 AEs (2,005,399 competition and 5,774,665 practice exposures), resulting in a concussion rate of 2.5 concussions per 10,000 AEs (competition rate = 6.4 concussions per 10,000 AEs; practice rate = 1.1 concussions per 10,000 AEs) (RR, 5.7; 95% CI, 5.2-6.3). The majority of concussions resulted from participation in football (47.1%,  $n = 912$ ), followed by girls' soccer (8.2%,  $n = 159$ ), boys' wrestling (5.8%,  $n = 112$ ), and girls' basketball (5.5%,  $n = 107$ ). Boys' volleyball was the only sport in which no concussions occurred. The rate of concussion was higher in competition than in practice for all sports except cheerleading, with this difference being significant in 13 of the 20 sports (Table 1).

### Symptoms and Return to Play

The most commonly reported concussion symptom was headache (94.2%), followed by dizziness (75.6%) and concentration difficulty (54.8%). Other symptoms included confusion (45.0%), light sensitivity (36.0%), and nausea (31.4%). Overall, 11.5% of high school athletes sustaining a concussion had previously sustained a sports-related concussion either that season or in a previous season; almost 20% of concussions in boys' wrestling were recurrent concussions. In more than 40% of athletes in 18 of the 20 sports (all but girls' swimming and girls' track), concussion symptoms resolved in 3 days or less (Figure 1). Although approximately one fourth of all athletes studied had concussion symptoms resolve within a day, 2.0% returned to play that same day (Figure 2). In 12 of the 20 sports studied, some athletes returned to play the same day they sustained a concussion.

### Patterns of Concussion Injuries

**Football.** The highest proportion of concussion injuries occurred during running plays (48.5%) and resulted from player-player contact (87.8%) (Figure 3). More specifically, tackling and being tackled were responsible for 62.5% of

concussions. Linebackers sustained 58.9% of all concussions among defensive players. Concussions represented a higher proportion of cornerbacks' total injuries (23.7%) than other defensive positions combined (18.5%) (IPR, 1.3; 95% CI, 1.04-1.6;  $P < .03$ ). Running backs sustained 46.0% of concussions sustained by players in offensive positions; however, concussions represented a higher proportion of all injuries among tight ends (18.3%).

**Soccer.** Girls had a higher rate of concussion (3.4 per 10,000 AEs) than boys (1.9) (RR, 1.8; 95% CI, 1.4-2.3;  $P < .001$ ), and concussions represented a greater proportion of total injuries among girls (15.4%) than boys (11.1%) (IPR, 1.4; 95% CI, 0.96-2.0;  $P = .08$ ) (Figure 4); however, this difference was not significant. Among both boys and girls, the activity most frequently associated with concussion was heading the ball (31.1% and 27.7%, respectively). Additionally, 60.8% of injuries sustained while heading the ball were concussions. Concussions sustained while heading the ball occurred as a result of player-player contact (boys: 74.2%; girls: 58.1%), player-equipment contact (boys: 12.9%; girls: 34.9%), and player-playing surface contact (boys: 12.9%; girls: 7.0%). Overall, player-player contact resulted in a greater proportion of concussions in boys (76.7%) than girls (52.8%) (IPR, 1.4; 95% CI, 1.2-1.7;  $P < .001$ ) (Figure 3). Conversely, player-playing surface contact (18.2% and 7.8%, respectively) (IPR, 2.4; 95% CI, 1.1-5.0;  $P = .01$ ) and player-ball contact (26.4% and 15.5%, respectively) (IPR, 1.7; 95% CI, 1.01-2.8;  $P = .03$ ) resulted in a greater proportion of concussions in girls than in boys.

**Volleyball.** Concussions were 2 times more likely to occur during competition than practice (RR, 2.1; 95% CI, 1.04-4.3) (Table 1). Activities commonly associated with concussion were digging (41.9%), passing (16.1%), and general play (16.1%). Mechanisms associated with concussion were player-playing surface contact (51.6%), player-player contact (25.8%), and player-equipment contact (22.6%) (Figure 3). More specifically, concussions most commonly occurred during diving for the ball (38.7%), player-teammate contact (25.8%), and player-ball contact (25.8%). Over half (51.6%) of concussions were sustained by the outside hitter and setter positions.

**Basketball.** Girls had a higher rate of concussion (2.1) than boys (1.6) (RR, 1.3; 95% CI, 1.03-1.8;  $P < .03$ ) (Table 1). Boys had quicker symptom resolution times and return-to-play outcomes than girls; however, neither difference was significant (Figures 1 and 4). Among girls, a greater proportion of concussions were sustained while defending (29.8%) compared with other activities (13.6%) (IPR, 2.2; 95% CI, 1.6-3.1;  $P < .001$ ). With regard to specific activities within basketball, boys sustained a greater proportion of concussions while shooting (12.0%) than girls (2.8%) (IPR, 4.2; 95% CI, 1.2-14.4;  $P < .03$ ). A larger proportion of boys (64.6%) than girls (50.5%) sustained a concussion due to player-player contact (IPR, 1.3; 95% CI, 1.01-1.6;  $P < .05$ ) (Figure 3).

**Wrestling.** Concussions were 3 times more likely to occur during competition than practice (RR, 3.6; 95% CI, 2.5-5.2). An activity most commonly associated with concussion was takedowns (58.7% of concussions). Takedowns

TABLE 1  
Concussion Rates Among High School Athletes by Sport: High School Sports-Related Injury Surveillance Study,  
United States, 2008-2010 School Years<sup>a</sup>

Sport <sup>b</sup>	Concussions			Athlete Exposures (AEs)			Rate per 10,000 AEs			Rate Ratio (95% CI) <sup>c</sup>
	Competition	Practice	Total	Competition	Practice	Total	Competition	Practice	Total	
Football	548	364	912	239,445	1,176,395	1,415,840	22.9	3.1	6.4	7.4 (6.5-8.4)
Boys' ice hockey	69	11	80	47,418	99,857	147,275	14.6	1.1	5.4	13.2 (7.0-25.0)
Boys' lacrosse	75	18	93	71,990	159,980	231,970	10.4	1.1	4.0	9.5 (5.5-15.5)
Girls' soccer	133	26	159	145,139	328,241	473,380	9.2	0.8	3.4	11.6 (7.6-17.6)
Girls' lacrosse	45	15	60	52,331	117,865	170,196	8.6	1.3	3.5	6.6 (3.8-12.1)
Girls' basketball	85	22	107	153,655	350,554	504,209	5.5	0.6	2.1	9.2 (5.5-14.1)
Boys' soccer	88	15	103	166,572	383,076	549,648	5.3	0.4	1.9	13.5 (7.8-23.3)
Boys' wrestling	63	49	112	132,203	365,981	498,184	4.8	1.3	2.2	3.6 (2.5-5.2)
Girls' field hockey	29	22	51	70,430	156,735	227,165	4.1	1.4	2.2	2.9 (1.7-5.1)
Boys' basketball	71	25	96	181,941	433,661	615,602	3.9	0.6	1.6	6.8 (4.3-10.7)
Girls' softball	36	22	58	123,815	239,850	363,665	2.9	0.9	1.6	3.2 (1.9-5.4)
Girls' gymnastics <sup>d</sup>	2	1	3	8431	35,882	44,313	2.4	0.3	0.7	8.5 (0.8-93.9)
Cheerleading <sup>e</sup>	2	21	23	16,412	145,124	161,536	1.2	1.4	1.4	1.2 (0.3-5.1)
Boys' baseball	19	4	23	167,233	312,033	479,266	1.1	0.1	0.5	11.0 (3.0-26.1)
Girls' volleyball	16	15	31	162,854	322,371	485,225	1.0	0.5	0.6	2.1 (1.04-4.3)
Girls' swim/dive <sup>d</sup>	2	2	4	45,564	187,588	233,152	0.4	0.1	0.2	4.1 (0.6-29.2)
Girls' track/field <sup>d</sup>	3	5	8	82,360	356,285	438,645	0.4	0.1	0.2	4.1 (0.6-10.9)
Boys' track/field	3	8	11	100,050	441,052	541,102	0.3	0.2	0.2	1.5 (0.4-6.2)
Boys' swim/dive <sup>d</sup>	0	2	2	37,556	162,135	199,691	—	0.1	0.1	—
Gender comparable <sup>f</sup>										
Boys	181	54	235	653,352	1,731,957	2,385,309	2.8	0.3	1.0	9.3 (6.6-12.0)
Girls	259	77	336	550,533	1,462,518	2,013,051	4.7	0.5	1.7	9.4 (6.9-11.5)
Total										
Boys	936	496	1432	1,144,408	3,534,170	4,678,578	8.2	1.4	3.1	5.9 (5.2-6.5)
Girls	353	151	504	860,991	2,240,495	3,101,486	4.1	0.7	1.6	5.9 (5.0-7.4)

<sup>a</sup>Table organized by competition rates from highest to lowest. CI, confidence interval.

<sup>b</sup>Boys' volleyball was not included because no concussions were reported.

<sup>c</sup>Calculated with practice as a referent group except for cheerleading, which has a higher concussion rate in practice and uses competition as a referent group.

<sup>d</sup>Caution should be used when interpreting results in tables and figures when considering sports with less than 10 total injuries such as girls' gymnastics, boys' and girls' swim/dive, and girls' track/field.

<sup>e</sup>Cheerleading was added to the survey starting in the 2009-2010 school year. One year of competition and practice data is represented in this table.

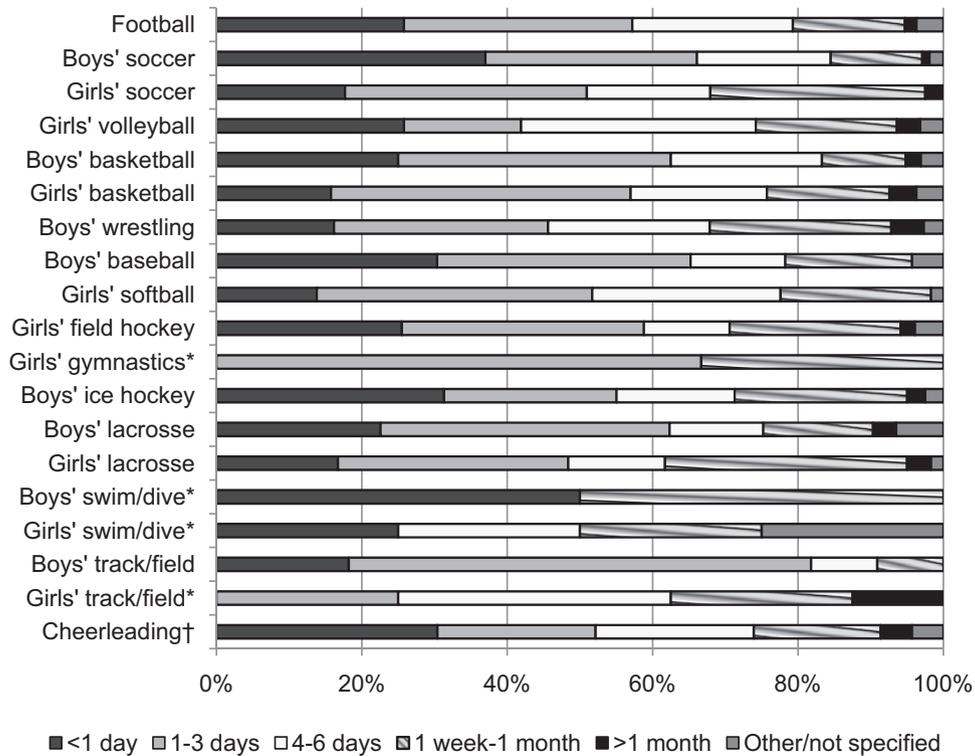
<sup>f</sup>Gender-comparable sports included soccer, basketball, baseball/softball, swim/dive, and track/field. Volleyball was not included because of boys' volleyball having 1 year of data and zero concussions reported.

were more likely to lead to a concussion (13.6%) than other wrestling activities (6.7%) (IPR, 2.0; 95% CI, 1.5-3.3;  $P < .001$ ). Additionally, 53.2% of wrestling concussions were from player–playing surface contact and 44.1% from player-player contact (Figure 3).

**Baseball/Softball.** Softball players had a higher rate of concussion (1.6) than baseball players (0.5) (RR, 3.2; 95% CI, 2.1-5.4;  $P < .001$ ) (Table 1), and concussions represented a greater proportion of total injuries among softball players (13.4%) than baseball players (5.4%) (IPR, 2.5; 95% CI, 1.6-3.9;  $P < .001$ ) (Figure 4). A greater proportion of baseball players' concussions resulted from being hit by a pitch (26.1%) than did softball players' concussions (5.2%) (IPR, 5.0; 95% CI, 1.4-18.5;  $P < .01$ ). Baseball and softball players sustained over a quarter of concussions as a result of fielding a batted ball (26.1% and 27.6%, respectively).

**Field Hockey.** Concussions were 3 times more likely to occur during competition than practice (RR, 2.9; 95% CI, 1.7-5.1) (Table 1). During competition, 37.1% of concussions occurred between the 25-yard and center-yard lines. Player-equipment contact (ball: 37.3%; stick: 23.5%) resulted in 60.8% of concussions, with an additional 29.4% resulting from player-player contact (Figure 3). Activities most commonly resulting in a concussion are defending (37.3%), chasing a loose ball (11.8%), and general play (11.8%). Midfielders (35.3%) sustained the greatest proportion of concussions, followed by defenders (29.4%) and forwards (21.6%).

**Gymnastics.** Concussions occurred nearly 9 times more frequently in competition than practice (RR, 8.5; 95% CI, 0.8-93.9) (Table 1). However, this difference was not statistically significant because of the low incidence of concussions



**Figure 1.** Concussion symptom resolution time for high school athletes by sport: High School Sports-Related Injury Surveillance Study, United States, 2008-2010 school years. Caution should be used when interpreting results on tables and figures when considering sports with less than 10 total injuries, such as girls' gymnastics, boys' and girls' swim/dive, and girls' track/field. Cheerleading was added to the survey starting with the 2009-2010 school year. One year of data is represented in this figure.

(n = 3). Dismounts on the balance beam and uneven parallel bars were responsible for 2 concussions, while tumbling during a floor exercise was responsible for 1. Two concussions occurred while the athlete was spotted by a coach (66.7%). More specifically, the 3 concussions were a result of contact with an apparatus, fall/slip, and jumping/landing.

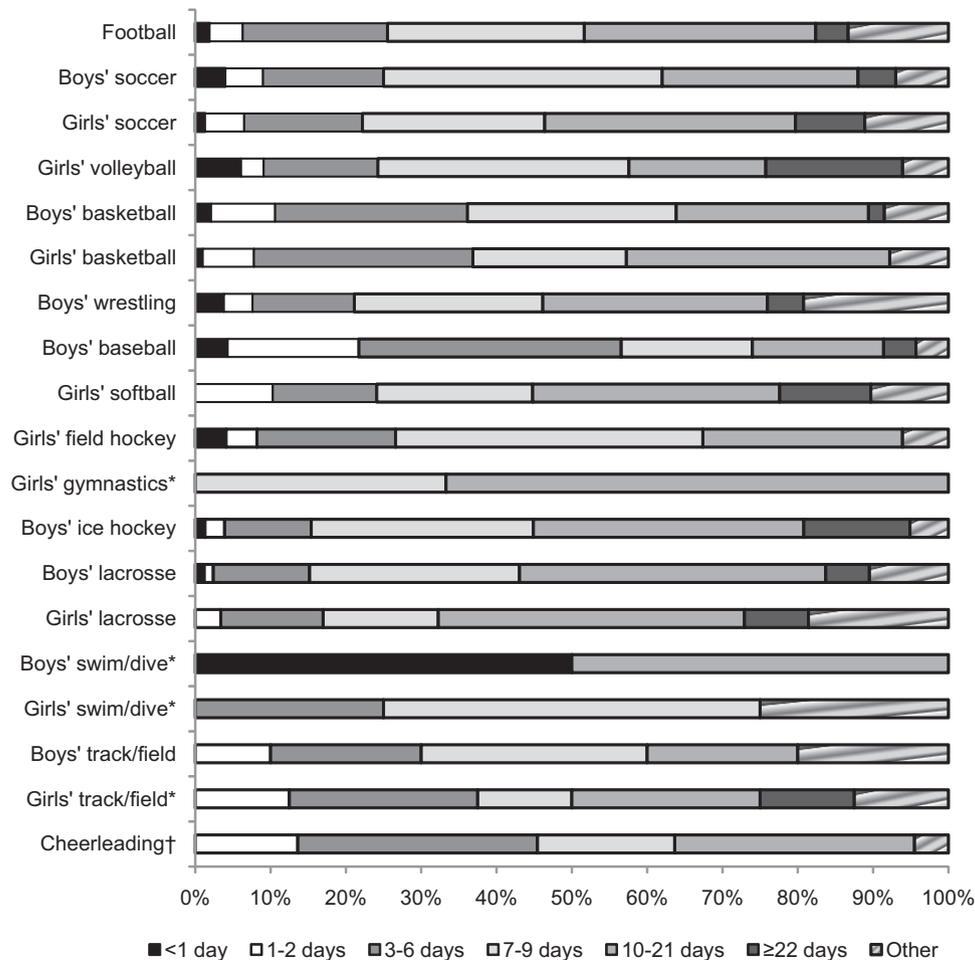
**Ice Hockey.** Concussions were 13 times more likely to occur during competition than practice (RR, 13.2; 95% CI, 7.0-25.0) (Table 1). Concussions represented a greater proportion of total injuries among boys' ice hockey (22.2%) than all other sports studied (13.0%) (IPR, 1.7; 95% CI, 1.4-2.1;  $P < .01$ ) (Figure 4) and were a result of player-player contact (63.6%), player-playing surface contact (24.7%), and player-equipment contact (10.4%) (Figure 3). More specifically, concussions most commonly resulted from player-player contact (45.0%), player-boards/glass contact (28.8%), and player-ice contact (20.0%). Activities commonly associated with concussion were being checked (30.0%), skating (30.0%), and chasing a loose puck (16.3%). Half of ice hockey concussions were sustained by wings.

**Boys' Lacrosse.** Concussions were 9 times more likely to occur during competition than practice (RR, 9.5; 95% CI, 5.5-15.5) (Table 1). Concussions were primarily a result of player-player contact (76.1%), player-playing surface contact (7.6%), and player-equipment contact (15.2%) (Figure 3). More specifically, concussion most commonly

resulted from player-player contact (76.7%), player-crosse/stick contact (14.4%), and player-ball contact (3.3%). Activities commonly associated with injury were being body checked (18.0%), chasing a loose ball (13.5%), body checking (12.4%), and defending (12.4%). Nearly half (47.6%) of all concussions were sustained by midfielders.

**Girls' Lacrosse.** Concussions were 6 times more likely to occur during competition than practice (RR, 6.6; 95% CI, 3.8-12.1) (Table 1). Among all girls' sports studied, concussions represented a greater proportion of total injuries in girls' lacrosse (21.1%) (Figure 4). Concussions frequently resulted from player-equipment contact (55.9%), player-player contact (28.8%), and player-playing surface contact (11.9%) (Figure 3). More specifically, concussion most commonly resulted from player-crosse/stick contact (41.7%), player-player contact (28.3%), and player-ball contact (20.0%). Activities commonly associated with injury were defending (16.9%), ball handling/cradling (15.3%), and general play (13.6%).

Girls' and boys' lacrosse cannot be considered directly comparable sports given the vast competition rule differences, particularly regarding the additional allowable body contact and required protective equipment in boys' lacrosse. However, there was no significant difference in competition-related concussion rates between boys' and girls' lacrosse (RR, 1.2; 95% CI, 0.8-1.8).



**Figure 2.** Length of time until return to play after concussion for high school athletes by sport: High School Sports-Related Injury Surveillance Study, United States, 2008-2010 school years. Caution should be used when interpreting results on tables and figures when considering sports with less than 10 total injuries, such as girls' gymnastics, boys' and girls' swim/dive, and girls' track/field. Cheerleading was added to the survey starting with the 2009-2010 school year. One year of data is represented in this figure.

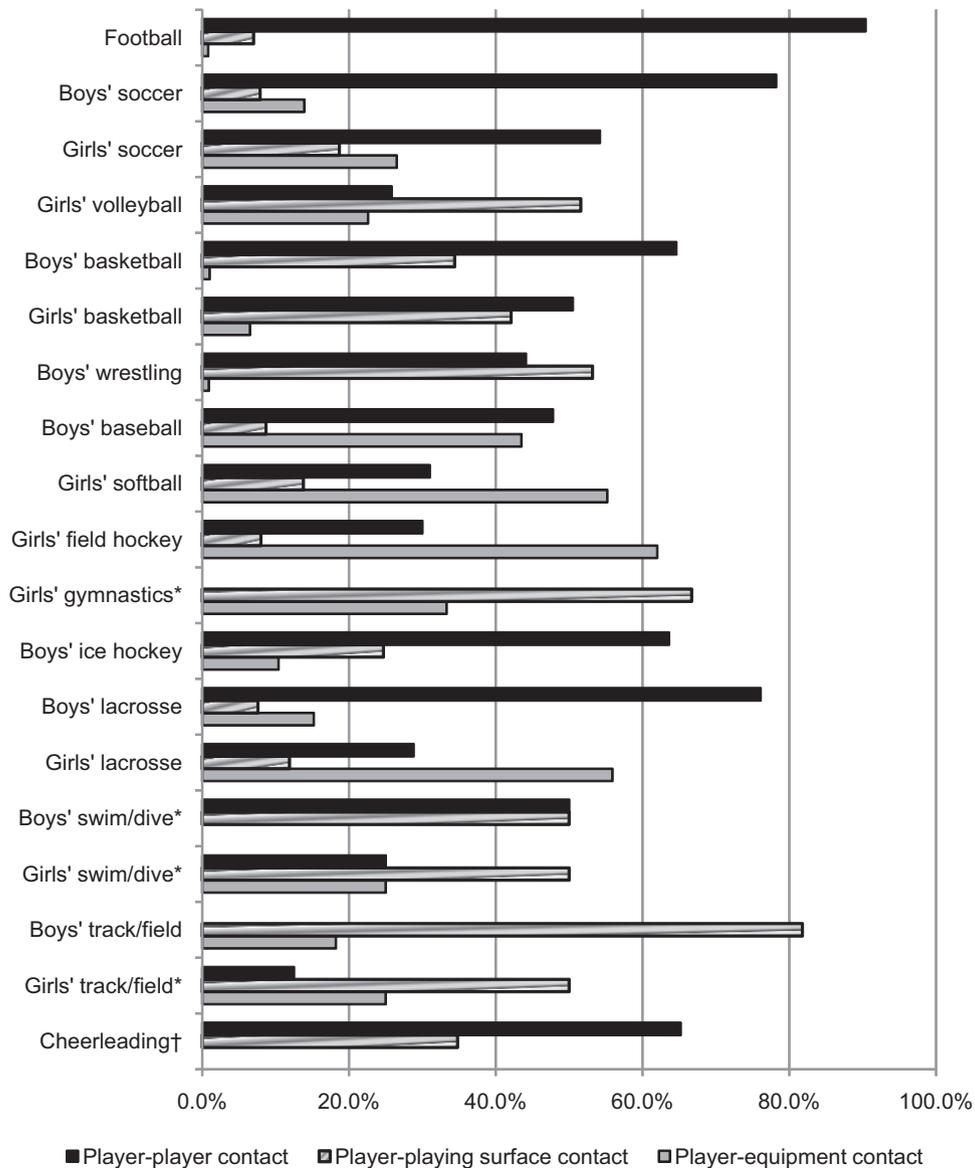
**Swimming and Diving.** There were 2 concussions among boys and 4 among girls. Concussions resulted from player-player contact (boys,  $n = 1$ ; girls,  $n = 1$ ), player-playing surface contact (boys,  $n = 1$ ; girls,  $n = 2$ ), and player-equipment contact (girls,  $n = 1$ ) (Figure 3). More specifically, concussion most commonly resulted from contact with the deck (boys,  $n = 1$ ; girls,  $n = 2$ ), a wall (girls,  $n = 1$ ), and another person (boys,  $n = 1$ ; girls,  $n = 1$ ).

**Track and Field.** Girls' track and field athletes were 4 times more likely to sustain a concussion during competition than practice (RR, 4.1; 95% CI, 0.6-10.9), while boys' track and field athletes were 2 times more likely (RR, 1.5; 95% CI, 0.4-6.2) (Table 1). However, given the small incidence of concussion (boys,  $n = 11$ ; girls,  $n = 8$ ), these differences were not significant. Boys' track and field athletes had a greater proportion of recurrent concussions (18.2%) than girls' track and field athletes (0.0%). Track events most commonly associated with concussions were pole vaulting (boys: 45.5%; girls: 28.6%) and high jump (boys: 18.2%; girls: 14.3%).

**Cheerleading.** Concussions occurred during competition ( $n = 2$ ), practice ( $n = 21$ ), and performance ( $n = 4$ ). Concussions represented 20.3% of total injuries (Figure 4) and most commonly resulted from player-player contact (65.2%) and player-surface contact (34.8%) (Figure 3). Those concussions sustained as a result of player-player contact were most commonly from contact with the elbow (33.3%), knee (20.0%), or head (20.0%) of another person. The activity associated with 90.9% of concussions was a stunt (ie, toss, lift, etc) most commonly with a 3 triple base (43.5%) extended (ie, above shoulder level) (48.7%). Half of the concussions were spotted by a teammate, while 45.5% did not have a spotter, and 4.5% were spotted by a coach.

## DISCUSSION

This study is the first to identify patterns of concussion across 20 high school sports by gender, injury mechanism, and type of exposure. Findings demonstrated that while

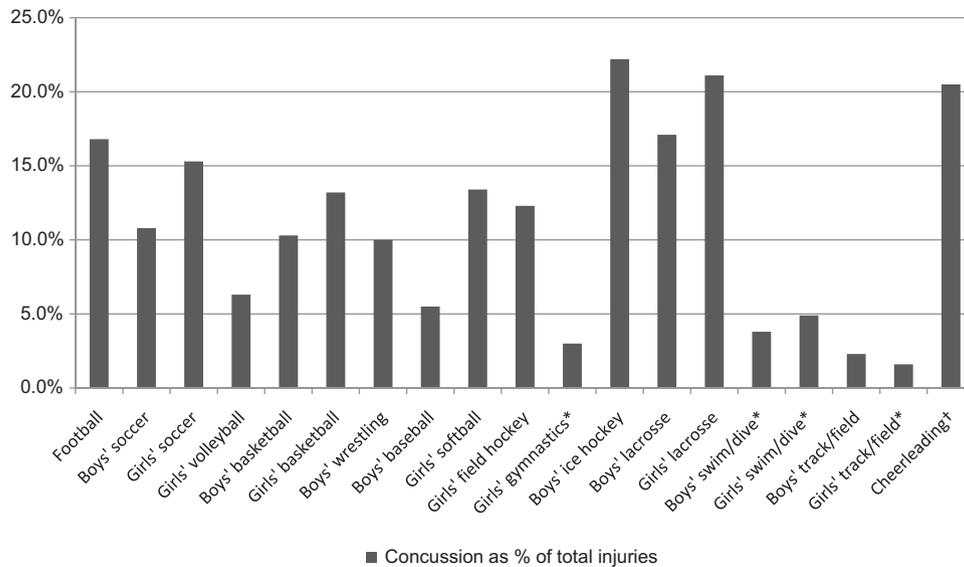


**Figure 3.** Mechanism of concussion for high school athletes by sport: High School Sports-Related Injury Surveillance Study, United States, 2008-2010 school years. Caution should be used when interpreting results on tables and figures when considering sports with less than 10 total injuries, such as girls' gymnastics, boys' and girls' swim/dive, and girls' track/field. Cheerleading was added to the survey starting with the 2009-2010 school year. One year of data is represented in this figure.

patterns of concussion varied by sport and gender, there were some consistencies across sports as well. For example, the overall rate of concussion was higher in competition than in practice, girls had higher concussion rates than boys in gender-comparable sports, and the majority of student-athletes missed more than 1 week of sports activity as a result of their concussion. Concussions are of concern because they can have serious acute and long-term complications. An understanding of concussion patterns in high school athletes can drive targeted preventive measures, such as better protective equipment, educational efforts, and legislative/regulatory efforts intended to reduce the incidence and/or severity of sports-related

concussions. Understanding the epidemiology of sports-related concussions is essential for improving the safety of the high school athletic experience.

In this study, concussions represented 13.2% of all reported injuries. This is greater than the 5.5% reported in a decade-old study conducted across 10 high school sports,<sup>23</sup> the 7.5% reported by a North Carolina study involving 12 high school sports,<sup>26</sup> and the 8.9% reported by a more recent study that used the original 9 high school sports included initially in the early years of the same High School RIO surveillance project.<sup>10</sup> One possible explanation for this is that prior research did not include boys' lacrosse or boys' ice hockey, which have relatively high concussion



**Figure 4.** Concussions as a percentage of total injuries sustained among high school athletes by sport: High School Sports-Related Injury Surveillance Study, United States, 2008-2010 school years.

rates. Additionally, the most recent of these studies did not include concussions that resulted in a time loss of less than 1 day.<sup>10</sup> The overall concussion rate determined in this study, 2.5 concussions per 10,000 AEs, is nearly the same as that determined by Gessel et al,<sup>10</sup> 2.3 concussions per 10,000 AEs. Moreover, consistent with previous studies, we found football represented the greatest proportion of total concussions (47.1%) and had the highest concussion rate (6.4 concussions per 10,000 AEs).<sup>10,23,26</sup>

In all gender-comparable sports studied, girls had higher rates of concussions than boys, and concussions represented a greater proportion of all injuries in girls than in boys. This gender disparity has been previously observed at both the high school and college level.<sup>6,10,23</sup> Biomechanical differences in the head and neck have been suggested as a reason why female athletes may be at higher risk for concussion than their male counterparts.<sup>3,14</sup> However, a recent discussion on concussion pointed out that there is evidence that female athletes may generally be more honest about reporting injuries than male athletes.<sup>7</sup> Such reporting bias would result in a greater proportion of boys' concussions going undiagnosed than girls', thereby misrepresenting girls as having higher concussion rates.<sup>7</sup>

We also found that in every gender-comparable sport studied, girls had a greater proportion of concussions resulting from player–playing surface contact and player–equipment contact than did boys. Particularly, in soccer, the vast majority of boys' and girls' concussions resulted from player–player contact; however, a greater proportion of girls' concussions were a result of player–equipment contact than boys'. Also worth noting is that in all gender-comparable sports, except track and field and swimming and diving, girls had a higher proportion of recurrent concussions than boys. This trend may indicate that girls are at a higher risk for recurrent concussions and could potentially

be linked to recent research showing that traumatic brain injury outcome is often worse in female athletes.<sup>4,7</sup>

Across all 20 sports, player–player contact caused a majority of concussions, with contact sports (ie, football, ice hockey, boys' lacrosse) having higher concussion rates than noncontact sports (ie, volleyball, swimming and diving). These results are consistent with prior research.<sup>10,26</sup> Methods of reducing the risk of concussion due to player–player contact might include better enforcement of rules limiting contact, education regarding the safest way to engage in contact, and the consistent use of fitted protective equipment or the development of better protective equipment.<sup>1</sup> The overall competition concussion rate was significantly higher than the overall practice rate. In competitive situations, officials play a crucial role in limiting dangerously aggressive or illegal activity among athletes.<sup>1</sup> Referees should remain especially vigilant in sports that include sticks and fast-moving projectiles; in girls' lacrosse and field hockey, a majority of concussions resulted from contact with playing equipment.

This study includes information on concussion symptom resolution time and length of time to return to play after injury, allowing an evaluation of compliance with current recommended return-to-play policies. For example, in 2.0% of the concussions reported here, athletes returned to play the same day they sustained the injury. This improper practice was widespread across sports. In 12 of the 20 sports studied, athletes returned to play the same day they sustained a concussion. This clearly violates the current consensus statement on sports-related concussion, which recommends that no adolescent athlete who sustains a concussion should return to play on the day of injury.<sup>16</sup> According to its stepwise return-to-play protocol, athletes should take approximately 1 week after becoming asymptomatic to return to the normal level of sports activity.<sup>16</sup> Additionally, it may be advantageous to err on the side of caution

in managing postconcussion return to play because athletes may be more prone to reinjury during acute recovery periods, and those who sustain multiple concussions may be at a greater risk for long-term complications.<sup>18</sup>

### Limitations

This study was not without limitations. Schools participating in this study were limited to those with National Athletic Trainers' Association-affiliated certified ATs. Thus, findings in this study may not be generalizable to all US high schools. However, the importance of having ATs, trained sports medicine clinicians, report this injury data to the surveillance system outweighed this concern. This study likely represented the best-case scenario for athletes sustaining concussions, as ATs are often the first, and frequently the only, sports medicine clinicians whom student-athletes seek care from. Additionally, caution should be used when interpreting results from sports with fewer than 10 reported concussions. Future research is needed to monitor such sports to see if trends remain stable over time. However, this is the first study to include information on concussions in this broad collection of high school sports, and it indicates that concussion rates and patterns vary across sports.

### CONCLUSION

Although interest in sports-related concussions is usually focused on full-contact sports like football and ice hockey, concussions occur across a wide variety of high school sports. Concussion rates vary by sport, gender, and type of exposure. An understanding of concussion rates, patterns of injury, and risk factors can drive targeted preventive measures and help reduce the risk for concussion among high school athletes in all sports.

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