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Title: Sport- and Gender-specific Trends in the Epidemiology of Concussions Suffered by High School Athletes

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ABSTRACT

Background: Over 300,000 adolescents suffer concussions annually while participating in organized athletics. Although these injuries among youth athletes present a public health crisis, the body of knowledge with respect to the magnitude of the problem and the influence of legislation is lacking. This study aimed to track gender- and sport-specific trends among high school sports-related concussions over time, identify whether a particular sport predisposes athletes to a higher risk, and assess whether traumatic brain injury (TBI) law enactments have been successful in improving recognition.

Methods: Injury data for 2005-2015 was collected from annual reports generated by High School Reporting Information Online. The relative proportions of total estimated concussions to total estimated injuries were compared using an injury proportion ratio (IPR). Concussion rate was defined as the number of concussions per 10,000 athlete-exposures (one athlete participating in one practice or competition), with rates compared using a rate ratio (RR). To evaluate the impact of legislation, trends in concussion rates and proportions were also analyzed pre- (2005-2009) and post-TBI law enactment (2010-2014).

Results: Between 2005-06 and 2014-15, a significant increase in the overall (all sports combined) number of concussions ($p<0.0001$), overall concussion rate (RR=2.30, 95% CI [2.04-2.59]; $p<0.0001$) and the overall proportion of concussions (IPR=2.68, 95% CI [2.66-2.70]; $p<0.0001$) was seen. There was no significant difference in concussion rate between boys football and girls soccer in 2005-2006 or 2014-2015. Based on the IPR, during the 2014-2015 school year concussions were more common in girls soccer than any other sport ($p<0.0001$).

Conclusions: Because of potentially devastating consequences, concussion prevention and recognition measures continue to be emphasized in high school contact sports. The data in our study suggest that significant increases in the overall rate and proportion of concussions during the last decade could have been affected by TBI legislation. To our knowledge, this is the first study to report that girls soccer players may have an even greater risk of sustaining a concussion than all other sports.

Level of Evidence: III; Retrospective cohort study

INTRODUCTION

Over 7.8 million students participated in high school athletics in 2014, and millions more in recreational sports.[1] The daily practices, physical demands, potential for physical contact, and repetitive stress associated with sports activities place young athletes at risk for injury. Among these, in the adolescent population, acute cerebral concussions are an especially serious public health concern because developmentally younger brains may have less cognitive reserve and be at risk for protracted recovery.[2-4] These injuries are considered a subset of traumatic brain injury (TBI),[5] a major cause of hospitalization and death among children and adolescents.[6]

Approximately 300,000 adolescents suffer a concussion annually while participating in organized athletics.[4, 6, 7] Previous multi-year studies have reported an increasing burden of concussions among high school athletes over the last decade.[8, 9] Although this finding may reflect a true increase in the number of concussion occurrences, other explanations exist: younger athletes may not previously have recognized the seriousness of concussion symptoms, may have had fear of negative consequences from reporting symptoms,[4, 10-12] or may not have been comfortable with communicating symptoms – with females shown to be more comfortable than males in such instances.[13] There has also been increased vigilance towards identifying concussions and greater guidance on concussion detection, leading to enhanced sensitivity of reporting.[8]

Sports-related concussions most commonly occur as a result of player-to-player contact.[14] In particular, collision sports such as boys American football has historically been shown to have the highest number of concussions, with special teams plays carrying an even greater concussion risk.[4, 14-16 17] The influence of younger age on concussion risk is currently not well understood, though it has been suggested that physiological differences between younger and older brains may make catastrophic injuries more likely in younger athletes.[16] Furthermore, previous studies have reported a higher incidence of concussions[8, 16] and elevated rates and severity of symptoms[13] among female athletes compared to male athletes, though more research is necessary to fully elucidate the underlying reasons for these findings.

This study sought to track gender- and sport-specific trends for organized high school sports-related concussion reports, identify risk factors for particular sports, and evaluate whether TBI law enactments have led to a greater awareness of this condition using a publically available database.

METHODS

Injury diagnosis and exposure data were collected prospectively during academic years 2005 through 2014 by the High School Reporting Information Online (RIO) injury surveillance system.[18] Using a protocol designed by High School RIO, this previously described[9, 19] system captures injury data directly from certified athletic trainers (ATs) at participating U.S. high schools. These schools were categorized by High School RIO into 1 of 8 sampling strata based on school size and geographic region. To obtain a representative national sample, High School RIO randomly selected 12 schools from each of the 4 "small" (<1000 students) strata and 13 schools from each of the 4 "big" strata (>1000 students), yielding a final study sample of 100 high schools.

Between academic years 2005 and 2014, High School RIO captured exposure and injury data for high school boys and girls participating in 9 sports: boys football, boys and girls soccer, girls volleyball, boys and girls basketball, boys wrestling, boys baseball, and girls softball. Exposure information (athlete-competitions, athlete-practices, and the number injuries for each sport) and injury information was reported online to High School RIO weekly by ATs at participating schools. Detailed information about the injured player (e.g., sport, age, year in school, etc.), the injury (e.g., diagnosis, severity, return to play, etc.), and the mechanism of injury and situation (e.g., phase of play, activity leading to injury, etc.) was all included in weekly AT injury reports. An athlete-

exposure (AE) was defined as one athlete participating in either one practice or competition. To produce representative national estimates, reported injuries were weighted by High School RIO to account for the total number of U.S. high schools that offer a given sport and the average number of participating study schools reporting each week for that sport. With the exception of injury rates, all reported values reflect weighted national estimates.

Starting in 2005, for an injury to be considered reportable, it must have (1) occurred as a result of participation in an organized high school competition or practice, (2) required evaluation by a physician or AT, and (3) resulted in one or more days restriction of the injured athlete's participation beyond the date of injury. After 2008, all concussions, fractures, and dental injuries were reported regardless of a student-athlete's time loss. The exact criteria used to diagnose a concussion were at the discretion of the local AT and physician.

Concussion diagnoses were reported in the current study both as an injury proportion and a concussion rate. Injury proportion was defined as the relative proportion of total estimated concussions to total estimated injuries while concussion rate was the number of concussions per 10,000 AEs. Cross-sport and cross-year comparisons were enabled by calculating an injury proportion ratio (IPR) and a concussion rate ratio (RR). Whereas the injury proportion draws only from the pool of injured athletes, the concussion rate uses AEs to account for the entire sample population at risk (including the uninjured), and thus describes the overall injury risk that an athlete is predisposed to in a given sport.[20] Participation data was obtained from the National Federation of State High School Associations.[1] Detailed information on state TBI legislation was obtained from LawAtlas.[21] The "pre-enactment era" was defined as academic years 2005 through 2009, as the first state TBI law was not enacted until July 2009.[21] Conversely, "post-enactment" denotes school years 2010 through 2014.

IBM SPSS Statistics software (version 24.0; IBM Inc., Armonk, New York, USA) was used for all statistical analyses. Concussion trends were analyzed using Student's *t*-Test, as well as linear regression for comparisons over time. For all statistical analyses, the threshold for significance was established at $p<0.05$ and 95% confidence intervals (CIs) not containing 1.0 were considered statistically significant. This study was deemed exempt by the Institutional Review Board as no identifiable patient information was collected and all data was obtained from publicly available sources.

SOURCE OF FUNDING

There were no external funding sources for this work.

RESULTS

Between the 2005 and 2014 school years, a total of 18,474,500 AEs and 40,843 injuries, including 6,399 concussions (3.46 concussions per 10,000 AEs), were reported to High School RIO by ATs from schools in the sample population. Injured student-athletes were on average 15.9±1.2 years old. Although total national participation rates for the 9 sports of interest increased only 1.04-fold ($p=0.004$) during the study period, the overall number of diagnosed concussions increased 2.2-fold ($p<0.0001$). Significant

increases in the overall concussion rate (RR=2.30, 95% CI [2.04-2.59]; $p<0.0001$) and the overall proportion of concussions (IPR=2.68, 95% CI [2.66-2.70]; $p<0.0001$) were seen between the first (2005-2006) and last (2014-2015) years of the study period (Table 1). A total of 8 sports demonstrated a statistically significant increase in concussion rates between the first and last years of the study period, including boys football ($p<0.0001$), boys soccer ($p=0.01$), girls soccer ($p=0.001$), girls volleyball ($p=0.001$), girls basketball ($p=0.002$), boys wrestling ($p=0.005$), boys baseball ($p=0.003$), and girls softball ($p=0.02$) (Figure 1). Between the first and last years, all 9 sports showed a significant increase in concussion proportion ($p<0.002$) (Figure 2). The most significant increase in concussion rate during the 10-year study period was observed for boys baseball (RR=6.13, 95% CI [2.11-17.79]; $p=0.0008$), and that of concussion proportion for girls volleyball (IPR=8.48, 95% CI [8.14-8.84]; $p<0.0001$) (Table 2).

In gender-matched sports, girls experienced significantly higher concussion rates and proportions compared to boys ($p<0.05$) (Table 3). During the 2005-2006 school year, boys football and girls soccer players demonstrated the highest concussion rates compared to all other sports (RR=3.26, 95% CI [2.67-3.99], $p<0.0001$; RR=1.75, 95% CI [1.30-2.34], $p=0.0002$, respectively).

Trends in concussion rates and proportions were analyzed pre- (2005-2009) and post-TBI law enactment (2010-2015). Both rate and proportion were significantly higher post-TBI law enactment ((RR=1.99, 95% CI [1.89-2.09]; $p<0.0001$) and (IPR=2.17, 95% CI [2.16-2.17]; $p<0.0001$), respectively). Among individual sports, 8 out of 9 showed a statistically significant increase in average concussion rates and proportions post-TBI laws ($p=0.02$) (Figure 3 and 4). During the post-TBI law years of the study, girls soccer players suffered a higher proportion of concussions than boys football players (IPR=1.13, 95% CI [1.13-1.13]; $p<0.0001$). Based on the IPR, during the 2014-2015 school year concussions were more common in girls soccer than any other sport ($p<0.0001$).

DISCUSSION

High school athletics predispose adolescents to a higher risk of sports-related injuries than the general population. Given the potential complications from concussions, trends regarding incidences and diagnoses can lead to interventions for prevention and treatment. The present study covers the most recent decade of data analyzing a nationally representative sample of high school athletes stratified by gender and sport.

The data in this study suggest that the overall rate of diagnosed concussions for high school athletes increased 2.3-fold and the proportion increased 2.7-fold during the 10-year study period, which is consistent with findings from a previous study.[9] This may be explained by several potential factors. First, the implementation state TBI laws in 2009 likely led to increased awareness and education for first responders (e.g., coaches, athletic trainers, and parents), increased recognition of symptoms by players, and a more open culture of communication within teams and schools. For example, as of 2015, 27 states require that coaches be trained in recognizing the symptoms of concussion and 34 states require annual distribution of a concussion information sheet.[21] Interestingly, 23 states also have provisions in their TBI laws that specifically address liability (e.g., for volunteers, coaches, school officials, and non-athlete participants).[21] More recently, the

topic of concussions has received greater mainstream media attention, which has likely also contributed to greater awareness of concussions and the seriousness of the injury.

While American football has been both scientifically and colloquially associated with a greater concussion risk than other sports,[4, 9, 14] our study suggests that other sports deserve attention in the prevention of this injury, such as girls soccer, which has been reported in a previous study.[17] Three possible reasons for the rise in concussion risk in girls soccer compared to boys football include the lack of protective gear, emphasis of in-game contact, and potential increase in headers during game play. It remains unclear why boys soccer players do not appear to have the same risk as girls.

High school girls appear to have a higher risk of a concussion diagnosis than boys, which has been supported by other studies.[8, 9, 14-16, 22] A number of possible explanations for this difference have been proposed, including reduced protective forces in females due to decreased head-neck segment mass and reduced neck strength and girth in females.[15] In sports such as soccer, it has also been suggested that females have a larger ball-to-head size ratio, which may predispose females to a higher risk of concussion compared to males.[15] There is also growing consensus in the literature that girls may experience increased symptom severity, protracted recovery, and may be more open with communicating symptoms than boys.[13, 15, 16] Currently, there is conflicting evidence regarding the role of estrogen in the pathophysiology of concussion with both neuroprotective and detrimental effects reported.[15]

Our findings suggest that the enactment of concussion laws may have had a varying degree of influence on diagnoses dependent upon sport. For example, girls volleyball and boys baseball had the greatest increase in both proportion and rate of diagnosis during the study period. One possible explanation for this finding is that these sports may have previously had a higher frequency of low-grade concussions that could have gone undiagnosed, as suggested by the low rates and proportions of concussions in these two sports during the 2005 school year (0.51 and 0.25, respectively; and 3.1% and 2.1%, respectively). While current recovery protocols are not standardized across school districts and are somewhat nebulous,[7] our data suggest that certain athlete populations should be targeted for measures of prevention and management. As it currently stands, no state laws have addressed age-, gender-, or sport-specific differences in the diagnosis of a concussion. Considering the unique demands of each athlete, protocols may need to be different to accommodate all sports effectively.

There are a number of well-recognized limitations with the methodology of this study. First, the High School RIO data that was analyzed only captures a small sample of the entire world's high school athlete population. The data only includes 9 sports played in the United States by approximately 58% of all high school student-athletes[1] and utilizes data from 100 sample schools compared to the 41,000+ public and private U.S. schools with secondary grades.[23] Consequently, there may be errors in imputation of this data. There were also changes in reportable injury criteria during the study period that may have altered inclusion criteria. Finally, the data used in this study from High School RIO reflects diagnostic and return-to-play protocols for concussion that were not standardized across schools, which may have affected incidence rates.

This study reports findings from the largest longitudinal data set for concussions in this patient population.[9, 14] As new evidence continues to emerge identifying additional risk factors and potential consequences of concussions in the adolescent population, it is

imperative that team physicians are precisely aware of the factors (e.g., sport, gender, position, playing style, etc.) that place athletes at the highest risk.

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TABLES

School Year	Participation[a]		No. Concussions[b]	Concussions/10,000 AEs[b]	Concussion (as % of total injuries)[b]
	Boys	Girls			
2005-2006	2,699,250	1,533,612	132,326	2.19	9.1%
2006-2007	2,773,492	1,573,879	122,629	2.17	8.2%
2007-2008	2,782,499	1,565,256	129,294	2.09	9.2%
2008-2009	2,781,834	1,562,507	146,123	2.33	11.7%
2009-2010	2,786,858	1,577,862	187,426	2.98	13.9%
2010-2011	2,797,393	1,583,356	237,931	3.97	20.0%
2011-2012	2,789,407	1,592,786	308,962	4.76	22.2%
2012-2013	2,781,239	1,587,348	314,331	4.85	23.4%
2013-2014	2,803,850	1,601,839	312,081	4.66	21.9%
2014-2015	2,802,440	1,601,464	292,632	5.03	24.3%

Table 1: Overall concussion trends among high school student-athletes participating in the 9 sports of interest between academic years 2005-2006 and 2014-2015. [a]Data obtained from the National Federation of State High School Associations for only those sports considered in this study. [b]Data obtained from High School RIO.

Sport	Concussions/ 10,000 AEs[a] 2005-2006	2014-2015	RR [95% CI]	Concussion (as % of total injuries)[a] 2005-2006	2014-2015	IPR [95% CI]
Boys Football	4.56	9.41	2.06 [1.74-2.44]*	10.5%	24.7%	2.36 [2.34-2.38]*
Boys Soccer	2.32	3.03	1.30 [0.84-2.00]	9.6%	18.9%	1.98 [1.95-2.01]*
Girls Soccer	3.58	9.10	2.52 [1.83-3.49]*	15.2%	34.5%	2.27 [2.24-2.30]*
Girls Volleyball	0.51	2.88	5.68 [2.42-13.29]*	3.1%	26.1%	8.48 [8.14-8.84]*
Boys Basketball	0.66	0.95	1.51 [0.76-2.99]	3.5%	8.8%	2.51 [2.41-2.62]*
Girls Basketball	2.39	4.23	1.79 [1.22-2.62]*	11.9%	25.6%	2.15 [2.11-2.20]*
Boys Wrestling	1.22	4.00	3.33 [1.99-5.57]*	4.9%	18.8%	3.85 [3.73-3.97]*
Boys Baseball	0.25	1.35	6.13 [2.11-17.79]*	2.1%	14.3%	6.83 [6.46-7.22]*
Girls Softball	0.47	1.83	4.09 [1.65-10.12]*	4.2%	18.3%	4.38 [4.20-4.57]*

Table 2: Comparison of concussion rates and proportions for individual sports during the 2005-2006 and 2014-2015 academic years. [a]Data obtained from High School RIO. *p<0.01.

School Year	Girls vs. Boys Soccer RR [95% CI]	IPR [95% CI]	Girls vs. Boys Basketball RR [95% CI]	IPR [95% CI]
2005-2006	1.53 [1.00-2.35]*	1.59 [1.56-1.61]*	3.69 [2.02-6.73]*	3.41 [3.29-3.53]*
2014-2015	2.99 [2.16-4.14]*	1.82 [1.80-1.85]*	4.36 [2.64-7.20]*	2.92 [2.83-3.00]*

Table 3: Comparison of concussion rates and proportions between gender-matched sports during the 2005-2006 and 2014-2015 academic years. *p<0.05.

FIGURES

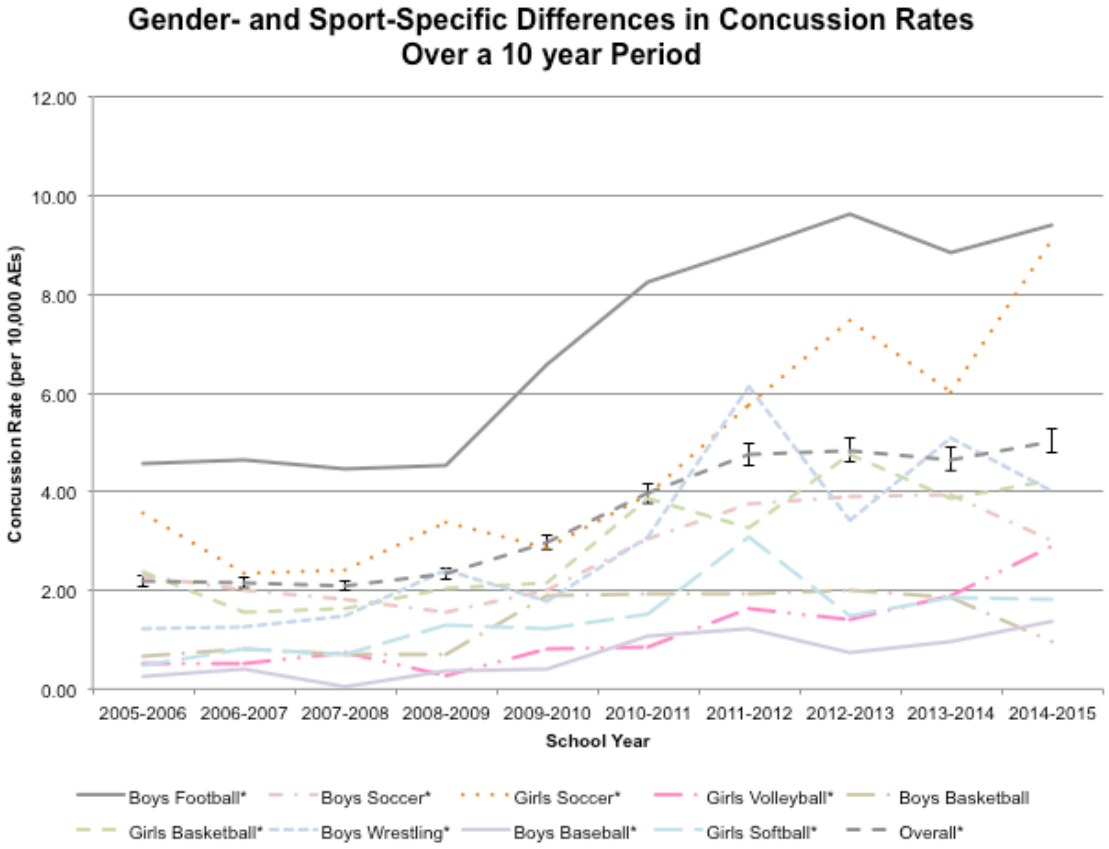

Figure 1: Gender- and sport-specific differences in concussion rates reported by High School RIO from 2005-2006 through 2014-2015. 95% CIs shown for overall rates. *p<0.05.

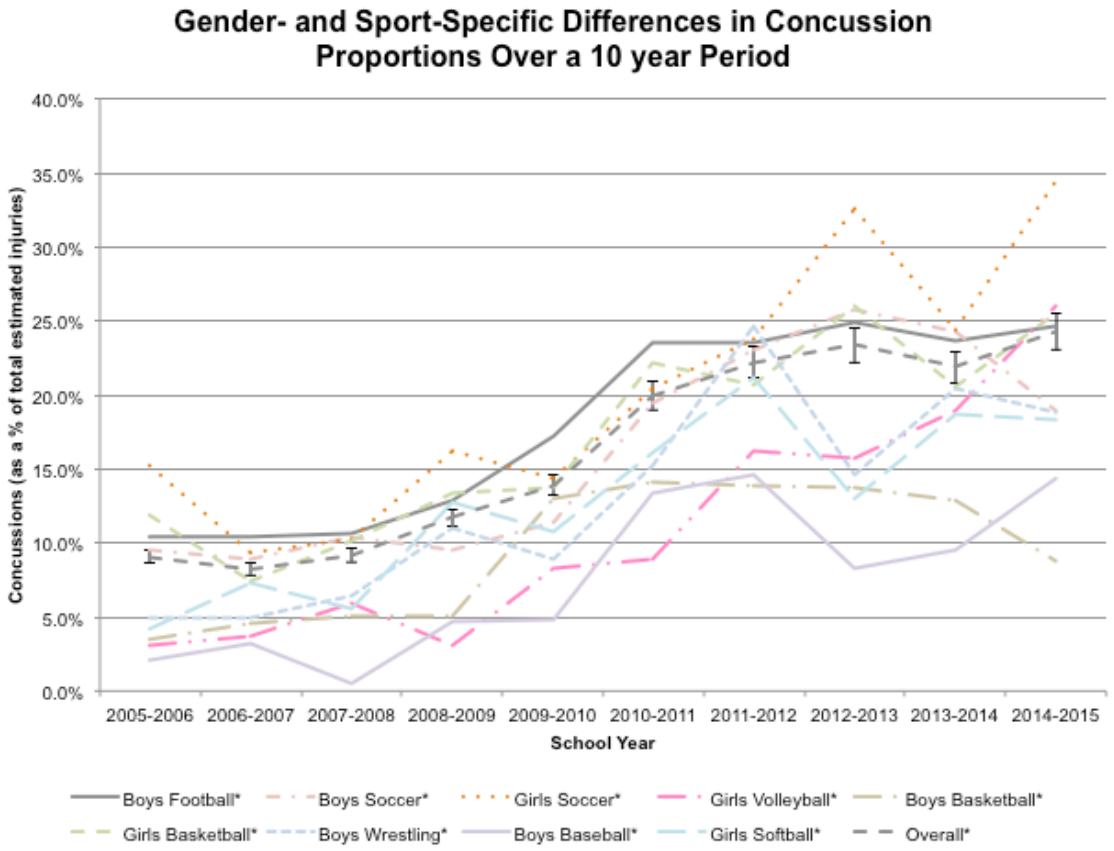

Figure 2: Gender- and sport-specific differences in concussion proportions reported by High School RIO from 2005-2006 through 2014-2015. 95% CIs shown for overall proportions. *$p<0.05$.

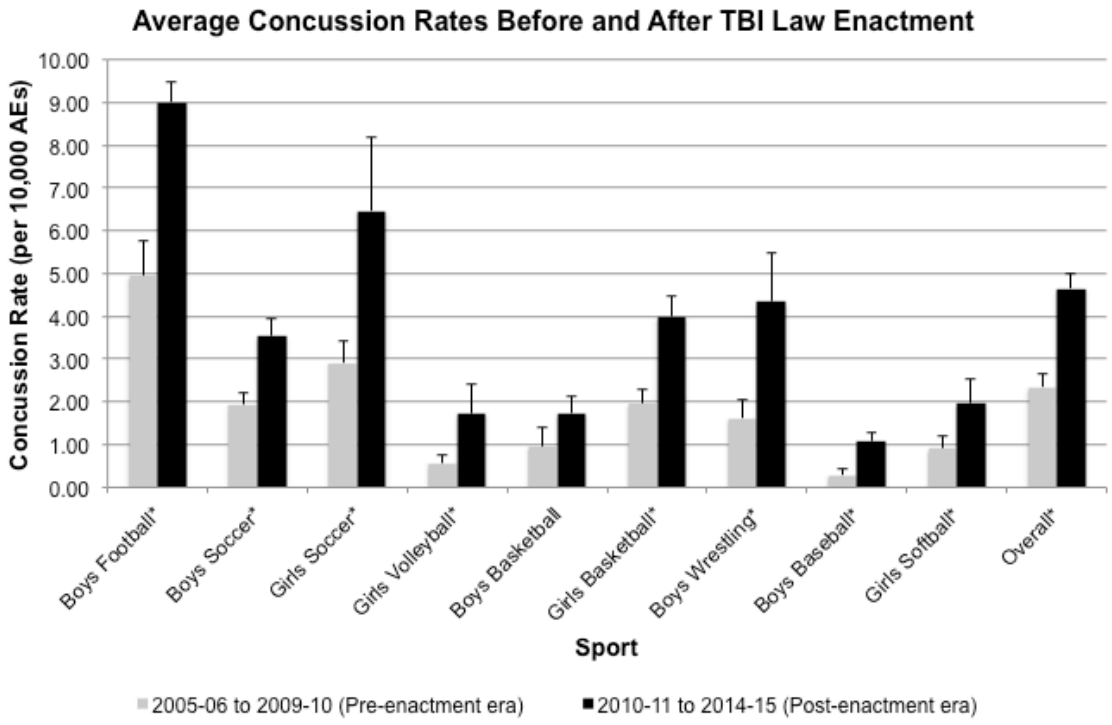

Figure 3: Gender- and sport-specific differences in average concussion rates reported by High School RIO before and after state TBI law enactments. **p*<0.05.

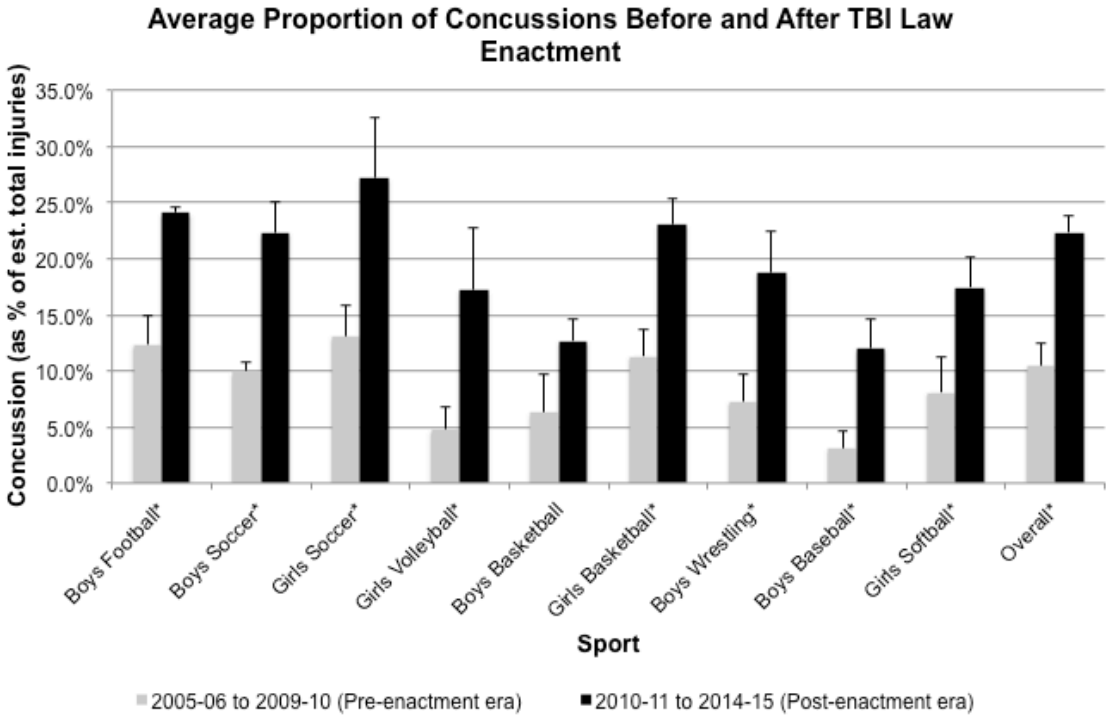

Figure 4: Gender- and sport-specific differences in average concussion proportions reported by High School RIO before and after state TBI law enactments. **p*<0.05.