Concussion Epidemiology in Youth Sports: Sports Study of a Statewide High School Sports Program

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Background: Current research on concussion incidence in youth athletes (age <18 years) is small and limited by variability in injury reporting and diagnostic methodology.

Hypothesis: Concussion injuries commonly occur in high school sports programs. The likelihood of concussion among student-athletes (aged 13-18 years) depends on the sport they are participating in as well as the sex of the athlete.

Study Design: Descriptive epidemiology study.

Methods: A retrospective analysis of all Hawaii high school athletes aged 13 to 18 years participating in 14 sports from 2011 through 2017 was performed as part of a statewide standardized concussion assessment and management program.

Results: A total of 5993 concussions were identified among 92,966 athletes. The overall concussion rate was 0.96 (95% CI, 0.94-0.99). Girls' judo had the highest concussion rate (1.92; 95% CI, 1.68-2.17) followed by football (1.60; 95% CI, 1.53-1.66). The concussion rate for boys (1.0; 95% CI, 0.97-1.03) was higher than that for girls (0.91; 95% CI, 0.87-0.95); however, in 4 of the 5 sports in which both girls and boys participated, girls had a higher rate of concussion injury.

Conclusion: The likelihood of concussion among student-athletes aged 13 to 18 years may be higher than previously thought and varies depending on sport and sex.

Clinical Relevance: Epidemiologic data on concussion injury in children and adolescents are useful in accurately determining the relative risks of high school sports participation and may be valuable in determining the appropriate allocation of health care and scholastic resources for student-athletes, as well as the impact of rule and training modifications designed to improve participant safety.

Keywords: concussion; adolescent; high school athlete; epidemiology; concussion risk; concussion rate

The majority of sports-related concussions are presumed to occur in the youth population, reported as 8.9% to 12.6% of all athletic injuries in US high schools.[4-6,8,9] In 2016-2017, the number of participants in high school sports increased to an all-time high of 7,963,595.[18] However, concerns regarding concussion underreporting remain.[2,5,7,13] Two-thirds of high schools in the United States currently lack a full-time certified athletic trainer (AT), and up to 30% do not have any access to an AT experienced in identifying concussion injuries.[17]

Research focusing on concussion injury incidence and risk in youth athletes remains relatively small[7,20] due to the limited number of studies available for each sport and the variability in study design and statistical analysis.[7] Therefore, the aim of this study was to report the year-to-year incidence of concussions across a statewide high school sports program with a standardized evaluation and management protocol (based on international consensus guidelines) and to determine relative incidence rates and risk based on sex and sport.

METHODS

The Research Determination Committee for the Kaiser Permanente Hawaii region reviewed this project and determined that it did not meet the regulatory definition of research

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Table 1. Athlete participation by sport and academic year

Sport	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	Total (2011-2017)
Football (boys)	3545	3502	3545	3364	3340	3303	20,599
Soccer (girls)	1341	1407	1486	1335	1295	1216	8080
Baseball (boys)	1273	1350	1376	1299	1323	1272	7893
Volleyball (girls)	1267	1372	1412	1259	1328	1168	7806
Softball (girls)	1225	1282	1282	1141	1192	1108	7230
Basketball (boys)	1129	1127	1165	1099	1074	1095	6689
Soccer (boys)	993	1028	1076	1062	1247	1250	6656
Basketball (girls)	934	929	956	851	918	811	5399
Wrestling (boys)	961	916	944	901	804	757	5283
Volleyball (boys)	794	782	818	941	989	933	5257
Cheerleading (girls)	897	942	814	654	571	562	4440
Judo (boys)	550	567	448	522	497	513	3097
Wrestling (girls)	418	386	381	401	450	466	2502
Judo (girls)	343	333	318	325	369	347	2035
Total	15,670	15,923	16,021	15,154	15,397	14,801	92,966

involving human participants and therefore did not require review by an institutional review board.

The state of Hawaii is unique in the United States for having the Hawaii Department of Education (HIDOE), a single unified public school system, with at least 1 AT assigned to every school. All athletes participate in baseline computerized neurocognitive testing. HIDOE rules and state law mandate immediate removal of all athletes suspected of concussion from sports participation. Each injured athlete is assessed by an AT, and those meeting clinical criteria for concussion injury[14-16] complete a postinjury computerized neurocognitive test (Immediate Post-Concussion Assessment and Cognitive Testing [ImPACT Posttest 1]).

We performed a retrospective analysis of all HIDOE high school student-athletes aged 13 to 18 years who entered the HIDOE concussion management protocol from academic years 2011-2012 through 2016-2017. The athlete's data were recorded in the online ImPACT database maintained by the Hawaii Concussion Awareness and Management Program. A concussion was defined by the evaluating AT to be consistent with diagnostic criteria as outlined by international consensus guidelines.[14-16] An athlete-exposure (AE) was defined as 1 student-athlete participating in 1 Hawaii High School Athletics Association (HHSAA) and HIDOE-sanctioned practice or competition in which he or she was exposed to the possibility of athletic injury, regardless of the participation duration.[10]

ImPACT Posttest 1 registration information with deidentified data was compiled to determine the total number of concussions identified by academic year, sport, and sex. Concussion incidence was determined by calculating the concussion injury rate (the number of concussions divided by the number of AEs) and was reported as number of concussions per 1000 AEs. AEs for a given sport in a given year were determined using estimates for the number of practices and games per season based on HHSAA season start and end dates and game schedules. The total number of athletes participating per sport per year was obtained from eligibility lists submitted by each HIDOE school for each sports season as reported to the HIDOE athletics office.

Finally, concussion risk was calculated as the number of concussed student-athletes divided by the number of athlete seasons, and was reported as the 1-season risk of concussion.[10]

RESULTS

The study population included 92,966 athletes from 63 schools across the state of Hawaii from 2011 to 2017 (Table 1). The total number of concussions identified over the 6-year study period was 5993, or 6.4% of participants (Table 2). The number of concussions per year by sex is presented in Figure 1.

The concussion rate per sport and per year and the pooled concussion rate for the 6-year study period was calculated, with

Table 2. Number of concussions by sport and sex per academic year

Sport	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	Total	% Total
Football (boys)	394	441	436	357	309	365	2302	38.41
Soccer (girls)	81	106	130	78	89	95	579	9.66
Cheerleading (girls)	47	66	86	53	50	103	405	6.75
Wrestling (boys)	60	78	79	56	65	52	390	6.5
Basketball (girls)	31	58	100	54	70	63	381	6.35
Soccer (boys)	41	50	59	53	55	41	299	4.98
Volleyball (girls)	24	44	56	51	45	57	273	4.55
Softball (girls)	30	42	63	54	41	37	267	4.45
Basketball (boys)	31	39	72	44	26	36	248	4.1
Judo (girls)	42	40	57	39	40	27	235	3.92
Judo (boys)	27	38	48	49	40	27	219	3.65
Baseball (boys)	15	38	37	31	32	25	178	2.97
Wrestling (girls)	27	23	33	17	36	29	165	2.75
Volleyball (boys)	9	8	6	11	13	5	52	0.86
Total	859	1071	1262	947	911	962	5993	

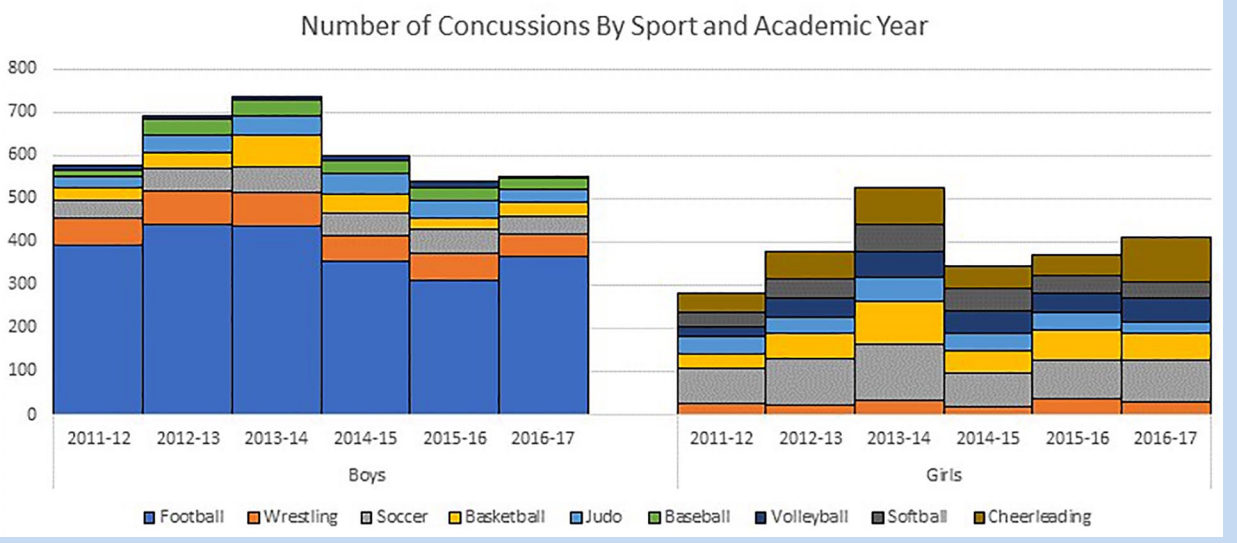

Figure 1. Number of concussions by sex.

results shown in Table 3 and Figure 2. The pooled concussion rate for boys' sports was higher overall than for girls' sports (Table 3), and this was statistically significant ($P < 0.01$). However, in 4 of the 5 sports monitored in which both girls and boys participated, girls had a statistically significant higher rate of concussion injury than boys: judo ($P < 0.01$), soccer ($P < 0.01$), basketball ($P < 0.01$), and volleyball ($P < 0.01$). The difference in concussion rate between girls and boys

Table 3. Annual concussion rate per sport and sex per 1000 athlete-exposures (95% CI)

Sport	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	Total
Judo (girls)	2.04 (1.42, 2.66)	2.00 (1.38, 2.62)	2.99 (2.21, 3.76)	2 (1.37, 2.63)	1.81 (1.25, 2.37)	1.30 (0.81, 1.79)	1.92 (1.68, 2.17)
Football (boys)	1.59 (1.43, 1.74)	1.80 (1.63, 2.00)	1.76 (1.59, 1.92)	1.52 (1.36, 1.67)	1.32 (1.17, 1.47)	1.58 (1.42, 1.74)	1.60 (1.53, 1.66)
Judo (boys)	0.82 (0.51, 1.13)	1.12 (0.76, 1.47)	1.79 (1.28, 2.29)	1.56 (1.13, 2.00)	1.34 (0.93, 1.76)	0.88 (0.55, 1.21)	1.18 (1.02, 1.33)
Wrestling (boys)	0.96 (0.71, 1.20)	1.31 (1.02, 1.60)	1.29 (1.00, 1.57)	0.96 (0.71, 1.21)	1.24 (0.94, 1.55)	1.06 (0.77, 1.34)	1.14 (1.02, 1.25)
Soccer (girls)	0.93 (0.73, 1.13)	1.16 (0.94, 1.38)	1.35 (1.11, 1.58)	0.90 (0.70, 1.10)	1.06 (0.84, 1.28)	1.20 (0.96, 1.44)	1.10 (1.01, 1.19)
Basketball (girls)	0.51 (0.33, 0.69)	0.96 (0.71, 1.21)	1.61 (1.29, 1.92)	0.98 (0.72, 1.24)	1.17 (0.90, 1.45)	1.20 (0.90, 1.49)	1.09 (0.98, 1.19)
Cheerleading (girls)	0.58 (0.42, 0.75)	0.78 (0.59, 0.97)	1.17 (0.93, 1.42)	0.90 (0.66, 1.14)	0.97 (0.70, 1.24)	2.04 (1.64, 2.43)	1.01 (0.91, 1.11)
Wrestling (girls)	0.99 (0.62, 1.37)	0.92 (0.54, 1.29)	1.33 (0.88, 1.79)	0.65 (0.34, 0.96)	1.23 (0.83, 1.63)	0.96 (0.61, 1.31)	1.01 (0.86, 1.17)
Soccer (boys)	0.64 (0.44, 0.83)	0.75 (0.54, 0.96)	0.84 (0.63, 1.06)	0.77 (0.56, 0.97)	0.68 (0.50, 0.86)	0.50 (0.35, 0.68)	0.69 (0.61, 0.77)
Softball (girls)	0.38 (0.24, 0.51)	0.50 (0.35, 0.66)	0.76 (0.57, 0.94)	0.73 (0.53, 0.92)	0.53 (0.37, 0.69)	0.51 (0.35, 0.68)	0.57 (0.50, 0.64)
Basketball (boys)	0.42 (0.27, 0.57)	0.53 (0.37, 0.70)	0.95 (0.73, 1.17)	0.62 (0.43, 0.80)	0.37 (0.23, 0.52)	0.51 (0.34, 0.67)	0.57 (0.50, 0.64)
Volleyball (girls)	0.29 (0.17, 0.41)	0.49 (0.35, 0.64)	0.61 (0.45, 0.77)	0.62 (0.45, 0.79)	0.52 (0.37, 0.67)	0.75 (0.56, 0.95)	0.54 (0.47, 0.60)
Baseball (boys)	0.18 (0.09, 0.27)	0.43 (0.30, 0.57)	0.41 (0.13, 0.55)	0.37 (0.24, 0.50)	0.37 (0.24, 0.50)	0.30 (0.18, 0.42)	0.35 (0.30, 0.40)
Volleyball (boys)	0.17 (0.06, 0.29)	0.16 (0.05, 0.27)	0.11 (0.02, 0.20)	0.18 (0.07, 0.29)	0.20 (0.09, 0.31)	0.08 (0.01, 0.15)	0.15 (0.11, 0.19)
Total	0.81 (0.76, 0.87)	1.00 (0.94, 1.06)	1.17 (1.11, 1.24)	0.93 (0.87, 0.99)	0.89 (0.83, 0.94)	0.97 (0.91, 1.03)	0.96 (0.94, 0.99)
Boys' sports							1.00 (0.97, 1.03)
Girls' sports							0.91 (0.87, 0.95)

participating in wrestling over the 6-year study period was not statistically significant ($P = 0.22$).

The 6-year pooled concussion injury risk per athlete-season was calculated for each sport, as shown in Table 4. Overall concussion injury risk was 6.45% for the entire group of participants, with boys at higher statistical risk than girls (6.65 vs 6.15; $P < 0.01$). However, once again, in 4 of the 5 sports monitored in which both girls and boys participated, girls had a statistically significant higher risk of concussion injury than boys: judo ($P < 0.01$), soccer ($P < 0.01$), basketball ($P < 0.01$), and volleyball ($P < 0.01$). The difference in pooled concussion injury risk between girls and boys participating in wrestling was not statistically significant ($P = 0.21$).

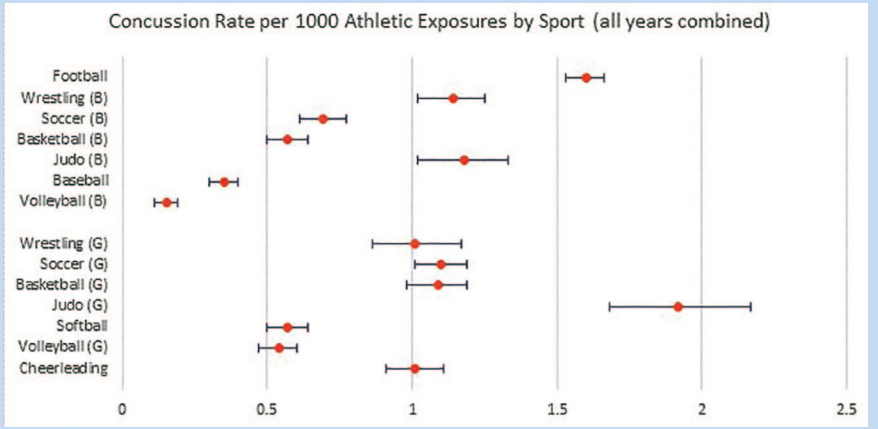

Figure 2. Six-year pooled concussion rates by sport and sex with 95% CIs.

Table 4. Pooled concussion injury risk (%)

Sport	Pooled Athlete-Seasons	No. of Concussions	Concussion Injury Risk, % (95% CI)
Judo (girls)	2035	235	11.55 (11.52, 11.58)
Football (boys)	20,599	2302	11.18 (11.17, 11.18)
Cheerleading (girls)	4440	405	9.12 (9.11, 9.13)
Wrestling (boys)	5283	390	7.38 (7.37, 7.39)
Soccer (girls)	8080	579	7.17 (7.16, 7.17)
Judo (boys)	3097	219	7.07 (7.06, 7.09)
Basketball (girls)	5399	381	7.06 (7.05, 7.07)
Wrestling (girls)	2502	165	6.59 (6.58, 6.61)
Soccer (boys)	6656	299	4.49 (4.49, 4.50)
Basketball (boys)	6689	248	3.71 (3.70, 3.71)
Softball (girls)	7230	267	3.69 (3.69, 3.70)
Volleyball (girls)	7806	273	3.50 (3.49, 3.50)
Baseball (boys)	7893	178	2.26 (2.25, 2.26)
Volleyball (boys)	5257	52	0.99 (0.99, 0.99)
Boys' sports	55,474	3688	6.65 (6.65, 6.65)
Girls' sports	37,492	2305	6.15 (6.15, 6.15)
Total	92,966	5993	6.45 (6.45, 6.45)

DISCUSSION

In studies on high school sports, the largest proportion of concussions occurs in football athletes, ranging from 33.6% to 63.4% of all diagnosed concussions.[4,5,11,12,21,23,24] In this study, the highest number of concussions also occurred in football. The next highest number of concussions occurred in girls' soccer. This is consistent with other studies in which girls' soccer

athletes typically represent the second largest group of concussed athletes behind football, representing 6.2% to 12.9% of concussion injuries.[4,11,12,21,24]

Concussion injury rates per 1000 AEs in high school athletic programs are between 0.17 and 0.43.[7,19] In this study, the overall concussion rate across a statewide program was significantly higher than previously reported. Other investigators have observed rising concussion injury rates from year to year: a 3.4- to 5.2-fold increase between 1997 and 2008[11] and from 0.23 in 2005-2006 to 0.51 in 2011-2012.[22] This study is consistent with these higher concussion rates but did not demonstrate a further statistically significant trend over the 6-year study period. This might reflect consistency and familiarity with consensus-based management protocols in recent years.

The majority of studies on youth sports concussion report the highest rates in high-speed collision sports, such as football.[4,5,7,8,11,12,19,21] The concussion incidence rate for football across the state of Hawaii is significantly higher than previously reported (range, 0.33-0.92),[4,11,12,19,23] though consistent with those studies that specifically looked at concussions occurring during game play (range, 1.55-2.82).[4,12,19,21,23]

While expected, the largest number of concussions were sustained in football players. When considering the relative danger of a particular sport, the highest concussion incidence rate overall was in girls' judo. Judo had the least number of participants among the girls' sports (see Table 1) and is uniquely represented in high school competition in the state of Hawaii.[18] Studies reporting youth injury surveillance data in martial arts show higher prevalence of concussion in judo.[25] Athletes are more likely to be injured while being thrown to the mat or flipped, compared with karate.[25]

This study was consistent with others, showing the lowest incidence of concussion in volleyball and baseball.[20] Studies that have included swimming and track and field participation have found even lower rates in those athletes.[4,12,23]

Existing literature has consistently demonstrated sex-based differences in concussion injury risk and incidence rates, with female athletes sustaining more concussion injuries per AE than their male counterparts for comparable sports played with similar rules.[1,3,12,19,24] Girls had 1.6 to 3.6 times the rate of concussion injury versus boys in 4 of the 5 sports in which they both competed (judo, soccer, basketball, and volleyball). Volleyball demonstrated the greatest sex-based disparity in injury rates. However, when evaluating the entirety of the state high school competitive sports program, boys had a higher overall rate and risk of concussion injury than girls.

There are multiple limitations to this study. Most important, ImPACT Posttest 1 data were utilized to identify athletes who entered the HIDOE concussion management protocol based on the evaluating AT's clinical suspicion per international consensus guidelines.[14-16] The study design did not confirm diagnosis of concussion on subsequent physician evaluation. As concussion remains a clinical diagnosis, this study may have included a small number of athletes whom the treating physician did not feel met enough clinical criteria to warrant the diagnosis, though they were initially held out of play and submitted to postinjury testing per the HIDOE protocol based on initial AT evaluation and an abundance of caution. Nevertheless, this study does accurately reflect the impact of the International Conference on Concussion removal-from-play guidelines[14]: "when in doubt, sit them out."

Additionally, because athletes were not individually identified, we were unable to account for instances in which a single athlete may have had more than 1 concussion within the same season of his or her sport, a known factor increasing the risk or probability of concussion injury after return to play.[5,8] This study also did not explicitly differentiate between concussions sustained during practice or play and those sustained by athletes outside of sports participation that required AT evaluation during the season. This is, however, representative of the real-world experience for care delivery teams in high school athletics.

CONCLUSION

The likelihood of concussion among student-athletes (aged 13-18 years) depends on the sport they are participating in as well as the sex of the athlete.

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