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Incidence and Risk of Concussions in Youth Athletes: Comparisons of Age, Sex, Concussion History, Sport, and Football Position

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Abstract

Objective: This study was designed to determine concussion incidence, risk, and relative risk among middle and high school athletes participating in various sports.
Method: Data were retrospectively obtained from 10,334 athletes of 12 different sports in Hawaii. In addition to determining the overall concussion incidence, comparisons of incidence, risk, and relative risk were made according to age, sex, concussion history, sport, and football position.
Results: The overall incidence of concussion among youth athletes was 1,250 (12.1%). The relative risk for a concussion was almost two times greater in 18-year olds than in 13-year-old athletes. In comparable sports, girls had a 1.5 times higher concussion risk than boys. Athletes with a prior concussion had 3–5 times greater risk to sustain a concussion than those with no history of a concussion. Among varied sports, wrestling and martial arts had the highest relative risk of a concussion, followed by cheerleading, football, and track and field. No differences in concussion risks were found among the football players in different positions.
Conclusions: Older youths, females, those with a history of concussion, and those participating in high contact sports were found to have higher risks of sustaining a concussion. The findings increase awareness of concussion patterns in young athletes and raise concerns regarding protective strategies and concussion management in youth sports.

Keywords: Concussion; Risks; Sports; Youth

Introduction

In the past decade, sports-related concussions have drawn considerable attention from the public, the media, state legislatures, and sports medicine. Epidemiological reports provide convincing evidence that numerous concussions occur at all levels of sport activity (Bakhos, Lockhart, Myers, & Linakis, 2010; Covassin & Elbin, 2011; O'Connor et al., 2017; Stewart, Gilliland, & Fraser, 2014). Public concern grows as concussion rates (CRs), typically defined as the number of concussions divided by the number of athlete exposures (AEs) or participation in a practice or competition, have risen in recent years (Comstock, Curie, & Pierpont, 2017; Lincoln et al., 2011; Zuckerman et al., 2015). The increasing trend may be due to greater participation in sports and recreation, more concussion education, improved recognition of concussive events, and new concussion management policies, but also to more concussions due to bigger, stronger, and faster athletes with greater magnitude of head collisions (Daneshvar, Nowinski, McKee, & Cantu, 2011; Houck et al., 2016). Factors such as age, sex, concussion history, sport played, and football position appear to be related to the occurrence of sport concussions.

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Age

Several recent epidemiologic reports of concussions among youth athletes have been published (Lincoln et al., 2011; Meehan, d'Hemecourt, & Comstock, 2010; O'Connor et al., 2017; Rosenthal, Foraker, Collins, & Comstock, 2014), with data pertaining to age and varying in content and consistency. Some researchers have found CRs to be higher among high school athletes than college athletes (Dompier, Kerr, & Marshall, 2015; Shankar, Fields, Collins, Dick, & Comstock, 2007; Webbe & Barth, 2003), while others indicated higher CRs in college athletes compared to high school athletes (Gessel, Fields, Collins, Dick, & Comstock, 2007; O'Connor et al., 2017). Reports have variably placed the highest rates of sport-related traumatic brain injury in the 10–14 year-old age group (Centers for Disease Control and Prevention, 2007; Stewart et al., 2014), in the 12–14-year-old range (Kontos et al., 2016), in the 14–19 years age range (Bakhos et al., 2010), and in the 15 to 24-year-old range (Thurman, Branche, & Sniezek, 1998). In sum, studies of youth sports concussion reveal varied and conflicting findings regarding age, probably due to the differences in research methodology.

Sex

In sports medicine literature, CRs have been found generally to be higher in male athletes (Langlois, Rutland-Brown, & Wald, 2006; Thurman et al., 1998), but in comparable sports females were consistently reported to have a similar or higher CRs than males (Marar, McIlvain, Fields, & Comstock, 2012; Noble & Hesdorffer, 2013; O'Connor et al., 2017; Rosenthal et al., 2014). Overall, past studies suggest that CRs are higher in female athletes than males participating in comparable sports.

Concussion History

Previous investigations have consistently found that individuals with a prior concussion have a greater risk to encounter another concussion than those who have had no prior concussion. In a longitudinal study of 11,867 head injured children, investigators found that having a head injury increases the risk of having a subsequent head injury (Swaine et al., 2007). Similarly, high school athletes with a history of a concussion are more prone to sustain a subsequent concussion than those who have had no previous concussion (Collins et al., 2002; Schulz et al., 2004). Researchers have found that high school players who sustain a concussion are 3–6 times more likely to sustain another concussion than those who had not had any concussion (Guskiewicz, Weaver, Padua, & Garrett, 2000; Zemper, 2003), and that among concussed high school athletes, 10.5% were recurrent (Meehan et al., 2010). A recent epidemiologic study of concussion in seven high school and collegiate sports found that athletes with a history of one concussion in the previous 24 months had over twice the rate of concussion compared to those with no prior concussion, and those with two or more previous concussions had a five times higher rate (Marshall, Guskiewicz, Shankar, McCrea, & Cantu, 2015).

Sport Activities

Studies have found varying CRs across different high school sports. In many reports, the high school sport with the highest CR is football (e.g., Marar et al., 2012; Noble & Hesdorffer, 2013; O'Connor et al., 2017; Rosenthal et al., 2014), with lower CRs observed in non-contact sports, such as volleyball, baseball, and swimming. However, a MEDLINE search from 1985–2000 stated that among high school male team sports, ice hockey athletes had the highest CR (3.6 per 1,000 AEs), while soccer athletes had the lowest CR (0.18 per 1,000 AEs) (Tommasone & Valovich McLeod, 2006). In another report, CRs were found to be highest in ice hockey and football in 12–17-year olds (Bakhos et al., 2010). Finally, the High School Reporting Information Online Injury Surveillance System (Comstock, Currie & Pierpoint, 2017) that collects data on 9 sports from 100 randomly chosen study schools reported that, in the 2015–2016 school year, CRs were highest in girls soccer (40.5%), girls basketball (31.7%), wrestling (28.3%), and football (27.5%). Overall, the sports medicine literature indicates that CRs differ among high school sports, reflecting the varying degrees of head impacts inherent in each sport (Harmon et al., 2013; Koh, Cassidy, & Watkinson, 2003).

Football Positions

Researchers have noted that the position on a team, particularly in football, seems to affect the risk of concussion. Within high school football, more concussions are found with linebackers and running backs than those in other positions (Gessel

et al., 2007; Marar et al., 2012), possibly due to their sustaining more frequent collision impacts (Broglio et al., 2011). A 3-year study of 23,566 high school sports-related concussions revealed that the largest proportion of mild traumatic brain injuries occurred among linebackers, running backs, and offensive linemen (Powell & Barber-Foss, 1999). The few available data on high school football players suggest that more concussions are sustained by linebackers and running backs compared to other football positions.

A report on sports-related concussion by the Institute of Medicine underlined the need for more comprehensive incidence data in young athletes (Graham, Rivara, Ford, & Spicer, 2014). To date, there is limited research on the incidence of sports concussions that occurs across the wide range of youth sports, particularly non-contact sports, like tennis or cross country. The aim of this study was, first, to determine concussion incidence, risk, and relative risk (RR) among middle and high school athletes covering a broad spectrum of sports. Epidemiologic reports of sport concussions typically cover the popular sports of football, basketball, soccer, baseball/softball, volleyball, and wrestling. In addition to these sports, this research examined other sport activities that are not usually evaluated, that is, cross country, cheerleading, track and field, water polo, and tennis. Secondly, this research assessed differences in concussion incidences, risks, and RRs across the various sports according to age, sex, concussion history, sport, and football position.

Method

The 10,334 participants in this research were athletes from schools who represented 67 public and private middle and high schools in the State of Hawaii. Data for this study were obtained from the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) that athletes underwent prior to their respective sport seasons in the 2013–2014 school year. ImPACT was administered in groups of 20 or fewer athletes, supervised by certified athletic trainers who were trained to administer this computerized neuropsychological battery in a standardized manner. Biopsychosocial data yielded by ImPACT included age, sex, sport played, football position, prior concussion and date of head injury. Approval for the use of the research data was granted by the State of Hawaii Department of Education. The study was reviewed by the Hawai'i Pacific Health Research Institute and was determined to be exempt from Institutional Review Board review.

Participants

The subjects for this study were 5,938 males and 4,396 females, grades 8–12. The mean age was 15.5 years (SD = 1.3). Participants included 250 male and 262 female 13-year-olds, 1,295 male and 1,057 female 14-year-olds, 1,414 male and 1,063 female 15-year-olds, 1,456 male and 1,014 female 16-year-olds, 1,148 male and 796 female 17-year-olds, and 375 male and 204 female 18-year-olds.

The number of athletes in the varied sports was football (n = 2,724), soccer (n = 1,681), volleyball (n = 1,202), basketball (n = 1,329), wrestling/martial arts (n = 980), baseball (n = 532), softball (n = 441), cheerleading (n = 533), water polo (n = 275), tennis (n = 140), track and field (n = 137), and cross country (n = 126). There were 234 who did not specify the sport in which they participated.

From a pool of 10,334 participants in this research, 1,250 (12.1%) athletes sustained a concussion during their season. Concussions were typically observed by the team staff and directly evaluated by the athletic trainer. A minority of athletes experienced concussive symptoms after a game or practice, and reported their conditions that were assessed by the athletic trainer. All of the concussed athletes underwent post-injury ImPACT testing. Certified athletic trainers at all of the schools were available to verify the concussive events, adhering to the criteria provided by the consensus statement on concussion (McCrory et al., 2013). Athletic trainers, having been certified to identify a concussion, received annual continuing education through the Hawaii Concussion Awareness and Management Program, a state-funded community program that provides the Hawaii's high school sports medical staffs with updated education to recognize and manage school-related sport concussions. Of the total sample, 8,580 reported having no previous concussion, 1,299 had one previous concussion, 300 had two previous concussions, and 111 had three or more previous concussions. There were 44 athletes with missing data regarding history of concussions.

Statistical Analyses

This study calculated concussion incidence, risk, and RRs for age groups, sex, concussion history, sport, and football position, with data provided by the Hawaii ImPACT database. Incidence refers to an injury occurring in a practice or competition requiring attention from an athletic trainer or team physician. In this study, incidence proportion, or risk, reported in

percentage, was calculated by dividing the number of athletes who incur a concussion during the season by the number of athletes who participated in the sport. Risk is a valid estimate of the probability of injury and is readily understood, but it is less often used in sports medicine literature because of its difficulty in comparing injury risk in different sports (Knowles, Marshall, & Guskiewicz, 2006). RR of a concussion was calculated by dividing the concussion risk of a group (e.g., 18 year-olds) by the risk of a reference or comparison group (e.g., 13-year olds). In addition, adjusted RR (ARR) was calculated via regression analyses to control for relevant factors, such as age, sex and sport. Ninety five percent confidence intervals (CI) were generated for RRs and ARRs. Statistical significance was set at $p < 0.05$.

Results

In the varied sports studied over the school year, 1,250 (12.1%) athletes incurred a concussion. Concussion risks were highest in the 18-year-old range (18.1%) and lowest in the 13-year-old (7.8%) and 14-year-old (7.6%) ranges. The ARR for concussion, adjusted for sex and sport, for the 18-year olds was found to be nearly two times greater than for 13- and 14-year olds (ARR = 1.91, $p = 0.0003$). Risk, RR, and ARR results, with 13-year olds as the reference group, are shown in Table 1.

In sports played by both sexes, girls had significantly higher concussion risks than boys in three comparable sports: basketball (14.8%), soccer (13.3%), and softball (12.8). The ARR for girls in all sports, including comparable sports, was 1½ times greater than boys (ARR = 1.50, $p < 0.0001$). The risks, RRs, and ARRs, adjusted for age and sport (with boys as the reference group), are shown in Table 2.

Of the 8,580 who reported no prior concussions, 611 (7.1%) had a concussion during the 2013–2014 school year. Of the 1,299 who reported one prior concussion, 436 (33.6%) had a concussion during the school year. Of the 300 who reported two prior concussions, 127 (42.3%) received a concussion. Of the 111 who reported three or more prior concussions, 33 (29.7%) sustained a concussion during the school year. The ARR, adjusted for sex and sport, of those with two self-reported prior concussions was 5.07 times greater than those with no self-reported prior concussion, while athletes with one self-reported prior concussion had an ARR which was 4.34 times greater than those with no self-reported prior concussion, and those with three or more self-reported prior concussions had an ARR which was 3.72 times greater than those with no self-reported previous concussion. The risks, RRs, and ARRs for the self-reported concussion groups, with the no concussion group as the reference, are presented in Table 3.

From among the various sports, the highest concussion risks were from participation in wrestling/martial arts (20.8%), followed by cheerleading (15.9%), and football (15.4%). The lowest risks were in cross country (3.2%), tennis (3.6%), and water polo (4.0%). Table 4 shows the risks, RRs, and ARRs by sports, adjusted for age and sex, with cross country as the reference group. Wrestling and martial arts obtained ARRs that were 6.07 times greater than cross country, followed by football (5.68) and track and field (4.24). Lowest ARR ratios were in water polo (1.00), tennis (1.10), and volleyball (1.35).

Among football players, the highest concussion risks were seen in running backs (18.9%), followed by defensive backs (16.7%), and kickers (15.8%). Lowest risks were found to be with linebackers (13.4%) and defensive linemen (13.9%). With linebackers as the reference group, running backs had an ARR, adjusted for age, that was 1.43 times greater than linebackers, followed by defensive backs (1.26) and offensive linemen (1.16). The lowest ARR was seen in kickers (1.06). The risks, RRs, and ARRs of the football positions are shown in Table 5.

Discussion

This large-scale research involving 10,334 middle and high school athletes offered a unique opportunity to examine the incidence of concussions occurring during a single season of a wide variety of high school sports. While there are different

Table 1. Risk, RR, and adjusted RR by age

Age	Number of athletes	Number of concussions	Risk (%)	RR	Adjusted RR[a] (95% CI)	ARR *p*-value
13	512	40	7.8	Reference	Reference	NA
14	2,352	178	7.6	0.97 (0.70, 1.35)	0.82 (0.59, 1.15)	0.248
15	2,477	363	14.7	1.88 (1.37, 2.56)	1.53 (1.11, 2.11)	0.009**
16	2,470	309	12.5	1.60 (1.17, 2.19)	1.32 (0.96, 1.83)	0.089*
17	1,944	255	13.1	1.68 (1.22, 2.31)	1.39 (1.01, 1.93)	0.046*
18	579	105	18.1	2.32 (1.65, 3.28)	1.91 (1.35, 2.71)	0.0003**

[a]Adjusted for sex and sport.
*$p < 0.05$. **$p < 0.01$.

Table 2. Risk, RR, and adjusted RR by sex and sport

	Number of athletes	Number of concussions	Risk (%)	RR	Adjusted RR[a] (95% CI)	ARR *p*-value
All sports						
Male	5,938	719	12.1	Reference	Reference	
Female	4,396	531	12.1	1.00 (0.90, 1.11)	1.50 (1.29, 1.73)	<.0001**
All comparable sports						
Male	2,974	292	9.8	Reference	Reference	
Female	3,603	434	12.1	1.23 (1.07, 1.41)	1.50 (1.29, 1.74)	<.0001**
Comparable Sports						
Soccer						
Male	711	55	7.7	Reference	Reference	
Female	970	129	13.3	1.72 (1.27, 2.32)	1.75 (1.30, 2.38)	0.0003**
Basketball						
Male	701	64	9.1	Reference	Reference	
Female	628	93	14.8	1.62 (1.20, 2.19)	1.62 (1.20, 2.19)	0.0018**
Volleyball						
Male	226	6	2.7	Reference	Reference	
Female	976	54	5.5	2.08 (0.91, 4.78)	2.21 (0.96, 5.09)	0.0626
Wrestling/martial arts						
Male	636	123	19.3	Reference	Reference	
Female	344	81	23.5	1.22 (0.95, 1.56)	1.19 (0.93, 1.53)	0.1691
Baseball/ Softball						
Male	525	34	6.5	Reference	Reference	
Female	438	56	12.8	1.97 (1.31, 2.97)	2.07 (1.38, 3.11)	0.0004**
Water polo						
Male	102	2	2	Reference	Reference	
Female	173	9	5.2	2.65 (0.58, 12.04)	2.04 (0.44, 9.41)	0.3611
Tennis						
Male	56	2	3.6	Reference	Reference	
Female	84	3	3.6	1.00 (0.17, 5.79)	1.04 (0.18, 6.00)	0.9676
Track & field						
Male	70	8	11.4	Reference	Reference	
Female	67	12	17.9	1.57 (0.68, 3.59)	1.66 (0.73, 3.80)	0.2269
Cross country						
Male	71	3	4.2	Reference	Reference	
Female	55	1	1.8	0.43 (0.05, 4.02)	0.45 (0.05, 4.17)	0.4792

[a]Adjusted for age.
**$p < 0.01$.

Table 3. Risk, RR, and adjusted RR by concussion

Concussion group	Number of athletes	Number of concussions	Risk (%)	RR	Adjusted RR[a] (95% CI)	ARR *p*-value
0	8,580	611	7.1	Reference	Reference	NA
1	1,299	436	33.6	4.71 (4.23, 5.25)	4.34 (3.89, 4.83)	<0.0001**
2	300	127	42.3	5.95 (5.10, 6.92)	5.07 (4.37, 5.88)	<0.0001**
3+	111	33	29.7	4.18 (3.11, 5.61)	3.72 (2.79, 4.97)	<0.0001**

[a]Adjusted for sex and sport.
**$p < 0.01$.

ways to report concussion data, we chose to examine concussion incidence in terms of risk, or the percent of athletes on a team who sustained a concussion during the season. Risk indicates the probability of a concussion per athlete and is a valid estimator of the chance of a concussion. Risk is less often employed in sports medicine research that typically reports CRs based on athletic exposure, that is, number of games and practices, and is less applicable when comparing concussion in different sports that have varying amounts of games and practices (Knowles et al., 2006). The advantage of the risk data is that they are more useful for risk assessment and may be more readily interpretable than CRs that require understanding the concept of the person-time in AEs. The present investigation reported risks, RRs, and ARRs of concussion among varied sports according to age, sex, concussion history, sport, and football position, expanding the understanding of youth sports concussion.

Table 4. Risk, RR, and adjusted RR by sport

Sport	Number of athletes	Number of concussions	Risk (%)	RR	Adjusted RR[a] (95% CI)	ARR *p*-value
Wrestling/martial arts	980	204	20.8	6.56 (2.48, 17.33)	6.07 (2.30, 16.02)	0.0003**
Cheerleading	533	85	15.9	5.02 (1.88, 13.44)	3.99 (1.49, 10.70)	0.0059**
Football	2,724	420	15.4	4.86 (1.84, 12.79)	5.68 (2.15, 14.98)	0.0005**
Track and field	137	20	14.6	4.60 (1.62, 13.09)	4.24 (1.49, 12.04)	0.0067**
Softball	441	56	12.7	4.00 (1.48, 10.82)	3.28 (1.21, 8.89)	0.0193*
Basketball	1,329	157	11.8	3.72 (1.40, 9.87)	3.52 (1.33, 9.32)	0.0114*
Soccer	1,681	184	10.9	3.45 (1.30, 9.13)	3.11 (1.18, 8.23)	0.0223*
Baseball	532	34	6.4	2.01 (0.73, 5.57)	2.39 (0.86, 6.61)	0.0945
Volleyball	1,202	60	5	1.57 (0.58, 4.25)	1.35 (0.50, 3.67)	0.5518
Water polo	275	11	4	1.26 (0.41, 3.88)	1.00 (0.32, 3.12)	0.9998
Tennis	140	5	3.6	1.13 (0.31, 4.10)	1.10 (0.30, 3.99)	0.8868
Cross country	126	4	3.2	Reference	Reference	NA

[a]Adjusted for age and sex
*$p < 0.05$. **$p < 0.01$.

Table 5. Risk, RR, and adjusted RR by football position

Position	Number of athletes	Number of concussions	Risk (%)	RR	Adjusted RR[a] (95% CI)	ARR *p*-value
Running back	196	37	18.9	1.41 (0.94, 2.12)	1.43 (0.95, 2.14)	0.09
Defensive back	365	61	16.7	1.25 (0.87, 1.80)	1.26 (0.87, 1.81)	0.22
Kicker	19	3	15.8	1.18 (0.40, 3.46)	1.06 (0.36, 3.12)	0.92
Offensive lineman	279	43	15.4	1.15 (0.77, 1.71)	1.16 (0.78, 1.73)	0.46
Quarterback	113	16	14.2	1.06 (0.62, 1.81)	1.07 (0.63, 1.83)	0.79
Receiver	487	69	14.2	1.06 (0.74, 1.51)	1.08 (0.75, 1.55)	0.67
Defensive lineman	366	51	13.9	1.04 (0.71, 1.52)	1.04 (0.71, 1.52)	0.84
Linebacker	306	41	13.4	Reference	Reference	NA

[a]Adjusted for age.

This research found that, from among the 10,334 athletes, 1,250 (or 12.1%) sustained a concussion during the school year. This finding is lower than the 16.7% incidence proportion noted in a prospective 11-year study of concussion incidence in high school sports by Lincoln et al. (2011). Differences in research methodology may account for the contrasting results. The Lincoln epidemiological research employed an electronic medical record-keeping program on a daily basis as contrasted with the retrospective data collection in this investigation. The different sports evaluated in the two studies could have also influenced the variable results. In this study, concussions were found to occur more frequently with older high school athletes, female athletes, players with a prior history of concussion, and athletes who participate in wrestling and martial arts.

Age

The findings of this study indicated that older student athletes, that is, 18-year olds, have a much higher incidence of concussions compared with younger student athletes, that is, 13-year olds. RR and ARR data showed that 18-year-old athletes have about twice the risk of sustaining a concussion compared to 13-year olds. These results are noteworthy in that, to our knowledge, no study has examined concussion risks in specific ages of youth athletes. Older youth athletes may suffer more concussions as they may have more playing time, are bigger and stronger, and play at a faster, more intense and competitive level that could increase the risk of severe impacts and concussion (Gessel et al., 2007). Some older athletes may have sustained a concussion earlier in their school years, thus increasing their risk of concussions in subsequent head injuries (Zemper, 2003).

This research highlights the need for additional studies into the age factor in youth sports concussions, especially for the older student athlete. Concussion data pertaining to middle school and grade school athletes are rare, calling for more research in these younger age groups, who receive less professional medical attention than college and professional athletes (Halstead & Walter, 2010).

Sex

The present study found higher concussion risks in female youth athletes when compared to males over a wide range of comparable sport activities. In certain sports, such as basketball, soccer, and softball, female athletes had over 1.5–2 times the

RR and ARR of a concussion than males. A literature review of sex difference in sport concussion in high school, college, and professional levels likewise showed higher CRs for females compared to males in similar sports (Dick, 2009), a pattern that has been noted in several previous studies of high school athletes (Lincoln et al., 2011; Marar et al., 2012; Rosenthal et al., 2014). Possible explanations for sex differences in concussion patterns are limited, with some suggesting biomechanical (body mass, small head-to-ball ratio, neck strength), neuroanatomical, or hormonal factors underlying female concussions (Covassin, Swanik, & Sachs, 2003; Strand, Lechuga, Zachariah, & Beaulieu, 2015). Psychosocial influences may lead males to minimize injuries, play despite injury and underreport symptoms in order to continue to play (Kerr, Register-Mihalik, Kroshus, Baugh, & Marshall, 2016). Along with prior findings that female athletes exhibit more neuropsychological decline than males following sports-related concussion (Broshek et al., 2005; Covassin, Elbin, Harris, Parker, & Kontos, 2012), the present results call for further research regarding concussion risks and prevention strategies in female youth athletes.

Prior concussion

One of the significant findings in this report is that youth athletes who report having a prior concussion are three to five times more likely to sustain a concussion during the school year than athletes without a reported history of concussion. The athletes with one self-reported prior concussion had an ARR that was over four times greater than those with no self-reported prior concussions. The ARR for athletes with two self-reported prior concussions was five times greater than those with no self-reported previous concussion, and for those with three or more self-reported prior concussion was more than three times greater than those who had no self-reported prior concussion. The data do not support a dose–response relationship between the number of self-reported concussions and subsequent concussive events.

A mild brain trauma results not only in immediate physiological changes but may affect neuronal plasticity and increase the risk for a subsequent concussion (Giza & Hovda, 2001; Noble & Hesdorffer, 2013). Thus, the capacity of the brain of previously concussed athletes to respond to another head trauma may be compromised and is, therefore, more susceptible to a subsequent concussion. It has also been proposed that high school athletes who had a prior concussion may be the more experienced players who participate more in games and practices and are more likely to have another concussion because of greater exposure to play activity (Schulz et al., 2004). The present findings are consistent with observations by previous investigators (Collins et al., 2002; Guskiewicz et al., 2000), and have important implications for the proper management of head injured young athletes (Gavett, Stern, & McKee, 2011; Graham et al., 2014; Harmon et al., 2013).

Sports

More concussion incidents seem to occur in certain sports. The highest percentage of concussions and ARRs was seen in wrestling and martial arts, followed by cheerleading and football. While many studies of high school sports have consistently found football to have the highest CRs among the varied sport activities (Lincoln et al., 2011; Marar et al., 2012; Noble & Hesdorffer, 2013; Rosenthal et al., 2014; Shankar et al., 2007), wrestling and cheerleading have also been noted to have high concussion risks (Comstock et al., 2017; Stewart et al., 2014). In previous studies of CRs, participants in wrestling and cheerleading have not been identified among those with the highest CRs, most likely because of their lower exposure to sport activity, compared with football or ice hockey. Instead of risk data, most previous comparisons of sports have employed CRs that take into account AE, or total person-time at risk, which is considered to be the most appropriate way to compare different sports (Knowles et al., 2006), but was not available for this study.

Football positions

None of the ARRs comparing the different football positions, with linebackers as the reference, was statistically significant. The lack of differences between the varied football positions may be attributed to the youth athletes playing in more than one position or playing on offense and defense.

Limitations

In this research, concussions that occurred during the school year were documented by a certified athletic trainer, but the history of prior concussions was obtained by the self-report of the athlete. The actual number of self-reported concussions is likely underestimated due to the failure of accurate documenting of head injuries by young athletes and support staff (Kerr et al., 2016; Williamson & Goodman, 2006). Reasons for the underreporting of concussions include the athlete's unawareness

of having sustained a concussion, minimizing the seriousness of the head blow, and deliberately not reporting a concussion so as to avoid being withheld from participating.

The participants in this study were a convenience sample enrolled in schools in Hawaii, with results that could assist in region-specific efforts to improve concussion education and increase player safety. However, our results may not be generalizable to schools in other geographic locations and with different sociocultural representation. The gathering of similar risk incidence data from other regions in the country could enhance the generalizability of these findings. Although this research examined 12 different sports in Hawaii, it did not include other sports that are associated with high risks of concussion in other states and countries, such as hockey, lacrosse, and rugby.

The athletes in this study were identified as participating in one sport, but youth athletes often play in multiple sports. If an identified football player sustained a concussion in baseball but not in football, he was counted as a baseball player who had a concussion and also counted as football player who did not have a concussion. However, we do not know how many athletes who did not suffer any concussion played in more than one sport. Limitations should be recognized regarding the retrospective nature of this study that lacked a systematic method for tracking athletes who sustained a concussion, with unknown intervals between the occurrence of a concussion and its reporting. The present data did not include the circumstances of the head injuries, for example, whether a concussion was due to head-to-head, head-to-body, or ground contact, and did not differentiate a concussion sustained in practice or in a game. Finally, our findings provide no clear understanding of factors, such as age and sex, which may predispose an athlete to a concussion.

Conclusion

While the interest in sports-related concussion is often focused in major collision sports, like football, the present study, through a large sample of high school athletes, provides information about the incidence and risk of concussion across a wide spectrum of team and individual sports. Our findings show that concussion risks vary considerably by age, sex, concussion history, and sport. Reporting concussion incidence and risk rates have intrinsic informative value for athletes, parents, coaches, and athletic staff. The present findings increase our knowledge and understanding of concussion patterns in high school athletes in various sports that can enhance protective and preventative strategies with these young participants.

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Conflict of interest

None declared.

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