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Epidemiologic Measures for Quantifying the Incidence of Concussion in National Collegiate Athletic Association Sports

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Context: Injury rates compare the relative frequency of sport-related concussions across groups. However, they may not be intuitive to policy makers, parents, or coaches in understanding the likelihood of concussion.

Objective: To describe 4 measures of incidence (athlete-based rate, athlete-based risk, team-based rate, and team-based risk) during the 2011–2012 through 2014–2015 academic years.

Design: Descriptive epidemiology study.

Setting: Aggregate injury and exposure data collected from the National Collegiate Athletic Association Injury Surveillance Program in 13 sports (men's baseball, basketball, football, ice hockey, lacrosse, soccer, and wrestling and women's basketball, ice hockey, lacrosse, soccer, softball, and volleyball).

Patients or Other Participants: Collegiate student-athletes.

Main Outcome Measure(s): Sport-related concussion data from the National Collegiate Athletic Association Injury Surveillance Program during the 2011–2012 through 2014–2015 academic years were analyzed. We calculated concussion rates per 1000 athlete-exposures (AEs), concussion risk, average number of concussions per team, and percentage of teams with at least 1 concussion.

Results: During the 2011–2012 through 2014–2015 academic years, 1485 concussions were sustained by 1410 student-athletes across 13 sports. Concussion rates ranged from 0.09/1000 AEs in men's baseball to 0.89/1000 AEs in men's wrestling. Concussion risk ranged from 0.74% in men's baseball to 7.92% in men's wrestling. The average ± SD number of concussions per team ranged from 0.25 ± 0.43 in men's baseball to 5.63 ± 5.36 in men's football. The percentage of teams with a concussion ranged from 24.5% in men's baseball to 80.6% in men's football.

Conclusions: Although men's wrestling had a higher concussion rate and risk, men's football had the largest average number of concussions per team and the largest percentage of teams with at least 1 concussion. The risk of concussion, average number of concussions per team, and percentage of teams with concussions may be more intuitive measures of incidence for decision makers. Calculating these additional measures is feasible within existing injury surveillance programs, and this method can be applied to other injury types.

Key Words: traumatic brain injury, collegiate sports, risk

Key Points

- Men's football, men's and women's ice hockey, and men's wrestling were the sports yielding the highest concussion incidence measures.
- As seen in previous research, concussion rates and risks were higher in females than in males.
- The risk of concussion, the average number of concussions per team, and the proportion of teams that can expect a concussion may be more intuitive measures of concussion incidence than rates for athletes and decision makers.

In disease epidemiology, population rates (ie, the number of events divided by the amount of person-time observed) are the most common expression of incidence. This preference for rates has carried over into sport injury epidemiology. Rates are statistically efficient because all cases of a disease or injury are included in the numerator. Additionally, they account for variation in the amount of exposure via the denominator and therefore provide a means to compare populations or sports (or both) with vastly different levels of playing exposure.[1] In sport injury epidemiology, injury rates are commonly expressed per unit of playing time (ie, minutes or hours)[2–5] or per frequency of athlete-exposure (AE; ie, 1 player participating in 1 game or practice).[6–11] In other words, scientists use rates because they facilitate comparisons between different activity types (ie, practices and games) or groups (ie, men versus women) where exposures might not be equal. However, rates are often not intuitive for policymakers, parents, or coaches in quantifying the probability of injury.

Risk is a more intuitive measure of injury incidence for most nonscientists. *Risk* is simply the probability that an injury will occur during a given activity (ie, sport) for a defined population (eg, a team) over a specific time frame (eg, 1 season). As a probability, risk is bounded by 0 and 1

(unlike rates, which can exceed 1). Risk is often expressed as a percentage. For example, authors of a recent study[12] reported the risk and rate of concussion in youth football players. The risk was 3.3% for 1 season. This measure has an obvious interpretation that (on average) 1 player on a team of 33 will suffer a concussion over the course of a season. This measure is more readily understandable than the rate of 9.9 per 10 000 AEs; understanding the rate would require some explanation, particularly for those who have not previously encountered AEs. The limitations of risk are that it does not intuitively differentiate game from practice injuries and that it does not account for various amounts of exposure across groups. However, these limitations may be unimportant if the consumer of the report is interested only in the bottom line and not in specifics. Such consumers could include parents, athletes, or athletic directors.

In addition to injury risk and rate for athletes, both measures can also be reported as team-based statistics. The *team-based risk statistic* is the proportion of teams with injuries. The *team-based rate statistic* is the average number of injuries per team-season.

The number of epidemiologic studies of concussive injuries has increased markedly over the past decade.[11] However, only a handful of researchers[1,12] have specifically reported concussion risks in sports. Therefore, using concussion data from the National Collegiate Athletic Association (NCAA) Injury Surveillance Program (ISP),[6] our primary aim was to describe these 4 measures of incidence (athlete-based rate, athlete-based risk, team-based rate, and team-based risk) across 13 collegiate sports during the 2011–2012 through 2014–2015 academic years. A secondary aim was to compare these measures between sexes for 5 sex-comparable sports (baseball/softball, basketball, ice hockey, lacrosse, and soccer).

METHODS

Data from the 2011–2012 through 2014–2015 academic years were obtained from the NCAA-ISP. The NCAA-ISP is a prospective surveillance program that is managed by the Datalys Center for Sports Injury Research and Prevention, Inc, an independent, nonprofit research organization. This study was approved by the NCAA Research Review Board.

National Collegiate Athletic Association ISP

Data Collection. The methodology of the NCAA-ISP has been previously described.[6] The NCAA-ISP uses a convenience sample of NCAA varsity teams from 25 NCAA championship sports, with athletic trainers (ATs) reporting injury and exposure data. The number of institutions and teams that provide data to the NCAA-ISP varies by sport and year. Athletic trainers who work with participating teams are present at all school-sanctioned practices and competitions. When injuries occur, the ATs report them in real time through the electronic health record application used by their team medical staff. In addition to musculoskeletal injuries, the surveillance system also captures other sport-related adverse health events such as general medical conditions, heat-related conditions, and skin infections. Varsity-level practices, competitions, and team conditioning sessions are included in the NCAA-ISP data sets; personal weight training and conditioning sessions and informal team training sessions are not included.

For each event, the AT completes a detailed event report on the injury or condition (eg, site, diagnosis) and the circumstances (eg, activity, mechanism, event type [ie, competition or practice]). Previously submitted information can be viewed and updated as needed during the course of a season. In addition, ATs also provide the number of student-athletes participating in each practice and competition.

From the electronic health record application, common data elements that include injury and exposure information are stripped of identifiers and personally identifiable information and transmitted electronically using secure and Health Insurance Portability and Accountability Act (HIPAA)–compliant Internet protocols.[6] This common data element standard allows ATs to document injuries as they normally would as part of their daily clinical practice, as opposed to having them separately report injuries for injury-surveillance purposes. All electronic health record applications must have successfully completed a data-validation process to be certified.

Exported data pass through an automated verification process composed of a series of range and consistency checks. Data are reviewed and flagged for invalid values using automated algorithms, with concerns resolved by the AT and data quality-assurance staff. Data that pass the verification process are then stored as line-level data sets on secure mirrored servers.

Injury, Concussion, and Exposure Definitions. A *reportable injury* in the NCAA-ISP was an injury that occurred as a result of participation in an organized intercollegiate practice or competition and required attention from an AT or physician. Multiple injuries could be included as the result of 1 event. We did not provide a definition of concussion, as we relied on the medical expertise of the medical professional supplying data for the NCAA-ISP. However, ATs were encouraged to follow the definition provided by the "Consensus statement on concussion in sport."[13]

A *reportable AE* was defined as 1 student-athlete participating in 1 NCAA-sanctioned practice or competition in which he or she was exposed to the possibility of athletic injury, regardless of the time associated with that participation. Only athletes with actual playing time in a competition, including warm-ups, were included in competition exposures.

A *team-season* was defined as 1 team sponsoring 1 season of sport. Thus, 10 team-seasons could be the result of 1 team in 10 seasons, 5 teams in 2 seasons, or 10 teams in 1 season. We calculated team-seasons by examining participation within the NCAA-ISP during the study period. For example, during 2011–2012 through 2014–2015 in men's football, 27, 20, 21, and 30 teams provided data in each academic year, respectively; this equated to a total of 98 team-seasons.

An *athlete-season* was defined as 1 student-athlete participating in 1 season of sport. Thus, 10 athlete-seasons could be the result of 1 student-athlete in 10 seasons, 5 student-athletes in 2 seasons, or 10 student-athletes in 1 season. Athlete-seasons were obtained from historical preseason team rosters on university athletic Web sites.

Sports Included and Excluded. We analyzed concussion data from 13 sports (men's baseball, basketball, football, ice hockey, lacrosse, soccer, and wrestling and women's basketball, ice hockey, lacrosse, soccer, softball, and volleyball). Data from 12 NCAA sports (men's cross-country, indoor track, outdoor track, swimming and diving, and tennis and women's cross-country, field hockey, gymnastics, indoor track, outdoor track, swimming and diving, and tennis) were not analyzed because of the low incidence of concussion during the study period (<10 for each sport). All data were from the 2011–2012 through 2014–2015 academic years.

Statistical Analysis

Data were analyzed to assess athlete-based concussion rates, athlete-based concussion risks, team-based concussion rates (ie, the average number of concussions per team-season), and team-based concussion risks (ie, the proportions of teams with reported concussion). Data were analyzed using SAS Enterprise Guide software (version 4.3; SAS Institute Inc, Cary, NC). Formulas with examples that use men's football are presented in the following sections.

Athlete-Based Concussion Rates. The concussion rate was calculated as the number of concussions divided by the number of AEs. Rates were presented per 1000 AEs. The formula for calculating a concussion rate is

$$Rate = \frac{\sum concussions}{\sum AEs}$$

During the 2011–2012 through 2014–2015 academic years in men's football, 140, 128, 134, and 150 concussions were reported in each academic year, respectively, equating to a total of 552 concussions. These occurred over 735 474 AEs. Thus, the athlete-based concussion rate is computed as

$$\frac{(140 + 128 + 134 + 150)}{735\,474} * 1000 = 0.75$$

One-Season Athlete-Based Concussion Risk. The 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. Because of fluctuation in student-athletes entering and graduating college, concussed student-athletes were considered on an annual basis. In other words, if a student-athlete sustained 1 concussion within each team-season, that student-athlete contributed to the number of concussed athletes for each team-season. Pooled risks were calculated as the sum of concussed student-athletes divided by the sum of participating student-athletes across all 3 academic years. The formula for calculating a pooled 1-season athlete-based concussion risk is

$$Pooled\ risk = \frac{\sum concussed\ athletes\ per\ team\text{-}season}{\sum athlete\text{-}seasons}$$

During 2011–2012 through 2014–2015 in men's football, there were 134, 120, 125, and 139 concussed individuals in each academic year, respectively; this equated to a total of 518 concussed individuals. In addition, rosters indicated that 2660, 2021, 2091, and 2946 student-athletes participated, respectively, equating to 9718 athlete-seasons. Thus, the pooled risk for men's football is computed as

$$\frac{(134 + 120 + 125 + 139)}{(2660 + 2021 + 2091 + 2946)} = 5.33\%$$

Weighted annual risks ensured equal weighting among the 1-season risks calculated from each academic year. The formula for calculating an weighted annual 1-year athlete-based concussion risk is

$$Weighted\ annual\ risk = \frac{\sum \left(\frac{concussed\ athletes\ per\ team\text{-}season}{athlete\text{-}seasons}\right)}{\sum academic\ years}$$

Thus, the weighted annual athlete-based risk for men's football is computed as

$$\frac{\left(\frac{134}{2660} + \frac{120}{2021} + \frac{125}{2091} + \frac{139}{2946}\right)}{4} = 5.42\%$$

Team-Based Concussion Rate: Average Number of Concussions per Team-Season. The average number of concussions per team-season was calculated as the number of concussions divided by the number of team-seasons. Thus, all concussions in student-athletes during the study period were included in this analysis. This statistic was calculated overall and separately for competitions and practices. The formula for calculating this statistic is

$$Average\ number\ of\ concussions\ per\ team\text{-}season = \frac{\sum concussions}{\sum team\text{-}seasons}$$

The average number of concussions per football team-season is computed as follows:

$$\frac{(140 + 128 + 134 + 150)}{(27 + 20 + 21 + 30)} = 5.63$$

Team-Based Concussion Risk: Proportion of Teams With Reported Concussion. The proportion of teams with at least 1 concussion is the number of team-seasons in which a student-athlete sustained a concussion divided by the total number of team-seasons. This statistic was calculated overall and separately for competitions and practices. The formula for calculating this statistic is

$$Proportion\ of\ teams\ with\ reported\ concussion = \frac{\sum team\text{-}seasons\ with\ reported\ concussion}{\sum team\text{-}seasons}$$

During the 2011–2012 through 2014–2015 academic years in men's football, 24, 15, 18, and 22 teams reported at least 1 concussion, respectively, equating to a total of 79 team-seasons. Thus, the average number of teams with reported concussion per football team-season is computed as

$$\frac{(24 + 15 + 18 + 22)}{(27 + 20 + 21 + 30)} = 80.6\%$$

Sex Differences. We compared results between sexes for sex-comparable sports (ie, baseball/softball, basketball, ice

Table 1. Number of Teams Providing Data to National Collegiate Athletic Association Injury Surveillance Program, 2011–2012 Through 2014–2015 Academic Years

Sport	2011–2012	2012–2013	2013–2014	2014–2015	Total
Men's					
Baseball	14	11	11	17	53
Basketball	32	23	21	43	119
Football	27	20	21	30	98
Ice hockey	9	44	35	42	130
Lacrosse	12	10	8	14	44
Soccer	22	12	12	18	64
Wrestling	8	6	7	8	29
Women's					
Basketball	31	27	29	37	124
Ice hockey	5	21	15	17	58
Lacrosse	11	16	15	21	63
Soccer	33	23	24	27	107
Softball	21	18	21	30	90
Volleyball	32	23	24	36	115
Total	257	254	243	340	1094

hockey, lacrosse, and soccer). These comparisons were performed solely on sample counts. Injury rate ratios (IRRs) compared athlete-based rates. Risk ratios (RRs) compared athlete-based and team-based risks. Those IRRs and RRs with 95% confidence intervals (CIs) not including 1.00 were deemed significant. As findings for pooled and weighted athlete-based annual risks were similar, only RRs for pooled risks are presented. Because the average number of concussions per team-season (ie, team-based risk) did not follow a normal distribution, we used the Wilcoxon rank sum test to compare average numbers of concussions per team-season in sex-comparable sports, with an a priori significance level of .05.

RESULTS

During the 2011–2012 through 2014–2015 academic years, a total of 1485 concussions were sustained by 1410 student-athletes across 13 sports and 1094 team-seasons (Table 1). In total, these 1094 team-seasons included 32 156 athlete-seasons.

Athlete-Based Concussion Rate

Athlete-based concussion rates ranged from a low of 0.09/1000 AEs in men's baseball to a high of 0.89/1000 AEs in men's wrestling (Table 2). This pattern was similar for competition and practice rates.

Sex differences were found, with a higher concussion rate in females than in males for baseball/softball (IRR = 3.01; 95% CI = 1.61, 5.62), basketball (IRR = 1.42; 95% CI = 1.05, 1.92), and soccer (IRR = 2.10; 95% CI = 1.40, 3.15). However, rates between females and males did not differ in ice hockey (IRR = 1.07; 95% CI = 0.85, 1.34) or lacrosse (RR = 1.47; 95% CI = 0.98, 2.02).

Athlete-Based Concussion Risk

Pooled 1-season concussion risks ranged from a low of 0.7% in men's baseball to a high of 7.9% in men's wrestling (Table 3). The rank order of sports did not vary between weighted 1-season risks and pooled 1-season risks; the only exceptions were men's football and women's basketball, whose changes in rank orders from weighted to pooled were fifth to fourth and fourth to fifth, respectively.

The sex differences observed using this measure were very similar to the sex differences observed using the concussion rate. The 1-season risk in females was larger than that in males for baseball/softball (2.4% versus 0.7%; RR = 3.27; 95% CI = 1.75, 6.12), basketball (5.3% versus 3.9%; RR = 1.36; 95% CI = 1.01, 1.84), soccer (3.3% versus 1.6%; RR = 2.06; 95% CI = 1.36, 3.10). However, differences between females and males were not found in ice hockey (7.2% versus 6.9%; RR = 1.05; 95% CI = 0.84, 1.32) or lacrosse (3.2% versus 2.5%; RR = 1.29; 95% CI = 0.87, 1.93).

Team-Based Concussion Rate

The average ± SD number of concussions per team-season ranged from a low of 0.25 ± 0.43 in men's baseball

Table 2. Athlete-Based Concussion Rates Among National Collegiate Athletic Association Student-Athletes in Collegiate Sports, National Collegiate Athletic Association Injury Surveillance Program, 2011–2012 Through 2014–2015 Academic Years

	Counts			Rates per 1000 Athlete-Exposures[a] (95% Confidence Interval)		
Sport	Overall	Competition	Practice	Overall	Competition	Practice
Men's						
Baseball	13	9	4	0.09 (0.04, 0.14)	0.16 (0.06, 0.27)	0.04 (0.00, 0.08)
Basketball	76	23	53	0.38 (0.29, 0.46)	0.53 (0.31, 0.74)	0.34 (0.24, 0.43)
Football	552	237	315	0.75 (0.69, 0.81)	3.25 (2.84, 3.66)	0.48 (0.42, 0.53)
Ice hockey	266	211	55	0.74 (0.65, 0.83)	2.40 (2.07, 2.72)	0.20 (0.15, 0.25)
Lacrosse	45	22	23	0.30 (0.22, 0.39)	0.91 (0.53, 1.30)	0.19 (0.11, 0.26)
Soccer	31	18	13	0.26 (0.17, 0.35)	0.67 (0.36, 0.98)	0.14 (0.06, 0.21)
Wrestling	68	35	33	0.89 (0.68, 1.10)	4.31 (2.88, 5.74)	0.48 (0.32, 0.65)
Women's						
Basketball	95	41	54	0.53 (0.43, 0.64)	1.00 (0.69, 1.31)	0.39 (0.29, 0.50)
Ice hockey	98	70	28	0.78 (0.63, 0.94)	2.11 (1.61, 2.60)	0.31 (0.19, 0.42)
Lacrosse	50	27	23	0.45 (0.32, 0.57)	1.28 (0.80, 1.77)	0.25 (0.15, 0.36)
Soccer	98	73	25	0.54 (0.43, 0.64)	1.65 (1.27, 2.03)	0.18 (0.11, 0.25)
Softball	40	23	17	0.26 (0.18, 0.35)	0.42 (0.25, 0.59)	0.18 (0.09, 0.26)
Volleyball	53	26	27	0.37 (0.27, 0.47)	0.64 (0.39, 0.88)	0.27 (0.17, 0.37)

[a] An athlete-exposure is defined as 1 student-athlete participating in 1 practice or 1 competition.

Table 3. Counts of Participating Teams, Student-Athletes, and 1-Season Athlete-Based Concussion Risks in Collegiate Sports, National Collegiate Athletic Association Injury Surveillance Program, 2011–2012 Through 2014–2015 Academic Years[a]

Sport	No. Athlete-Seasons[b]	No. Concussed per Team-Season	Risk, % (95% Confidence Interval)[c]	
			Pooled	Weighted
Men's				
Baseball	1757	13	0.7 (0.3, 1.1)	0.7 (0.3, 1.1)
Basketball	1889	74	3.9 (3.0, 4.8)	4.0 (3.1, 5.0)
Football	9718	518	5.3 (4.9, 5.8)	5.2 (4.7, 5.6)
Ice hockey	3689	253	6.9 (6.0, 7.7)	7.3 (6.4, 8.1)
Lacrosse	1768	44	2.5 (1.8, 3.2)	2.8 (2.0, 3.6)
Soccer	1810	29	1.6 (1.0, 2.2)	1.7 (1.1, 2.3)
Wrestling	821	65	7.9 (6.1, 9.8)	7.8 (5.9, 9.6)
Women's				
Basketball	1690	90	5.3 (4.3, 6.4)	5.6 (4.5, 6.8)
Ice hockey	1301	94	7.2 (5.8, 8.6)	7.6 (6.1, 9.1)
Lacrosse	1522	49	3.2 (2.3, 4.1)	3.5 (2.5, 4.5)
Softball	1569	38	2.4 (1.7, 3.2)	2.5 (1.7, 3.3)
Soccer	2831	93	3.3 (2.6, 3.9)	3.6 (2.9, 4.3)
Volleyball	1791	50	2.8 (2.0, 3.6)	3.0 (2.1, 3.8)

[a] A team-season is defined as 1 team participating in 1 season of sport; an athlete-season is defined as 1 student-athlete participating in 1 season of sport.

[b] Number of athlete-seasons taken from preseason rosters of participating universities' athletics Web sites for the 2011–2012 through 2014–2015 academic years.

[c] Pooled risks were calculated as the sum of concussed student-athletes divided by the sum of participating student-athletes across all 3 academic years. Weighted risks ensured equal weighting among 1-season risks calculated for each academic year.

to a high of 5.63 ± 5.36 in men's football (Table 4). Findings were similar when restricted to competitions or practices.

Sex differences were found only in soccer; more concussions were reported per team-season in females than males ($P = .004$). However, when restricted to the stratum of competitions or practices, this finding was present for competitions ($P = .002$) but not for practices ($P = .74$). There were no differences between females and males in baseball/softball ($P = .21$), basketball ($P = .53$), ice hockey ($P = .22$), or lacrosse ($P = .56$).

Team-Based Concussion Risk

Men's baseball had the lowest proportion of teams with at least 1 concussion (24.5%; Table 5). When restricted to the stratum of competitions or practices, these findings were mostly similar; the only exception was men's basketball, which had the lowest proportion of teams with at least 1 competition concussion (14.3%). Overall and within competitions or practices, men's football had the largest proportion of team-seasons with at least 1 concussion. In addition, men's football had the highest reported number of concussions overall (n = 25), within competitions (n = 12), and within practices (n = 15).

Sex differences were observed only for soccer; the proportion of teams with concussion in females was larger than that in males within soccer overall (50.5% versus 26.6%; RR = 1.90; 95% CI = 1.21, 2.98). In addition, differences between females and males were not found in baseball/softball (31.1% versus 24.5%; RR = 1.27; 95% CI = 0.72, 2.23), basketball (42.7% versus 40.3%; RR = 1.06;

Table 4. Team-Based Rate (Average Number of Concussions Sustained per Team per Season) in Collegiate Sports, by Event Type, National Collegiate Athletic Association Injury Surveillance Program, 2011–2012 Through 2014–2015 Academic Years

Sport	Overall		Competitions		Practices	
	Average ± SD	Median	Average ± SD	Median	Average ± SD	Median
Men's						
Baseball	0.25 ± 0.43	0	0.17 ± 0.38	0	0.08 ± 0.27	0
Basketball	0.64 ± 1.04	0	0.19 ± 0.53	0	0.45 ± 0.85	0
Football	5.63 ± 5.36	5	2.42 ± 2.69	2	3.21 ± 3.56	2
Ice hockey	2.05 ± 2.11	2	1.62 ± 1.78	1	0.42 ± 0.82	0
Lacrosse	1.02 ± 1.42	0	0.50 ± 0.73	0	0.52 ± 1.00	0
Soccer	0.48 ± 1.02	0	0.28 ± 0.74	0	0.20 ± 0.51	0
Wrestling	2.34 ± 3.38	1	1.21 ± 1.88	0	1.14 ± 1.92	0
Women's						
Basketball	0.77 ± 1.17	0	0.33 ± 0.63	0	0.44 ± 0.86	0
Ice hockey	1.69 ± 1.90	1	1.21 ± 1.41	1	0.48 ± 0.71	0
Lacrosse	0.79 ± 1.22	0	0.43 ± 0.95	0	0.37 ± 0.60	0
Soccer	0.89 ± 1.11	0	0.66 ± 0.94	0	0.23 ± 0.59	0
Softball	0.46 ± 0.77	0	0.26 ± 0.58	0	0.20 ± 0.48	0
Volleyball	0.46 ± 0.85	0	0.23 ± 0.50	0	0.23 ± 0.57	0

Table 5. Team-Based Risk (Proportions of Teams per Season With at Least 1 Reported Concussion) in Collegiate Sports, by Event Type, National Collegiate Athletic Association Injury Surveillance Program, 2011–2012 Through 2014–2015 Academic Years

	Overall		Competitions		Practices	
Sport	Team-Seasons With Concussion Events No. (%)	Highest No. Reported Within 1 Team-Season	Team-Seasons With Concussion Events No. (%)	Highest No. Reported Within 1 Team-Season	Team-Seasons With Concussion Events No. (%)	Highest No. Reported Within 1 Team-Season
Men's						
Baseball	13 (24.5)	1	9 (17.0)	1	4 (7.5)	1
Basketball	48 (40.3)	7	17 (14.3)	3	36 (30.3)	5
Football	79 (80.6)	25	68 (69.4)	12	72 (73.5)	15
Ice hockey	92 (70.8)	12	84 (64.6)	8	37 (28.5)	5
Lacrosse	20 (45.5)	5	16 (36.4)	2	13 (29.5)	4
Soccer	17 (26.6)	5	11 (17.2)	4	11 (17.2)	3
Wrestling	17 (58.6)	12	13 (44.8)	7	12 (41.4)	7
Women's						
Basketball	53 (42.7)	6	31 (25.0)	3	35 (28.2)	5
Ice hockey	32 (55.2)	6	31 (53.4)	5	22 (37.9)	3
Lacrosse	28 (44.4)	6	15 (23.8)	4	19 (30.2)	2
Soccer	54 (50.5)	4	45 (42.1)	4	18 (16.8)	3
Softball	28 (31.1)	3	18 (20.0)	3	14 (15.6)	2
Volleyball	37 (32.2)	6	23 (20.0)	3	20 (17.4)	3

95% CI = 0.79, 1.43), ice hockey (55.2% versus 70.8%; RR = 0.78; 95% CI = 0.60, 1.01), or lacrosse (44.4% versus 45.5%; RR = 0.98; 95% CI = 0.64, 1.50).

DISCUSSION

Injury rates are typically preferred to injury risks by scientists because they can account for multiple events sustained by 1 individual and for variability in at-risk time among a sample. However, rates may not be intuitive to nonscientists, including members of sports organizations concerned about the incidence of concussion among their players. We highlighted additional measures to consider using for estimating incidence of concussion that may be easier to interpret and disseminate to stakeholders. This more diverse toolbox of measures, in combination with traditional athlete-based rates, may help sports organizations better identify specific athletes at risk for concussion.

Our study is the first to examine multiple measures of concussion incidence across multiple sports at the collegiate level. Athlete-based concussion rates were found to be the highest in men's wrestling, followed by men's and women's ice hockey and men's football. These 4 sports also yielded the highest estimates for the other 3 measures reported here. Men's football, wrestling, and ice hockey are classified as full-contact sports.[14] The high velocity of game play in women's ice hockey is not full contact but places athletes at risk for player-player contact,[15] resulting in the majority of concussions in this sport.[14,16] The findings may pinpoint those sports with the greatest need for medical coverage related to concussion, which may be of particular use for clinicians working with multiple sports or athletic directors overseeing athletic programs. Clinicians working in settings with multiple teams (such as within a recreational youth league setting) may also benefit from using these measures to determine specific clusters of teams with increased concussion incidence. Last, these concussion measures are important to policymakers because they highlight the need for sport-specific injury prevention. Guidelines such as the recently published practice safety guidelines for NCAA football to limit the amount of contact during the preseason[17] as well as other policies may have a positive effect on reducing the incidence of concussion.

Some small variations in the rank order of sports depended on whether the incidence measure was athlete based or team based. Although sports such as men's and women's ice hockey and men's wrestling had higher athlete-based 1-season risks, men's football had the largest average number of concussions per team-season and the largest proportion of team-seasons with at least 1 concussion. These findings reflect differences in squad sizes among sports. In the 2013–2014 academic year, the average squad size per sport ranged from 28.8 for men's ice hockey to 30.9 for men's wrestling to 107.4 for men's football.[18] Athlete-based measures use a denominator that incorporates squad size, and thus the larger squad size for men's football will naturally decrease the athlete-based incidence measures. At the same time, the larger men's football squad size also provides more at-risk individuals, which will naturally increase the number of concussions sustained within a team and the probability that a team has a concussion. Thus, it is important to understand the limitations of the team-based measures that are presented here. Although these team-based measures may be more intuitive and useful for administrators such as athletic directors (eg, for resource-planning purposes), they do not have an interpretation in terms of individual (ie, athlete-based) incidence. Specifically, they are a biased measure for comparing personal incidence across teams (or sports) with varying squad sizes or varying numbers of athletic sessions per season or both.

Several groups[14,19,20] have found that female athletes were at a higher risk for concussion than male athletes. As seen in previous research,[14,16,20,21] we noted sex differences for athlete-based rates and risks. These differences were observed only in soccer for team-based measures. To underscore the point of the previous paragraph, the presence of sex differences for the athlete-based measures and the absence of sex differences for the team-based measures indicate that athlete-level differences likely underlie these sex differences. Speculation has invoked

biomechanical,[22] biological,[23] and psychosocial factors.[24,25] The presence of sex differences in soccer when using team-based incidences may indicate a structural element that predisposes athletes to concussion or may simply reflect the strong nature of the observed personal sex differences for this sport.

LIMITATIONS

Our study was based on a convenience sample that varied in yearly participation. Because of this, the data may not represent all NCAA teams for a given sport. However, aggregation of the data across years tempers this limitation. Still, data for sports with low numbers of team-seasons, such as wrestling, may lack precision and be prone to bias. Also, football contributed the majority of concussions; thus, the precision varied across sports. As these data demonstrate, the average number of concussions per team-season was under 1.00 for 8 sports. Therefore, capturing substantial numbers of concussions in many sports requires a much larger sample or many more years of data collection. Online preseason team rosters are useful resources to estimate squad size but may not account for changes in the roster during the season. Thus, athlete-seasons do not account for student-athletes who arrive after the preseason or those who leave midseason differently from those who remain on the team throughout the season. We did not explore additional factors, such as recurrence, that may be important, as work from previous researchers[14,16] has suggested evidence for sex differences related to concussion incidence. Online preseason team rosters and AEs do not stratify starters versus nonstarters; analyses specific to starters may be more important to coaches and administrators. Lastly, these data are limited to only those concussions that were reported to or were identified by ATs or other sports medicine professionals working with the individual teams. In lieu of observable symptoms, it is possible that some concussions were underreported for a variety of reasons, which may be reflected in our findings that a number of team-seasons had no reported concussions.

CONCLUSIONS

This is the first study to introduce alternative measures to describe the incidence of concussion across multiple NCAA sports. Personal 1-season risk, average number of injuries per team, and proportion of teams that can expect a concussion may be more intuitive measures of concussion incidence for athletes and decision makers. Calculating these additional measures is feasible within existing injury-surveillance programs such as the NCAA-ISP and can be applied to other sports and injury types.

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