A SYSTEMATIC REVIEW AND META-ANALYSIS OF SEX-BASED DIFFERENCES IN RECURRENT CONCUSSION INCIDENCE ACROSS SPORTS

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BACKGROUND: Disparities in concussion incidence exist on the basis of sex. This meta-analysis aimed to summarize the evidence for recurrent concussion incidence between male and female athletes across various sports.
METHODS: Systematic review and meta-analysis. *Data Sources* - PubMed, EMBASE, and Cochrane Library databases. *Eligibility Criteria for Selecting Studies* - Studies written in English containing sex comparisons of recurrent concussion data published between January 2000 and June 2021 were included.
RESULTS: A total of 1,509 records were identified, of which 114 studies were assessed for eligibility with full-text review. Six studies were ultimately included. Women were found to have more recurrent concussions than men across all sex-comparable sports, which included soccer, basketball, and baseball/softball [RR=2.16 (95% CI: 1.09-4.30)]. More specifically, women were found to have more recurrent concussions in soccer [RR=3.01 (95% CI: 2.08-4.35)] and basketball [RR=2.68 (95% CI: 1.39-5.17)], but inconclusive results were seen for baseball/softball [RR=2.54 (95% CI: 0.54-11.94)].
CONCLUSION: Recurrent concussion rates are greater in sex-comparable women's sports than in men's sports. Not all sports had sufficient evidence for inclusion in the meta-analysis. There are sex differences in recurrent concussion incidence in soccer and basketball.

INTRODUCTION

Sports-related concussions are regarded as a significant public health issue and are often associated with a constellation of symptoms and various clinical subtypes, including cognitive difficulties, post-traumatic headaches/migraines, vestibular dysfunction, ocular impairments, and problems with mood and sleep.[1-3] A qualitative literature review conducted in 2013 by Makdissi et al. found that up to 15% of individuals experiencing concussions have persistent symptoms and that this proportion may be even greater for children if left undiagnosed and untreated.[4] Historically, sports-related concussions were managed with the anticipation that most physical and cognitive symptoms would eventually resolve with rest.[5]

Presently, following the initial days post-injury, concussions are managed with active treatments such as vestibular therapy, neck strengthening, athletic training, and cognitive behavioral therapy.[2, 6-7] A retrospective cohort study conducted in 2021 by French et al. has shown that no significant differences in clinical factors such as recovery time, visual and verbal memory, and reaction time exist between patients' first and second concussions when they are formally treated through a clinic

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specializing in concussion recovery.[8] It is possible for individuals who sustain concussions to develop persistent concussion symptoms such as headache, fatigue, and depression.[9] Studies have suggested that female athletes display more severe persistent concussion symptoms than those of male athletes.[10] Additionally, the underreporting of sports-related concussions is a substantial concern that can lead to more long-term detrimental neurological outcomes for athletes in addition to affecting incidence and prevalence data collection. [11]

Recurrent concussions are of particular concern as repeated head trauma increases the probability of delayed neurological function recovery.[12] In fact, sustaining recurrent concussions can lead to long-term impairments such as headaches and memory loss if left untreated.[13] Although recurrent concussion rates have decreased (0.47 to 0.28 per 10 000 AEs from 2013 to 2018) across sports in recent years due to improved education around the signs and symptoms of injury, recurrent concussion incidence rates remain high.[14] At the high school level, Kerr et al. have demonstrated 8.3% of concussions to be recurrent.[14] Similarly, from 2009-2014, an estimated 9% of concussions sustained by NCAA college athletes were recurrent.[15] A history of concussions is considered a potential risk factor for sustaining further concussions.[16] Compared to athletes sustaining their first concussions, athletes sustaining recurrent concussions have been shown to miss more playing time and become unconscious more frequently.[13] Additionally, recurrent concussion incidence rates are affected by the length of sport participation and the field position played.[16]

Differences in concussion incidence exist on the basis of sex. Soccer and basketball concussion incidence rates are significantly higher in females than males (1.76 and 1.99 respectively).[17] For soccer, female players sustain more concussions while heading and goalkeeping than experienced by male players.[18] In particular, the mechanism of injury (MOI) differs between male and female athletes, with player contact being the predominant MOI in men and equipment contact being the predominant MOI in women.[19] A study by van Ierssel et al. found that children and adolescents who have sustained previous concussions have nearly four times greater risk of a recurrent concussion compared to those with no previous concussion incidence.[20] Our meta-analysis aimed to compare recurrent concussion incidence between male and female athletes across various sports. We hypothesized that in sex-comparable sports, female athletes would experience a greater rate of recurrent concussions.

Quality assessment results are shown in Appendix 2. All of the included studies were rated as fair quality, mostly due to the retrospective nature of most studies.

METHODS

Literature Search Methodology

A medical librarian (BJ) conducted a comprehensive search of the PubMed, EMBASE, and Cochrane Library databases in adherence with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Search terms utilized were "sex," "gender," "sex differences," "gender identity," "brain concussion," "concussion," "traumatic brain injury," "brain injury," "sports," "athletes," "incidence," "epidemiology," "symptoms," and "injury rate." The exact search string can be found in Appendix 1.

Studies that included head-to-head comparisons of recurrent concussion incidence by sex and were published between January 2000 and June 2021 were included in this meta-analysis to focus on incidence within the last twenty years during which interventions have been implemented to actively prevent concussions. Conference abstracts, studies that did not present sex comparisons, studies that presented concussion data from a non-sports-related setting (for example, emergency room settings), and studies written in a language other than English were excluded from this meta-analysis. Two authors (UD, DL) used the online software program Covidence (Veritas Health Innovation Ltd; Melbourne, Australia) to independently screen titles, abstracts, and full-article texts. Any disagreements were resolved through consensus with the senior author (DL).

Data Extraction

The following data were independently extracted from full-text articles: study design, sample size information (i.e., number of athletes, number of athlete exposures, etc.), population (i.e., high school, college, professional), recurrent concussion incidence, type of sport, and database used. Each included study defined recurrent concussions as concussions sustained by

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individuals who had previously sustained at least one formally diagnosed concussion.

Data Synthesis and Meta-analysis

Each study in the meta-analysis contributed at least two pairs of numbers: the number of recurrent concussions and the number of athlete-exposures in males and females. One athlete-exposure was defined as participation in 1 game or 1 practice session. All incidence rates were converted to a common denominator of 10,000 athlete-exposures, which is the predominantly used denominator across the included studies. A rate ratio (RR) was calculated by dividing recurrent concussion rates for females by that for males. Therefore, RRs greater than 1 indicated a greater recurrent concussion rate among women, and RRs less than 1 indicated a greater recurrent concussion rate among men.

Data from each study were pooled using the DerSimonian-Laird random-effects model (REM). This model provides more conservative estimates with wider confidence intervals compared to fixed-effects models since it assumes that the studies included in the meta-analysis are only a sample of all possible studies and that there is a possibility of relevant studies not being included.[21] Additionally, the REM accounts for both between-study variability (heterogeneity) and within-study variability (random error). A separate meta-analysis was performed for each sport if there were at least 3 studies reporting recurrent concussion data for the particular sport. The forest plots display RRs and 95% confidence intervals for each comparison. It is possible that certain individual concussions were represented multiple times in the pooled analysis because multiple studies used the same concussion databases.[13-15] However, each study covered different date ranges for different sports, indicating a low probability of any such overlap between subjects. Additionally, each study reported a different RR and recurrent concussion incidence rate.

RESULTS

Study Selection

A total of 1,509 records were identified through database, as well as manual searches of articles that were included in the meta-analysis by van Ierssel et al.[20] 439 records were duplicates and excluded. Title and abstract screening were performed on the remaining 1,070 records and 956 of these were determined to be irrelevant to the study aims. The remaining 114 studies were assessed for eligibility with full-text review. After excluding 49 studies for not having sex-specific recurrent concussion data, 17 studies for not having sex-specific concussion data, 10 studies for having wrong outcomes or comparators, and 18 studies for having the incorrect study design (e.g., reviews), patient populations, and settings, 20 studies were included for data extraction. Of these studies, eleven were excluded for having insufficient data, and three were excluded because they were conference abstracts. Thus, six studies were included in this meta-analysis (**Figure 1**).

Study Characteristics

Of the six included articles, five were retrospective database studies that utilized national injury surveillance systems. Three of these studies incorporated the High School Reporting Information Online (RIO) database,[13-14, 23] one study used aggregate exposure data from the high school National Athletic Treatment, Injury and Outcomes Network (NATION) study[22], and one study used the National Collegiate Athletic Association–Injury Surveillance Program (NCAA-ISP).[15] Of the six included articles, one was a prospective study. This study recruited Swedish elite soccer teams to self-report injury and exposure data. Of particular note is the high representation of soccer across all included studies. A summary of the characteristics of the included studies is provided in **Table 1**.

Concussion Incidence

Four of the six included studies were used to compare recurrent concussion rates across soccer, basketball, and baseball/softball.[13-15, 22] The remaining two studies were not included because they only reported data about soccer.[23-24] The pooled summary estimate indicated that female athletes experience more recurrent concussions than male athletes across sex-comparable sports [RR=2.16 (95% CI: 1.09-4.30)] (**Figure 2**). With one exception, each individual study reported an RR significantly greater than 1, indicating female athletes experienced more recurrent concussions than male athletes.[13, 14, 22] Zuckerman et al.[15] reported a 95% confidence interval of the RR that crossed the null value [RR= 0.90 (95% CI: 0.62-1.32)].

Female basketball players were found to experience nearly three times as many recurrent

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concussions as male basketball players [RR= 2.68 (95% CI: 1.39-5.17)] (**Figure 3**). Two of the three included studies displayed an RR significantly greater than 1.[13-14] The Zuckerman et al.[15] study reported an RR greater than 1, but with a 95% confidence interval that crossed the null value [RR=1.21 (95% CI: 0.53-2.74)], suggesting this study did not have conclusive results about sex disparity in recurrent concussion incidence.

Female soccer players were also found to experience three times as many recurrent concussions as male soccer players [RR=3.01 (95% CI: 2.08-4.35)] (**Figure 4**). Four of five included studies displayed an RR significantly greater than 1.[8-10, 18] The study by Vedung et al.[24] was an exception as it reported an RR greater than 1 but with a 95% confidence interval that crossed the null value [RR=2.06 (95% CI: 0.87, 4.90)].

Non-significant results were observed for the comparison of baseball and softball.[8-10] The pooled summary estimate for this sport type crossed the null value [RR=2.54 (95% CI: 0.54-11.94)] (**Figure 5**), suggesting that a conclusive statement about a sex disparity in recurrent concussion incidence in baseball and softball cannot be made.

DISCUSSION

This study demonstrated that women face a greater risk of recurrent concussions than men in sex-comparable sports. The pooled summary RR across all included studies demonstrated that women experience roughly twice as many recurrent concussions across sex-comparable sports as their male counterparts. In particular, our sport-specific analysis found that recurrent concussion rates were nearly three times higher for female athletes playing soccer and basketball.

The results of this study show the existence of a stark sex disparity in recurrent concussion incidence. Previous studies have shown that women experience more concussions in sex-comparable sports[17] and that in ball-based sports like lacrosse and soccer, women are at higher risk for concussions due to contact with the ball or equipment.[19] Furthermore, in soccer, women are more likely to sustain concussions when heading the ball or while goalkeeping.[18] This study builds on these findings by demonstrating that this sex-based discrepancy in primary sports concussion incidence is observed with concussion recurrence as well. Recurrent concussion risk is important to understand given that athletes who have sustained recurrent concussions take longer for their symptoms to resolve, more frequently lose consciousness, and miss more playing time.[13, 25-26] In some cases, athletes who sustain multiple untreated concussions may have poorer long-term outcomes and can be vulnerable to persistent symptoms such as memory loss and depression over 20 years after ending their careers.[27-28]

The role of factors such as age, sex, and genetic makeup in concussion incidence and recurrence are not fully understood.[24,29] Neidecker et al. showed that female adolescent athletes have a longer duration of symptoms following first-time concussion compared to male athletes, with women remaining symptomatic for a median of 28 days compared to 11 days for their male counterparts.[30] It is possible that having a longer duration of symptoms or returning to sport before complete recovery of symptoms may predispose female athletes to an increased risk of sustaining a recurrent concussion. Additionally, female athletes are more likely than male athletes to report a concussion.[31] Sex-differences in reporting behavior could affect both first-time and recurrent concussion incidence rates.

Many biomechanical explanations have been outlined for the discrepancy in male and female sports concussion incidence. It has been proposed that women experience more frequent concussions given their smaller neck girth, head-neck length, and subsequent weaker head-neck strength compared to men.[18, 32] Furthermore, men have greater neck-torso strength on average than women, which may enable them to better distribute forces across their upper bodies instead of their heads alone.[33-35] Differences in the levels of estrogen and progesterone may also explain potential sex-based differences in concussion incidence.[18, 20, 36]

Recurrent concussions may also have a disparate neurostructural impact on female athletes. In two studies, women exposed to repetitive subconcussive head impacts have more significant microstructural white matter alterations compared to men.[37-38]

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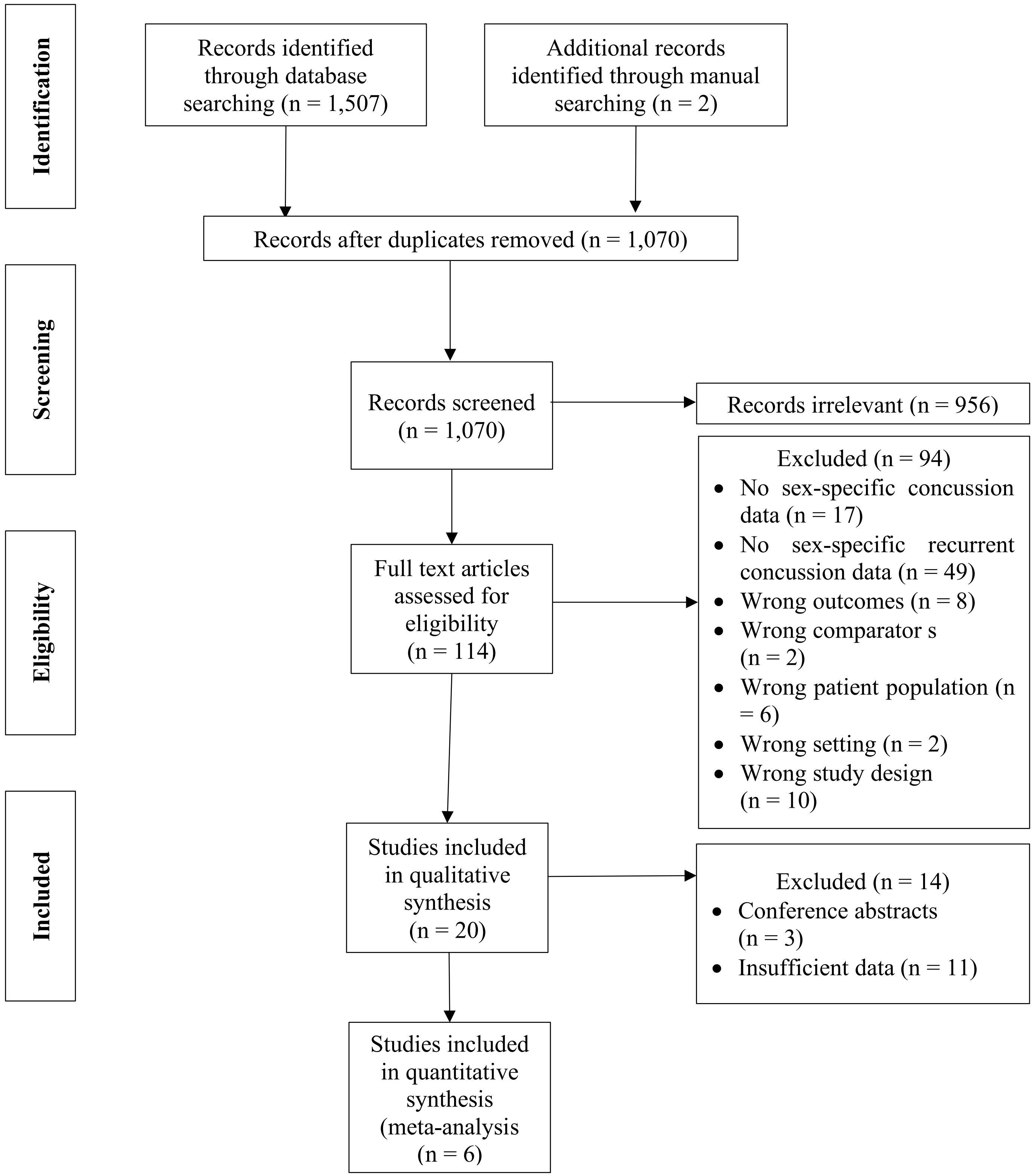

Figure 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) study selection flow diagram. The numbers of screened, excluded, and included studies are shown.

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Table 1. Characteristics of studies included in the meta-analysis[13-15, 22-23]

Author	*Years Included*	*N (Athlete-Exposures)*	*Sex or Gender-Comparable Sports*	*Database*	*Population*
Castile et al.	2005-2010	9,503,641	Soccer, Basketball, Baseball/Softball	High School RIO	High School
Zuckerman et al.	2009-2014	3,638,885	Soccer, Ice Hockey, Basketball, Baseball/Softball, Lacrosse	NCAA-ISP	Collegiate
O'Connor et al.	2011-2014	5,151,671	Overall (27 Sports)	High School NATION	High School
Kerr/Campbell et al.	2012-2016	1,271,931	Soccer	High School RIO	High School
Kerr/Chandran et al.	2013-2018	22,870,364	Soccer, Lacrosse, Basketball, Baseball/ Softball, Swimming, Track and Field, Cross Country	High School RIO	High School
Vedung et al.	2017	25,146	Soccer	N/A (direct recruitment of athletes)	Professional

Given these sex disparities in outcomes associated with recurrent head trauma, it is important to further understanding of patterns of recurrent concussion incidence to inform proper preventative measures, targeted treatment options, and to address any sex-based or sport-based disparities.[25, 39] A recent study identified that female athletes at the high school level were less likely to be removed from play after sustaining a concussion compared to male athletes.[40] It is possible that sex differences in recurrent concussions may be due to inadequate management or recovery from the initial episode.

This meta-analysis has a few limitations. Only studies written in English were included in our literature search, which could have led to relevant research being excluded. Analysis could only be performed on available data from studies that fit the inclusion criteria, therefore we were unable to stratify by setting (competition versus practice) or level (high school versus college versus professional). Data was derived from databases without patient-specific data, and there was insufficient data to evaluate position-specific recurrent concussion risks. There were also insufficient data to summarize time between the first and subsequent concussions and the number of previous concussions. Furthermore, there were insufficient data to evaluate the extent to which athletes sustaining recurrent concussions recovered from their most recent concussion. There was also a high availability of soccer data relative to data regarding basketball and baseball/softball, which suggests that soccer is overrepresented in the pooled summary for sex-comparable sports.

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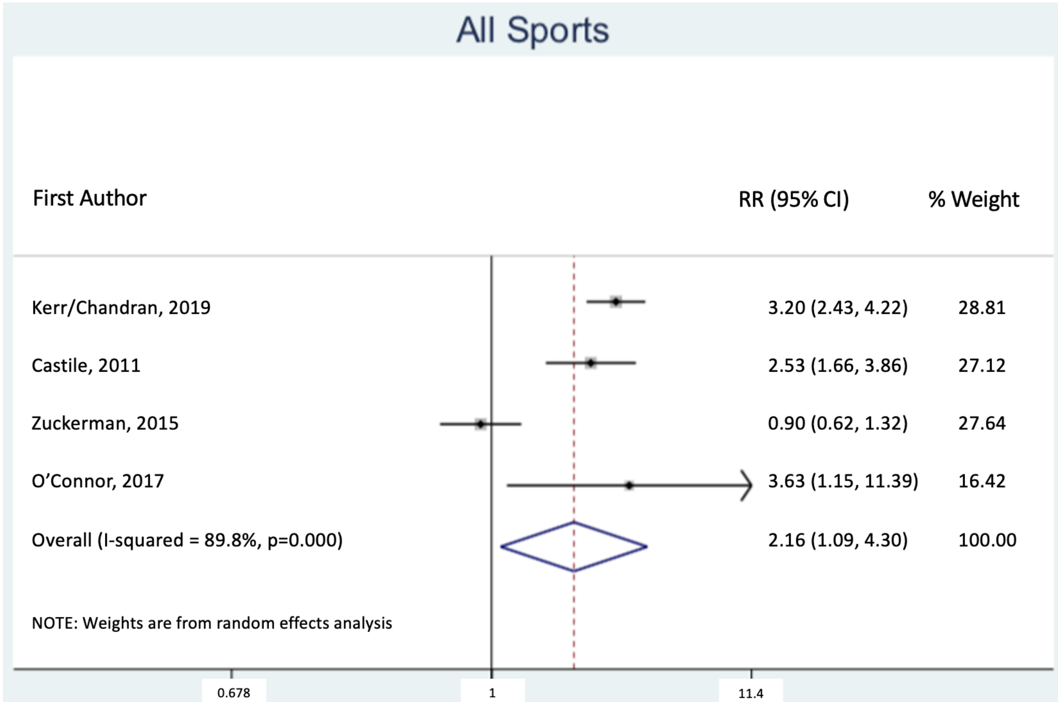

Figure 2. Recurrent concussion incidence rate ratios for all sex-comparable sports are shown for each study and as an overall pooled summary estimate.

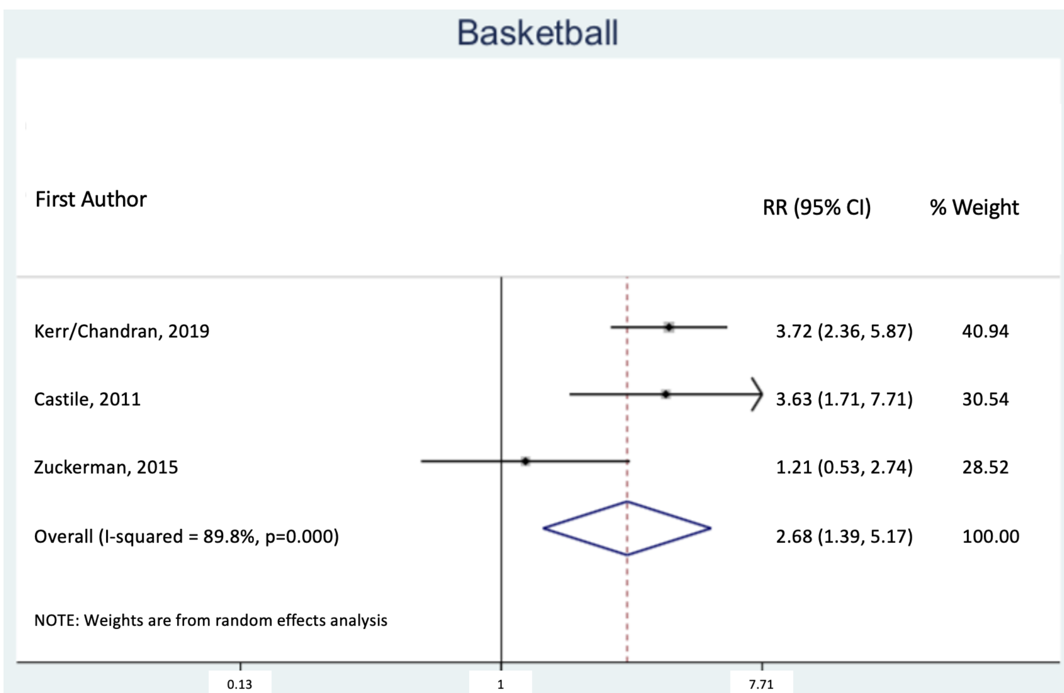

Figure 3. Recurrent concussion incidence rate ratios for basketball are shown for each study and as an overall pooled summary estimate.

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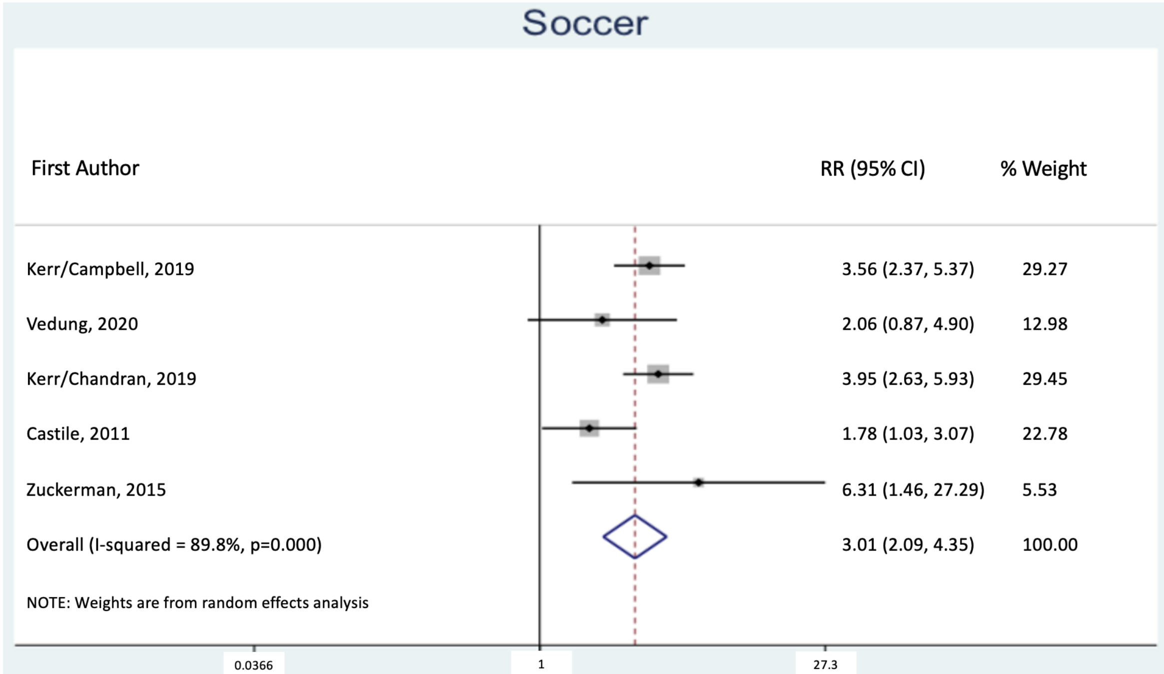

Figure 4. Recurrent concussion incidence rate ratios for soccer are shown for each study and as an overall pooled summary estimate.

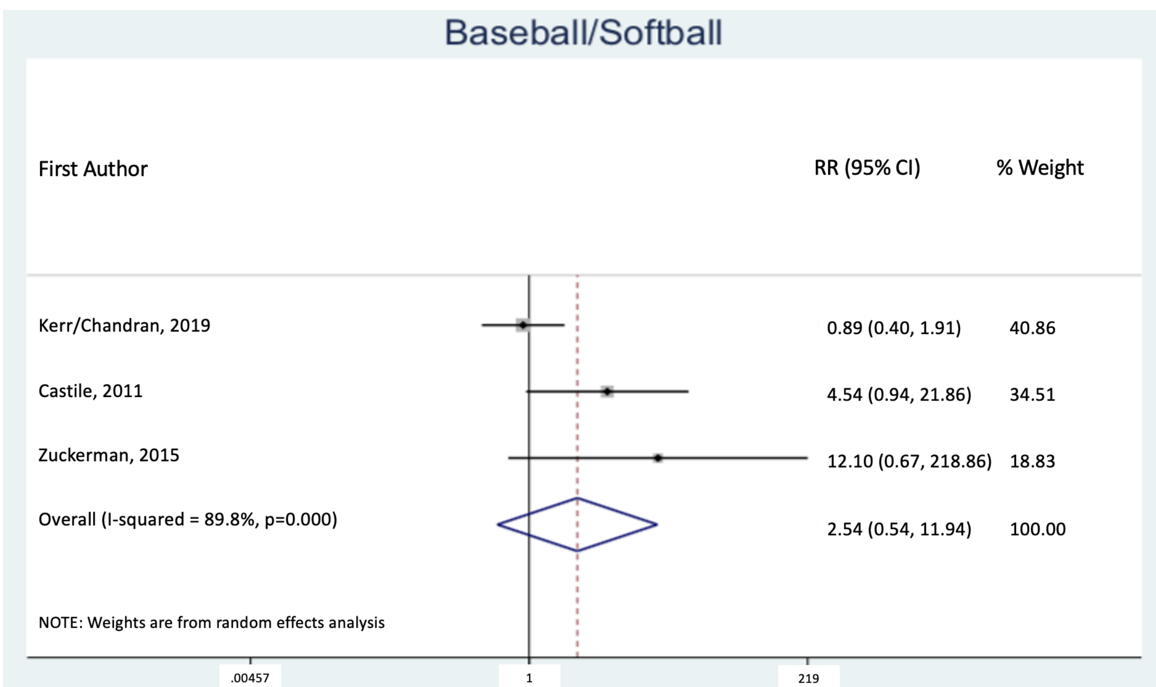

Figure 5. Recurrent concussion incidence rate ratios for baseball/softball are shown for each study and as an overall pooled summary estimate.

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Our study also has several strengths. We were able to conduct a comprehensive search strategy with overlapping approaches with the help of a medical librarian. Previous studies have shown that systematic reviews with librarians as coauthors are associated with enhanced study quality.[41] In addition, the pooled summary estimates in our meta-analysis were based on head-to-head sex comparisons from the same study rather than data from disparate studies. Summarizing the incidence of recurrent concussions from men's and women's sports separately would not allow for the calculation of RRs. Furthermore, the evidence would be based on different settings and populations across the studies. Our approach provides direct comparisons between men and women in sex-comparable sports.

Our findings suggest that recurrent concussions may be more common in women compared to men, especially for athletes participating in high-risk sports such as soccer and basketball. For these sports, women are three times more likely to sustain a recurrent concussion than men. Greater education regarding the signs and symptoms of injury, rule changes, protective equipment, and concussion prevention exercises are potential interventions, but they have not been widely evaluated. Given the increased likelihood of experiencing persistent neurologic symptoms associated with recurrent concussions, it is imperative that sports are made safer to reduce concussion rates and athletes are evaluated immediately after a potential injury and referred for specialized treatment and management if deemed concussed.[13] More studies exploring the factors responsible for recurrent concussion incidence and subsequent recovery will improve safety of sports at all levels.

Health care providers, athletic trainers, and sports coaches should develop an understanding of factors leading to concussions to reduce their risk. The hypothalamic-pituitary-ovarian axis should be further explored to better understand the effect of menstrual cycle patterns in concussion incidence, recovery, and recurrence. Future studies should also explore the efficacy of interventions such as rule changes, protective equipment incorporation, and incorporation of neck strengthening exercises in mitigating recurrent concussion incidence.

CONCLUSION

This meta-analysis showed recurrent concussion rates are greater in sex-comparable women's sports than in men's sports, particularly soccer and basketball. Future studies should focus on mechanisms commonly seen in individuals who sustain recurrent concussions to evaluate specific risk factors for each sex.

Conflict of Interest Statement

The authors report no conflict of interest with the contents of this manuscript.

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REFERENCES

1. Baldwin GT, Breiding MJ, Dawn Comstock R. Epidemiology of sports concussion in the United States. Handb Clin Neurol. 2018;158:63-74. doi:10.1016/B978-0-444-63954-7.00007-0
2. Kontos AP, Sufrinko A, Sandel N, Emami K, Collins MW. Sport-related Concussion Clinical Profiles: Clinical Characteristics, Targeted Treatments, and Preliminary Evidence. Curr Sports Med Rep. 2019;18(3):82-92. doi:10.1249/JSR.0000000000000573
3. Collins MW, Kontos AP, Reynolds E, Murawski CD, Fu FH. A comprehensive, targeted approach to the clinical care of athletes following sport-related concussion. Knee Surg Sports Traumatol Arthrosc 2014;22(2):235-246. doi:10.1007/s00167-013-2791-6
4. Makdissi M, Cantu RC, Johnston KM, et al. The difficult concussion patient: what is the best approach to investigation and management of persistent (>10 days) postconcussive symptoms?. Brit J Sports Med 2013;47:308-13 doi:10.1136/bjsports-2013-092255.
5. Ellis MJ, Leddy J, Willer B. Multi-Disciplinary Management of Athletes with Post-Concussion Syndrome: An Evolving Pathophysiological Approach. Front Neurol 2016;7:136 doi:10.3389/fneur.2016.00136.
6. Leddy JJ, Haider MN, Ellis M, Willer BS. Exercise is Medicine for Concussion. Curr Sports Med Rep. 2018;17(8):262-270. doi:10.1249/JSR.0000000000000505
7. McCrory P, Meeuwisse W, Dvořák J, et al. Consensus statement on concussion in sport-the

DOI: 10.53646/jwsm.v2i2.28
Published online: December 22, 2022

5th international conference on concussion in sport held in Berlin, October 2016. Br J Sports Med. 2017;51(11):838-847. doi:10.1136/bjsports-2017-097699
8. French J, Jennings S, Eagle SR, Collins MW, Kontos AP. A Within-Subjects Comparison of Clinical Outcomes for Patients' First and Second Concussions. J Head Trauma Rehabil. 2021;36(2):114-119. doi:10.1097/HTR.0000000000000612
9. Leddy JJ, MD, Baker JG, PhD, Willer B, PhD. Active Rehabilitation of Concussion and Post-concussion Syndrome. Phys Med Reh Clin N 2016;27:437-54 doi:10.1016/j.pmr.2015.12.003.
10. Dvorak J, McCrory P, Kirkendall DT. Head injuries in the female football player: incidence, mechanisms, risk factors and management. Brit J Sports Med 2007;41:i44-6 doi:10.1136/bjsm.2007.037960.
11. Kroshus E, Garnett B, Hawrilenko M, et al. Concussion under-reporting and pressure from coaches, teammates, fans, and parents. Soc Sci Med 2015;134:66-75 doi:10.1016/j.socscimed.2015.04.011.
12. Guskiewicz KM, McCrea M, Marshall SW, et al. Cumulative Effects Associated With Recurrent Concussion in Collegiate Football Players: The NCAA Concussion Study. JAMA 2003;290:2549-55 doi:10.1001/jama.290.19.2549.
13. Castile L, Collins CL, McIlvain NM, et al. The epidemiology of new versus recurrent sports concussions among high school athletes, 2005–2010. Brit J Sports Med 2012;46:603-10 doi:10.1136/bjsports-2011-090115.
14. Kerr ZY, Chandran A, Nedimyer AK, et al. Concussion Incidence and Trends in 20 High School Sports. Pediatrics 2019;144:e20192180 doi:10.1542/peds.2019-2180.
15. Zuckerman SL, Kerr ZY, Yengo-Kahn A, Wasserman E, Covassin T, Solomon GS. Epidemiology of Sports-Related Concussion in NCAA Athletes From 2009-2010 to 2013-2014: Incidence, Recurrence, and Mechanisms [published correction appears in Am J Sports Med. 2016 Jan;44(1):NP5]. Am J Sports Med. 2015;43(11):2654-2662. doi:10.1177/0363546515599634
16. Giza C, Kutcher J, Ashwal S, et al. Summary of evidence-based guideline update: Evaluation and management of concussion in sports: Report of the Guideline Development Subcommittee of the American Academy of Neurology. Neurology 2013;80:2250-7 doi:10.1212/WNL.0b013e31828d57dd.
17. Cheng J, Ammerman B, Santiago K, et al. Sex-Based Differences in the Incidence of Sports-Related Concussion: Systematic Review and Meta-analysis. Sports Health: A Multidisciplinary Approach 2019;11:486-91 doi:10.1177/1941738119877186.
18. Dave U, Kinderknecht J, Cheng J, Santiago K, Jivanelli B, Ling DI. Systematic review and meta-analysis of sex-based differences for concussion incidence in soccer. Phys Sportsmed. 2022;50(1):11-19. doi:10.1080/00913847.2020.1868955
19. Ling DI, Cheng J, Santiago K, et al. Women Are at Higher Risk for Concussions Due to Ball or Equipment Contact in Soccer and Lacrosse. Clin Orthop Relat R 2019 doi:10.1097/CORR.0000000000000995.
20. van Ierssel J, Osmond M, Hamid J, Sampson M, Zemek R. What is the risk of recurrent concussion in children and adolescents aged 5-18 years? A systematic review and meta-analysis. Br J Sports Med. 2021;55(12):663-669. doi:10.1136/bjsports-2020-102967
21. Lau J, Ioannidis JPA, Schmid CH. Quantitative Synthesis in Systematic Reviews. Ann Intern Med 1997;127:820 doi:10.7326/0003-4819-127-9-199711010-00008.
22. O'Connor KL, Baker MM, Dalton SL, Dompier TP, Broglio SP, Kerr ZY. Epidemiology of Sport-Related Concussions in High School Athletes: National Athletic Treatment, Injury and Outcomes Network (NATION), 2011-2012 Through 2013-2014. J Athl Train. 2017;52(3):175-185. doi:10.4085/1062-6050-52.1.15
23. Kerr ZY, Campbell KR, Fraser MA, et al. Head Impact Locations in U.S. High School Boys' and Girls' Soccer Concussions, 2012/13–2015/16. J Neurotraum 2019;36:273-2082 doi:10.1089/neu.2017.5319.
24. Vedung F, Hänni S, Tegner Y, Johansson J, Marklund N. Concussion incidence and recovery in Swedish elite soccer - Prolonged recovery in female players. Scand J Med Sci Sports. 2020;30(5):947-957. doi:10.1111/sms.13644
25. Brook EM, Luo X, Curry EJ, Matzkin EG. A heads up on concussions: are there sex-related differences?. Phys Sportsmed. 2016;44(1):20-28. doi:10.1080/00913847.2016.1142834
26. Wasserman EB, Kerr ZY, Zuckerman SL, Covassin T. Epidemiology of Sports-Related Concussions in National Collegiate Athletic Association Athletes From 2009-2010 to 2013-2014: Symptom Prevalence, Symptom Resolution Time, and Return-to-Play Time. Am J Sports Med. 2016;44(1):226-233. doi:10.1177/0363546515610537
27. Hänni S, Vedung F, Tegner Y, Marklund N, Johansson J. Soccer-Related Concussions Among Swedish Elite Soccer Players: A Descriptive Study of 1,030 Players. Front Neurol. 2020;11:510800. Published 2020 Sep 23. doi:10.3389/fneur.2020.510800
28. Decq P, Gault N, Blandeau M, et al. Long-term consequences of recurrent sports concussion. Acta

DOI: 10.53646/jwsm.v2i2.28
Published online: December 22, 2022

Neurochir (Wien). 2016;158(2):289-300. doi:10.1007/s00701-015-2681-4
29. Noble JM, Hesdorffer DC. Sport-related concussions: a review of epidemiology, challenges in diagnosis, and potential risk factors. Neuropsychol Rev. 2013;23(4):273-284. doi:10.1007/s11065-013-9239-0
30. Neidecker JM, Gealt DB, Luksch JR, Weaver MD. First-Time Sports-Related Concussion Recovery: The Role of Sex, Age, and Sport. J Am Osteopath Assoc. 2017;117(10):635-642. doi:10.7556/jaoa.2017.120
31. Wallace J, Covassin T, Beidler E. Sex Differences in High School Athletes' Knowledge of Sport-Related Concussion Symptoms and Reporting Behaviors. J Athl Train. 2017;52(7):682-688. doi:10.4085/1062-6050-52.3.06
32. Bretzin AC, Mansell JL, Tierney RT, McDevitt JK. Sex Differences in Anthropometrics and Heading Kinematics Among Division I Soccer Athletes. Sports Health. 2017;9(2):168-173. doi:10.1177/1941738116678615
33. Aubry M, Cantu R, Dvorak J, et al. Summary and agreement statement of the First International Conference on Concussion in Sport, Vienna 2001. Recommendations for the improvement of safety and health of athletes who may suffer concussive injuries. Br J Sports Med. 2002;36(1):6-10. doi:10.1136/bjsm.36.1.6
34. Johnston KM, McCrory P, Mohtadi NG, Meeuwisse W. Evidence-Based review of sport-related concussion: clinical science. Clin J Sport Med. 2001;11(3):150-159. doi:10.1097/00042752-200107000-00005
35. Scott Delaney J, Puni V, Rouah F. Mechanisms of injury for concussions in university football, ice hockey, and soccer: a pilot study. Clin J Sport Med. 2006;16(2):162-165. doi:10.1097/00042752-200603000-00013
36. Chandran A, Barron MJ, Westerman BJ, DiPietro L. Multifactorial examination of sex-differences in head injuries and concussions among collegiate soccer players: NCAA ISS, 2004-2009. Inj Epidemiol. 2017;4(1):28. Published 2017 Oct 25. doi:10.1186/s40621-017-0127-6
37. Rubin TG, Catenaccio E, Fleysher R, et al. MRI-defined White Matter Microstructural Alteration Associated with Soccer Heading Is More Extensive in Women than Men. Radiology. 2018;289(2):478-486. doi:10.1148/radiol.2018180217
38. Sollmann N, Echlin PS, Schultz V, et al. Sex differences in white matter alterations following repetitive subconcussive head impacts in collegiate ice hockey players. Neuroimage Clin. 2017;17:642-649. Published 2017 Nov 21. doi:10.1016/j.nicl.2017.11.020
39. Swenson DM, Yard EE, Fields SK, Comstock RD. Patterns of recurrent injuries among US high school athletes, 2005-2008. Am J Sports Med. 2009;37(8):1586-1593. doi:10.1177/0363546509332500
40. Zynda AJ, Petit KM, Anderson M, Tomczyk CP, Covassin T. Removal From Activity After Sports-Related Concussion in Sex-Comparable Sports From the Michigan High School Athletic Association. Am J Sports Med.2021;49(10):2810-2816. doi:10.1177/03635465211020007
41. Rethlefsen ML, Farrell AM, Osterhaus Trzasko LC, Brigham TJ. Librarian co-authors correlated with higher quality reported search strategies in general internal medicine systematic reviews. J Clin Epidemiol. 2015;68(6):617-626. doi:10.1016/j.jclinepi.2014.11.025

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APPENDIX 1. Search strings for the systematic review

PubMed
(((((("sex"[MeSH] OR "sex"[TW] OR "gender identity"[MeSH] OR "gender"[TW] OR "sex differences"[TW]))) AND ("brain concussion"[MeSH] OR "concussion"[TW] OR "Concussions"[TW] OR "traumatic brain injury"[TW])) AND ("sports"[MeSH] OR "sports"[TW] OR "sport"[TW] OR "athletes"[TW])) AND ("incidence"[MeSH] OR "incidence"[TW] OR "epidemiology"[MeSH] OR "epidemiology"[TW] OR "symptoms"[TW] OR "injury rate"[TW]) AND (2000/1/1:3000/12/12[pdat]

EMBASE
('sex'/exp OR sex:ti,ab,de,tn OR 'gender identity'/exp OR gender:ti,ab,de,tn OR "sex differences":ti,ab,de,tn)
AND ('brain concussion'/exp OR concussion:ti,ab,de,tn OR Concussions:ti,ab,de,tn OR "traumatic brain injury":ti,ab,de,tn)
AND ('brain concussion'/exp OR concussion:ti,ab,de,tn OR Concussions:ti,ab,de,tn OR "traumatic brain injury":ti,ab,de,tn)
AND
('sport'/exp OR sports:ti,ab,de,tn OR sport:ti,ab,de,tn OR athletes:ti,ab,de,tn)
AND
('incidence'/exp OR incidence:ti,ab,de,tn OR 'epidemiology'/exp OR epidemiology:ti,ab,de,tn OR symptoms:ti,ab,de,tn OR "injury rate":ti,ab,de,tn)
AND [1-1-2000]/sd

COCHRANE
([mh sex] OR sex:ti,ab,kw OR [mh "gender identity"] OR gender:ti,ab,kw OR "sex differences":ti,ab,kw)
AND
([mh "brain concussion"] OR concussion:ti,ab,kw OR Concussions:ti,ab,kw OR "traumatic brain injury":ti,ab,kw)
AND
([mh sports] OR sports:ti,ab,kw OR sport:ti,ab,kw OR athletes:ti,ab,kw)
AND
([mh incidence] OR incidence:ti,ab,kw OR [mh epidemiology] OR epidemiology:ti,ab,kw OR symptoms:ti,ab,kw OR "injury rate":ti,ab,kw)
with Cochrane Library publication date from January 2000 to June 2021

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APPENDIX 2. Quality assessment results of included studies using the Newcastle-Ottawa Scale

Study	Selection[a]						Comparability[b]	Outcome[c]				Quality assessment
	A	B	C	D				A	B	C	D	
Castile et al.	1	0	1	0			1	1	1	1	1	Fair
Zuckerman et al.	1	0	1	0			1	1	1	0	0	Fair
O'Connor et al.	1	0	1	0			1	1	1	1	1	Fair
Kerr, Campbell, et al.	1	0	1	0			1	1	1	0	0	Fair
Kerr, Chandran, et al.	1	0	1	0			2	1	1	0	0	Fair
Vedung et al.	1	0	1	0			2	1	1	1	1	Fair

[a] Selection criteria - (A) representativeness of the exposed cohort (athletes), 1: truly representative of the average youth, high school, collegiate, or adult athlete in the community; 0: not representative of the average athlete in the community or no description of the derivation of the cohort; (B) selection of the non-exposed cohort, 1: drawn from the same community as the athlete cohort; 0: drawn from a different source than the athlete cohort or no description of the derivation of the non-exposed cohort; (C) ascertainment of exposure, 1: secure record of concussion incident or structured interview; 0: written self-report or no description; (D) demonstration that outcome of interest (concussion incidence) was not present at start of study, 1: yes, 0: no.

[b] Comparability between males and females on the basis of the design or analysis: 1, study includes concussion incidence for males and females in a specific sport; 2, study includes concussion incidence for males and females in a specific sport as well as other factors, such as age or skill level; 0, study does not include concussion incidence for males and females.

[c] Outcome criteria - (A) assessment of outcome: 1: independent blind assessment or blind linkage; 0: self-report or no description; (B) was follow-up long enough for outcomes to occur: 1: yes, 0: no; (C) adequacy of follow-up of cohorts: 1: complete follow-up of all subjects or subjects lost to follow-up were unlikely to introduce bias; 0: follow-up rate not adequate or no statement; and (D) statistical test: 1: the statistical test used to analyze data is
clearly described and appropriate, and the measurement of the association is presented, including confidence intervals and p values; 0: the statistical test is not appropriate, not described, or incomplete.

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