# Prevention strategies and modifiable risk factors for concussion: a systematic review and meta-analysis for the Female, woman and girl Athlete Injury pRevention (FAIR) consensus

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## ABSTRACT

**Objective** To examine prevention strategies and potential modifiable risk factors (MRFs) for sport-related concussion (SRC) and head impact/head acceleration event (HAE) outcomes in female, woman and/or girl athletes.

**Design** Systematic review with meta-analyses and Grading of Recommendations, Assessment, Development and Evaluation.

**Data sources** Medline, CINAHL, PsycINfo, SportDiscus, ERIC, CENTRAL and CDSR.

**Eligibility** Primary data studies with comparison group(s) assessing the association of prevention interventions and/or MRFs for SRC or HAE with ≥1 female/woman/girl in each study group.

**Results** Of the 108 included studies, 67 evaluated a SRC prevention strategy (equipment n=25, policy/rule n=21, training n=10, management n=11) and 41 evaluated potential MRFs (34 distinct MRFs across nine categories). In total, 40/108 (37%) studies (prevention 19/67; MRF 21/41) included female/woman/girl-specific estimates. Three meta-analyses were conducted: two SRC prevention strategies (headgear, eyewear) and one MRF (artificial turf vs grass) based on availability of female/woman/girl-only estimates and similar outcomes and exposure. Headgear was associated with 30% lower SRC rates in adolescent female/girl lacrosse and soccer (IRR=0.70, 95% CI 0.50 to 0.99; very-low certainty). Eyewear use was not protective for SRC (IRR=1.08, 95% CI 0.69 to 1.68; very-low certainty). SRC rates did not differ by artificial turf versus grass (IRR=0.95, 95% CI 0.62 to 1.45; very-low certainty).

**Conclusion** We found limited evidence for prevention strategies and MRFs in female/woman/girl athletes except for very-low certainty evidence supporting headgear use in adolescent lacrosse and soccer. Future studies should consider the design, implementation and evaluation of SRC prevention strategies that target MRFs to guide safe practice recommendations specifically for female/woman/girl athletes.

## INTRODUCTION

Sport-related concussions (SRC) are a public health concern with elevated rates for female, woman and/or girl (hereafter female/woman/girl) athletes relative to males/men/boys.[1–3] The higher burden of SRC in female/woman/girl athletes may be related to sex-specific and/or gender-specific physiological, biomechanical and/or sociocultural factors and mechanisms.[4 5] These could be linked to hormonal differences, differences in neck strength/control, a higher likelihood of reporting a concussion, or mechanistic differences, such as heading a ball in soccer or tackle characteristics within rugby.[1 6–8]

SRC primary prevention strategies can include training programmes (eg, neuromuscular training warm-up, tackle training), equipment (eg, headgear, mouthguards) and policy/rule changes (eg, body checking policy, reduced legal tackle height).[9] Secondary prevention strategies facilitate early detection and care following SRC to reduce recurrence.[10 11] Potential modifiable risk factors (MRFs) consider intrinsic (individual) and extrinsic (environmental) factors to inform the development of targeted prevention strategies to reduce SRC incidence rates, severity and burden.[11 12]

The Consensus Statement on Concussion in Sport (Amsterdam 2022) provided recommendations for the prevention, diagnosis and management of SRC and head impact (ie, typically measured through video analysis and expressed as frequencies and/or rates) and/or head acceleration events (HAEs) (ie, typically measured through wearable technologies such as instrumented mouthguards to measure linear and rotational acceleration) (hereafter, head impact/HAE).[10] Only 3% of studies informing prevention and modifiable risk factor recommendations in the Consensus Statement were female/woman/girl focused.[13] Although some recommendations translate, studies reporting aggregate data across males/man/boy and female/woman/girl athlete contexts may not be appropriate. SRC prevention strategy

**WHAT IS ALREADY KNOWN**

- ⇒ Female/woman/girl athletes experience high rates of sport-related concussion, particularly in collision sports.
- ⇒ It is unclear if there are sex-specific or gender-specific injury prevention approaches or risk factors for sport-related concussion.
- ⇒ Prevention strategies (eg, mouthguards, headgear, policy disallowing body checking in child/adolescent ice hockey, limited contact practice in American football, neuromuscular training in rugby and concussion management) have been shown to reduce concussion rates in primarily male, man and/or boy sports.

**WHAT ARE THE NEW FINDINGS**

- ⇒ Only 37% of included studies report female/woman/girl athlete-specific findings that assessed prevention interventions or identified modifiable risk factors for sport-related concussion.
- ⇒ Very-low certainty evidence (two cohort and one RCT) demonstrated headgear use reduced sport-related concussion rates by 30–39% in adolescent female and/or girl lacrosse and soccer.
- ⇒ Very-low certainty evidence (three cohort studies) indicated protective eyewear is not protective of concussion in adolescent female/girl lacrosse.
- ⇒ Very-low certainty evidence (three cohort studies) revealed soccer-related concussion rates do not differ between grass and artificial turf fields for adult female and/or woman players.
- ⇒ There is limited evidence on training, equipment or policy/rule changes for preventing sport-related concussion in female/woman/girl athletes.
- ⇒ The absence of female/woman/girl Para sport athlete-specific data highlights the significant need for further research on sport-related concussion prevention strategies and modifiable risk factors in athletes with disabilities.

evaluations specific to female/woman/girl athlete contexts are needed to inform female/woman/girl athlete recommendations. Globally, female/woman/girl participation rates in contact/collision sports (eg, rugby, soccer) are growing.[14–17] There is an urgent need for sex-specific and/or gender-specific concussion and head impact/HAE prevention strategies for female/woman/girl athletes.

The primary research questions addressed by this systematic review were:

1. What prevention strategies (eg, training strategies, policy/rules, personal protective equipment, management) reduce SRCs, recurrent SRCs and/or head impacts/HAEs in female/woman/girl athletes, and are there unintended consequences?
2. What are the potential MRFs for SRCs and/or head impacts and/or HAEs in female/woman/girl athletes?

## METHODS

### Registration

This review was registered in the PROSPERO registry (CRD42023485808).

### Framework

The Cochrane Handbook, Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines and PRISMA-Search extension informed the conduct and reporting

**Box 1 Equity, diversity and inclusion statement**

In this review, we refer to participants with the terms ‘female, woman and/or girl’ athletes (with the abbreviation of female/woman/girl) and ‘male, man and/or boy’ athletes (male/man/boy). We recognise the terms are not synonymous and may mean different things to different people. Also, we use the term ‘sex and/or gender’ (sex/gender). We acknowledge the active conversation on the meaning and definitions of gender and sex, and note that the term female(s) is not intended to reduce humans to their biological sex, and terms women and girls are not intended to reduce humans to their gender.

The Female, woman and girl Athlete Injury pRevention (FAIR) Consensus Steering Committee planned and designed this review. The recommendations and FAIR Consensus will be developed in consultation with the FAIR External Advisory Committee. This group (n=24, 80% women; n=17, 71%) affiliated with International Olympic Committee (IOC) Research Centres for prevention of injury and protection of athlete health includes academics and sports medicine/health professionals (n=19; 79%) with broad expertise ranging from epidemiology (n=18; 75%), injury prevention (n=21; 88%), sport sciences (n=4; 17%), health promotion (n=2; 88%), and across career stage (n=7 late-career, n=9 mid-career, n=8 early career) from 4 continents, who are mostly white, and from well-resourced countries.

For this systematic review, authors were chosen by the FAIR Steering Committee based on relevant and diverse experiences, backgrounds, expertise and professions. Authors were 58% women (n=14); 79% white (n=19); 4% from middle-to-low income birth countries (n=1); 13% ability limited (n=3), with self-reported lived experience as an athlete (n=11; 46%), coach (n=9; 38%), referee (n=2; 8%), health, medical or exercise practitioner (n=13; 54%), and member for sport organisation (n=8; 33%), government (n=2; 8%), or healthcare (n=7; 29%) committees across paediatric (n=20; 83%), adult (n=17; 71%), and Para sport (n=14; 58%) spanning four continents and career stage (n=3 graduate students; n=9 early-, n=6 mid-, n=6 late-career). The author demographics related to the current concussion prevention and modifiable risk factor review are in online supplemental material 4. We recognise that the limited number of authors who are not white, from low-income countries, and ability-limited may also reflect the limited diversity of the study participants included in studies included in this review.

of this review (online supplemental material 1).[18–20] Equity, diversity and inclusion, and patient and public engagement statements are provided in Box 1 and Box 2, respectively.

### Data sources and search strategy

Relevant studies were identified by searching eight databases (Medline ALL-OVID, CINAHL Plus with Full Text-EBSCOhost, APA PsycINFO-OVID, Cochrane Database of Systematic Reviews-OVID, CENTRAL-OVID, SPORTDiscus with Full Text-EBSCOhost EMBASE-OVID, ERIC-EBSCOhost). Search strategies consisted of subject headings and text words related to (1) SRC, head impact and HAE; (2) sports and (3) prevention and risk factors, with limits for publication (2001 to current), consistent with the International Consensus Statement on Concussion

**Box 2 Patient and public involvement**

**FAIR Consensus External Advisory Committee (EAC)**: The FAIR EAC consists of 8 women with lived experiences as elite (n=1 Olympian, n=1 Paralympian) and youth (n=1) athletes, team physicians/physiotherapists (n=3), coaches (n=2), sport scientists (n=1), and leadership roles in sport (n=5), government (n=2), industry (n=1), and healthcare (n=5) organisations spanning multiple ethnicities (62.5% white), birth countries (50% from low to middle-income), and abilities (n=4 Para sport). The EAC level of engagement is consistent with the International Association for Public Participation 'consult' or 'involve' level with tasks including reviewing and providing feedback on FAIR consensus and recommendations. The EAC will also participate in future knowledge translation activities with tasks including reviewing and providing feedback on systematic review summaries and papers, consensus and recommendations.

in Sport (Amsterdam 2022) methodology.[10] The concepts for 'sports' and 'prevention' were adapted from searches conducted for the International Consensus Statement on Concussion in Sport (Amsterdam 2022).[10 13] A health sciences librarian (KAH) developed the MEDLINE search strategy in consultation with the methods (IJS) and lead authors (CAE, KJS), which was pilot tested with six seed studies. KAH then adapted the search strategy for other databases. An external health sciences librarian reviewed the search strategy. KAH performed the searches on 30 October 2023 and 23 November 2023 for CENTRAL and CDSR (online supplemental material 2) and uploaded records to an online screening platform (Covidence, Veritas Health Innovation) to support independent and blinded title/abstract and full-text screening. The Cochrane systematic review database was searched to enable hand-searching of the reference lists from systematic reviews.

## Eligibility

Included studies met the following criteria: (1) English language, (2) human participants, (3) original data, (4) outcome of SRC and/or mild traumatic brain injury (mTBI) and/or concussion severity and/or recurrent concussion and/or head impact and/or HAE and/or unintended consequences, (5) specific prevention intervention or MRF, (6) comparison group and (7) at least one female/woman/girl participant in each study group. Unintended consequences include any adverse results that are presented from the evaluation of a concussion prevention strategy (eg, change in injury epidemiology, change in game metrics). Para sport was specifically included to encompass an inclusive sport population. Exclusion criteria included review articles, commentaries, letters-to-editor, case-series, case-studies, reports, abstracts, conference proceedings, dissertations and pre-experimental study designs.

## Study selection

After removing duplicates, a three-step screening process was conducted in Covidence: (1) rapid review, (2) title/abstract screen and (3) full-text screen.[21] First, individual reviewers (IJS, PHE, OH, ATK, CAS, SS, CAE) performed a rapid review to remove any clearly irrelevant studies (eg, non-human based studies, commentaries). Remaining title/abstracts were screened by two independent authors (IJS, MGK, CAE, AC, KJS, OHA, SB, PHE, SH, CAS, OH, DP, GM, SWW, MM, ATK, KP, SS). Finally, the full text of remaining records was independently reviewed by CAE, IJS, PHE or ATK and one other reviewer (KJS, OHA, SB, AC, SH, OH, GM, MM, MGK, DP, KP, SS, CAS, SWW, HAS). Discrepancies at title-abstract or full-text screening were resolved by the lead (CAE) or methods (IJS) author. Before screening, inter-rater agreement was established (≥80% agreement) between all raters and a consensus between lead (CAE) and methods author (IJS) based on a sample set of 50 records.

## Data extraction

Two authors independently extracted data from studies. Discrepancies were discussed by raters for consensus, or a third reviewer (IJS, CAE) resolved the disagreement. Extracted data included the following: authors, year, country of study, study design, outcome definition (SRC, SRC severity, head impact/HAE), comparison group(s), demographics (sample size, age, sex/gender, sport, sport-level), intervention, MRF and results (descriptors, point estimates, variability). All potentially modifiable risk factors were extracted by two authors, with consensus on disagreements achieved and/or a third author's input to achieve consensus. MRFs were categorised following data extraction to summarise across categories including arthropometric, lifestyle, training, competition, skill/technique, environmental, muscle function and ball characteristic factors.

## Risk of bias

Dyads from 18 reviewers (IJS, MGK, CAE, AC, KJS, OHA, SB, PHE, SH, CAS, OH, DP, GM, SWW, MM, ATK, KP, SS, HAS) independently assessed the quality of evidence across studies in duplicate, based on criteria for transparent reporting, internal validity (study design, reporting quality, presence of selection and misclassification bias, potential confounding) and external validity (generalisability) with the 27-item Downs and Black quality assessment tool (DBQAT; online supplemental material 3).[22] A risk-of-bias score was assigned for intervention studies based on 22-items (omitting items 1, 4, 6, 8) and for MRF studies based on 16-items (omitting items 1, 4, 6, 8, 13–15, 17, 19, 23, 24, 27 for non-intervention studies). Disagreements were resolved through consensus and/or a third reviewer (IJS, HAS). The percentage of items at low risk of bias (achieved maximum rating) was calculated for each study.

## Data syntheses

Prevention interventions and potential MRFs were categorised by type, and female/woman/girl-specific data were disaggregated. Relative risk (RR; 95% CI), incidence rate ratio (IRR; 95% CI), OR (95% CI) or HR (95% CI) for interventions or MRF was summarised and calculated where data were available.

Meta-analyses or semi-quantitative syntheses were completed when ≥3 included studies reporting female/woman/girl with similar intervention or MRF (and outcomes) were identified with disaggregated female/woman/girl data reported. Intent-to-treat and per-protocol (as-treated) analyses were included as applicable. Meta-analyses considered random effects models to account for between-study heterogeneity and used a restricted maximum likelihood model. Stata V.18 was used to conduct all meta-analyses.[23]

Certainty of evidence for interventions and MRFs was rated by three authors (IJS, KJS, CAE) using Grading of Recommendations Assessment, Development, and Evaluation (GRADE).[24] Potential MRFs were assessed using a modified approach considering study design strength.[24] If the criteria for meta-analyses were not met, the certainty of evidence was determined using the same GRADE or modified GRADE criteria adapted for non-pooled data. A rating based on domains, a statement of certainty

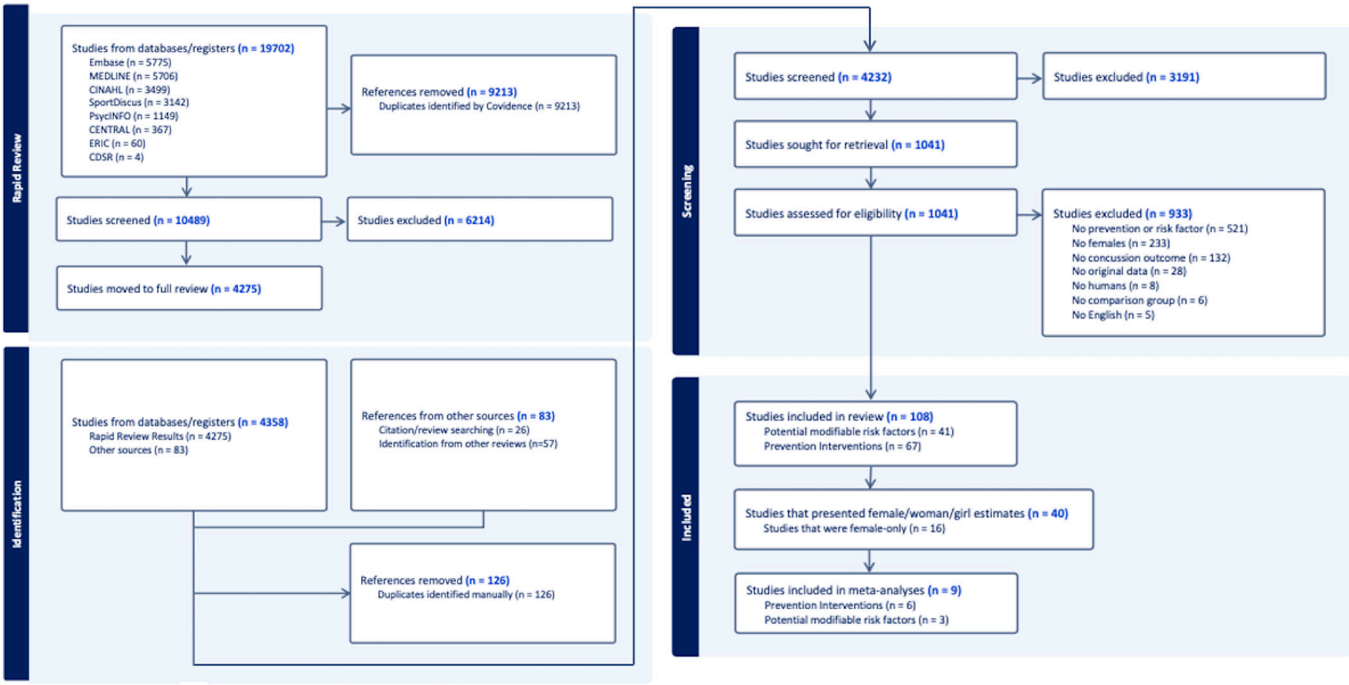



**Figure 1** Study identification Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.

based on consistency and directionality, and magnitude of effect was completed by lead/methods authors (IJS, KJS, CAE). Semi-quantitative GRADE approach for pooled and non-pooled data is described in online supplemental material 4.

## RESULTS

In total, 108 studies (67 prevention, 41 MRFs) were included (figure 1). 40 (37%) reported female/woman/girl-specific estimates and 72 (67%) included participants under age 18. 27 (25%) studies reported girl (paediatric ages ≤18) specific data. No studies reported female/woman/girl Para athlete-specific data.

### Study characteristics

The 108 studies included 7 randomised controlled trials, 5 quasi-experimental, 67 cohort, 7 case-control, 21 cross-sectional and 1 case-cross over study representing 12 countries and 13 individual sports. Across all studies, five outcomes of interest were assessed (SRC: 74 studies; HAE: 20 studies; SRC severity: 15 studies; head impact: 8 studies; recurrent SRC: 4 studies). Online supplemental material 5 shows aggregate and disaggregate female/woman/girl and male/man/boy study results for all included studies.

### Prevention strategy evaluation

Prevention strategies spanned training (15%; 10/67), equipment (37%; 25/67), policy/rule (31%; 21/67) and management (16%; 11/67) interventions. Table 1 displays the female/woman/girl results of the 19 (28%) prevention strategy studies across seven sports that presented female/woman/girl-specific estimates (most common: soccer (37%; 7/19); lacrosse (21%; 4/19)). Nine of the studies that provided female/woman/girl-specific estimates were female/woman/girl athlete-only evaluations. After considering the studies investigating relationships between a unique intervention and SRC, mTBI, head impact or HAE, plus availability of female/woman/girl-specific estimates and estimate type (eg, IRR, OR, HR) reported, a meta-analysis and semi-quantitative analysis were performed for two interventions (headgear, eyewear). No semi-quantitative analyses were performed for non-pooled data due to heterogeneity of outcomes and interventions. In studies that reported female/woman/girl-specific estimates, none examined unintended consequences.

#### Training

Training programme strategies[25–34] were examined in 10 (15%; 10/67) prevention strategy studies (four training studies (40%; 4/10) included female/woman/girl-specific estimates;[27 30 32 33] two (20%; 2/10) were female/woman/girl-only[32 33]). Considering studies that contained female/woman/girl-specific estimates, all were performed in soccer.[27 30 32 33] There were conflicting results from studies assessing neck strength training (FIFA 11+ with added neck strengthening exercises),[27 30] and heading training (neck and core strengthening) programmes in female/woman/girl soccer.[32 33] One RCT evaluating neck strength training found no association between neck strength training and changes in HAE magnitude (head kinematics),[27] while another RCT demonstrated 27.7% ($F_{(1,40)}=2.68$, $\eta^2=0.21$ (0.03, 0.36)) lower peak angular head velocity in female/girls completing the FIFA 11+ with added neck exercises, compared with the standard FIFA 11+.[30] No training-related effects were observed on head impact kinematics in two quasi-experimental studies after a 3–5-month heading training programme ($p>0.05$) including neck and core strengthening in adolescent female/girl soccer.[32 33]

#### Policy/rule change

Policy/rule change strategies were evaluated in 21 (21/67; 31%) studies,[35–55] where four policy/rule change cohort studies (4/21; 19%) included female/woman/girl-specific estimates.[47 49 50 53] These four studies evaluated head-kick regulations in taekwondo,[47] a heading ban in soccer,[49] a change in head kicking rule in karate[50] and the implementation of fair play rules in ice hockey.[53]

A 2013 sparring-taekwondo competition rule change acknowledging simple light touch head kicks (rather than

**Table 1** Female/women/girl results of prevention intervention studies with female/woman/girl estimates

| Author year<br>Country; study design<br>FWG*<br>Paediatric† | Type of prev | Participant characteristics<br>sport sample characteristics | Definition of outcome (concussion, head impact) | Intervention (IG) and control (CG) group descriptions | Effect estimates (eg, incidence rate ratios (IRR), OR) reported or calculated based on data provided (95% CI where applicable) or other relevant main findings | Downs and Black Score |
|---|---|---|---|---|---|---|
| Mansell 2005<br>USA; RCT<br>FWG: 53%‡<br>Paediatric: N | Training | Soccer; National Collegiate Athletic Association Division 1 Collegiate<br>age=19.16 ±0.898<br>n female=19 | Head acceleration (Peak head-neck segment angular acceleration). | IG: 8 weeks cervical resistance training programme twice a week (+ offseason weightlifting/ conditioning sessions 2 days/week).<br>CG: offseason weightlifting/ conditioning sessions 2 days/week. | No significant differences before and after the training intervention in flexion or extension movements. | 19 |
| Peek 2022<br>Australia; RCT<br>FWG: 40%‡<br>Paediatric: Y | Training | Soccer; National Premier League<br>12–17 years<br>n=21 players (IG: N=2 female teams, n=14 female; CG: N=2 female teams, n=7 female) | Head acceleration (PLA, PAV). | IG: FIFA 11+with additional neck exercises (3×/week for 5 weeks).<br>CG: FIFA 11+ without additional neck exercises (3×/week for 5 weeks). | PLA: F (1,40)=3.25, effect size $h^2$=0.14 (95% CI 0.01 to 0.28)<br>PAV: F (1,40)=2.68, effect size $h^2$=0.21 (95% CI 0.03 to 0.36); PAV reduced 27.7% IG versus CG. | 19 |
| Wahlquist 2021<br>USA; Quasi-exp<br>FWG: 100%<br>Paediatric: Y | Training | Soccer Under-12<br>All female;<br>age=mean 10.5 years (SD 0.5)<br>n=12 (attrition 25)<br>CG=pre-season, IG=post-season | Head acceleration (PLA, PRV, PRA). | IG: Get aHEAD safely in Football programme: 1×/week header drill(s); 2×/week neck/core strengthening exercises.<br>CG: No intervention. | No changes in PLA, PRA, PRV.<br>No statistics reported. | 16 |
| Wahlquist 2022<br>USA; Quasi-exp<br>FWG: 100%<br>Paediatric: Y | Training | Soccer Under-12<br>All female n=2, n=27 (IG: N=1 team; n=14 (age=mean 10.6 SD 0.5); CG: N=1 team; n=13 (age=mean 11.0 SD 0.4)) | Head acceleration (PLA, PRV, PRA). | IG: Get aHEAD safely in Football programme: 1×/ week: header drill(s); 2×/week neck/core strengthening exercises.<br>CG: No intervention programme. | No significant differences between IG and CG.<br>PLA: p=0.692; PRA: p=0.379; PRV: p=0.852 | 14 |
| Jae-Ok 2016<br>South Korea; Cohort<br>FWG: 50%‡<br>Paediatric: N | Policy/law change | Taekwondo<br>World Championship competition<br>n female=32<br>IG: n female=16; CG: n female=16 | Head contact (head kick). | IG: Definition of head kick expanded to a soft touch.<br>CG: Head kicks were included if they generated force. | RR:<br>/1000 athlete-exposure: 2.0 (95% CI 0.69 to 6.49), p=0.17<br>/1000 match-exposure: 2.09 (95% CI 0.72 to 6.78), p=0.14 | 6 |
| Lalji 2020<br>USA; Cohort<br>FWG: 39%‡<br>Paediatric: Y | Policy/law change | Soccer<br>10–13 years<br>IG: n female=1400; CG: n female=1520 | Concussion. | IG: Heading ban.<br>CG: No heading ban. | Unadjusted OR: 1.31 (95% CI 1.01 to 1.69) | 12 |
| Macan 2006<br>Canada; Cohort<br>FWG: 32%‡<br>Paediatric: Y | Policy/law change | Karate; National championships, international tournament, Croatia Cup<br>IG: n female=498 matches; CG: n female=287 matches | Concussion. | IG: World Karate Federation rule implementation introduced.<br>CG: Before World Karate Federation rule implementation. | Head injury IRR (95% CI):<br>All: 0.52 (0.34 to 0.79);<br><18: 0.22 (0.12 to 0.39);<br>≥18: 0.90 (0.49 to 1.67) | 13 |
| Smith 2016<br>USA; Cohort<br>FWG: 22%‡<br>Paediatric: Y | Policy/law change | Ice hockey; All levels<br>11–14 years<br>n female=328 (Under-14A/B)<br>IG: n female=171; CG: n female=157 | Concussion, head contact (HHWDC: impact without diagnosed concussion). | IG: Implementation of fair play rules within hockey tournament.<br>CG: No implementation of fair play rules within hockey tournament. | IRR (95% CI)<br>Concussions IG/CG: 2.38 (0.10 to 50.00); p=0.596<br>HHWDC IC/CG: 0.79 (0.05 to 12.5); p=0.869 | 16 |

Continued

**Table 1** Continued

| Author year Country; study design FWG* Paediatric† | Type of prev | Participant characteristics sport sample characteristics | Definition of outcome (concussion, head impact) | Intervention (IG) and control (CG) group descriptions | Effect estimates (eg, incidence rate ratios (IRR), OR) reported or calculated based on data provided (95% CI where applicable) or other relevant main findings | Downs and Black Score |
|---|---|---|---|---|---|---|
| Baron 2020<br>USA; Cohort<br>FWG: 100%<br>Paediatric: Y | PPE | Lacrosse; High school<br>All female; Age NR<br>CG: 683 183 athlete-exposure (n=unknown)<br>IG: 22 397 athlete-exposures (n=1585) | Concussion. | IG: F3137 Headgear.<br>CG: No headgear. | IRR all=0.238 (95% CI 0.029 to 0.870)<br>IRR (game)=0.152 (95% CI 0.004 to 0.860)<br>IRR (Practice)=0.431 (95% CI 0.011 to 2.48) | 18 |
| Caswell 2020<br>USA; Cohort<br>FWG: 100%<br>Paediatric: Y | PPE | Field lacrosse; High school varsity<br>All female; Mean age=16.2±1.2 years<br>N=1 team, n=49 players | Head acceleration (PLA, PRV), Head impacts (verified impacts where contact was to player's head). | IG: Players wore Women's LX headgear (Cascade Lacrosse; 2017 season).<br>CG: Players did not wear headgear (2016 season). | Calculated IRR:<br>IRR=1.03 (95% CI 0.39 to 2.71) | 15 |
| Herman 2022<br>USA; Cohort<br>FWG: 100%<br>Paediatric: Y | PPE | Lacrosse; High school<br>All female n=289 school-seasons, n NR<br>Total athlete-exposures: 357 225 (Game: 98 858, Practice: 258 367)<br>IG: n=96 school-seasons, Total athlete-exposures: 357 225 (Game: 98 858, Practice: 258 367)<br>CG: N=193 school-seasons, Total athlete-exposures: 91 074 (Game: 25 733, Practice: 65 341) | Concussion, Concussion severity (# days RTP). | IG: Mandating use of headgear (mandated in Florida).<br>CG: No headgear mandate (other states). | Overall: RR: 0.63 (95% CI 0.41 to 00.97<br>Games only: RR: 0.57 (95% CI 0.33 to 1.00)<br>Practices only: RR: 0.70 (95% CI 0.35 to 1.41)<br>The significance of the point estimates are assumed based on non-overlapping CI | 11 |
| Kriz 2012<br>USA; Cohort<br>FWG: 100%<br>Paediatric: Y | PPE | Field Hockey; High school<br>All female; Age range: 14–18<br>N=180 schools (IG=39, CG=141)<br>N=110 submitted data (39% attrition)<br>n NR; Total=329 601 athlete-exposure (IG: 66 286, CG: 263 315) | Concussion. | IG: Mandate on the use of protective eyewear.<br>CG: No mandate on the use of protective eyewear. | IRR=1.04 (95% CI 0.63 to 1.75)<br>p=0.857 | 10 |
| Kriz 2015<br>USA; Cohort<br>FWG: 100%<br>Paediatric: Y | PPE | Field hockey, High school<br>All female<br>Age range: 14–18<br>N=206 schools (IG=117, CG=180)<br>n NR; Total=624 803 athlete-exposure (IG:361 488, CG:263 315) | Concussion. | IG: Mandate on the use of protective eyewear.<br>CG: No mandate on the use of protective eyewear. | IRR=0.77 (95% CI 0.58 to 1.02)<br>p=0.068 | 10 |
| Lincoln 2012<br>USA; Cohort<br>FWG: 100%<br>Paediatric: Y | PPE | Lacrosse; High school<br>All female<br>N=25 schools; n NR (IG: 5566 player-seasons; CG: 3864 player-seasons) | Concussion. | IG: Mandated use of protective eyewear.<br>CG: Prior to mandated use of protective eyewear. | IRR=1.6 (95% CI 1.1 to 2.3) | 10 |
| McGuine 2020<br>USA; RCT<br>FWG: 67%‡<br>Paediatric: Y | PPE | Soccer<br>Age 15.6±1.2<br>IG: N female=44; n female=1031<br>CG: N female=44; n female=999<br>n=17 females dropped out prior to regular season start. | Concussion. | IG: Wearing headgear (Full90 Sports, Premier; Forcefield, Ultra Forcefield Sweatband; LDR Headgear, Soccer Headband; Storelli ExoShield; Unequal Technologies Halo 10 mm).<br>CG: Not wearing headgear. | Intent to treat: RR=0.90 (95% CI 0.55 to 1.48); HR=0.86 (95% CI 0.54 to 1.36)<br>As-treated: RR=0.64 (95% CI 0.38 to 1.08); HR=0.70 (95% CI 0.43 to 1.15)<br>Models consisted of multivariate modelling controlling for covariates (age, sex, year, concussion in last year, symptom severity score) and cluster effect (school) | 21 |

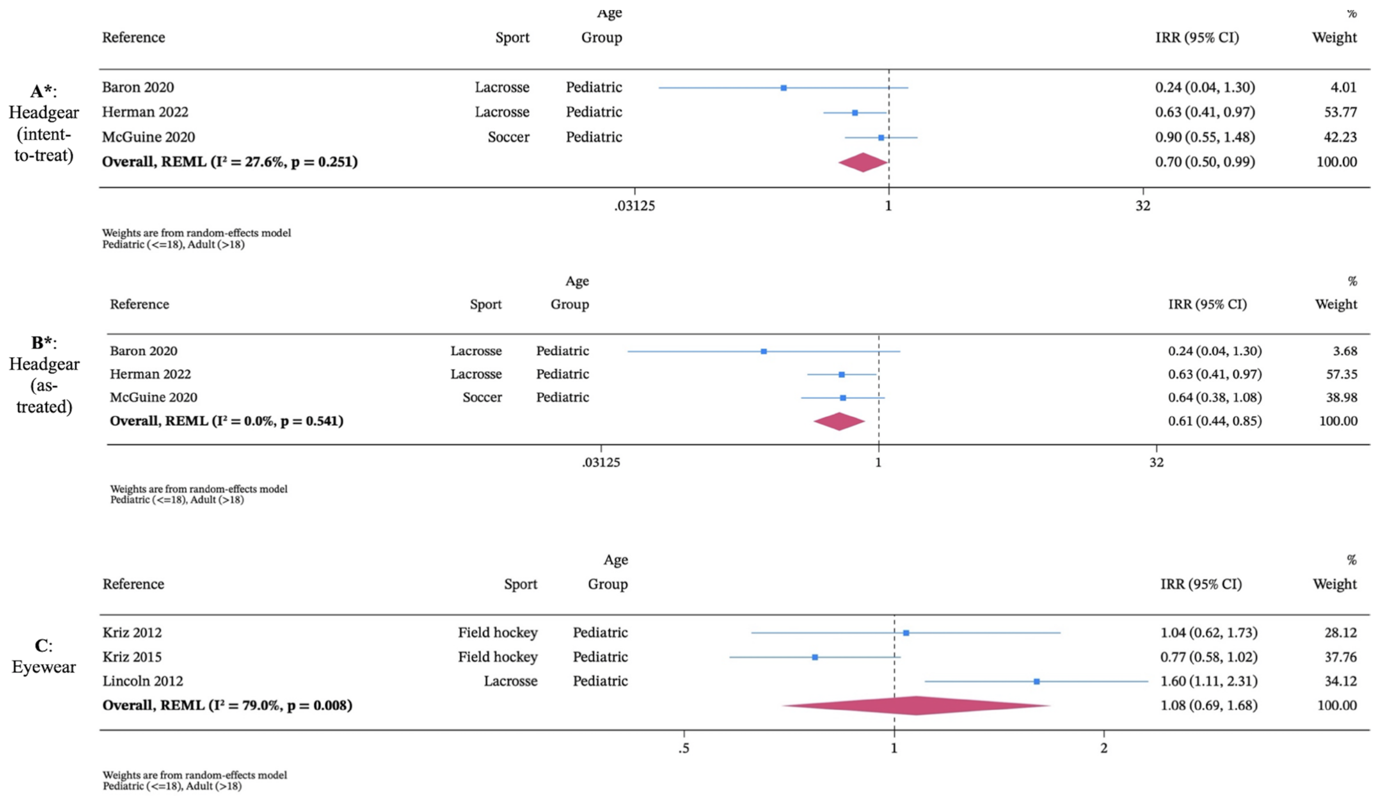
Continued

**Table 1** Continued

| Author year<br>Country; study design<br>FWG*<br>Paediatric† | Type of prev | Participant characteristics sport sample characteristics | Definition of outcome (concussion, head impact) | Intervention (IG) and control (CG) group descriptions | Effect estimates (eg, incidence rate ratios (IRR), OR) reported or calculated based on data provided (95% CI where applicable) or other relevant main findings | Downs and Black Score |
|---|---|---|---|---|---|---|
| Tierney 2008<br>USA; Cross-sectional<br>FWG: 66%‡<br>Paediatric: N | PPE | Soccer; University<br>n women=29<br>age=19.5 (SD 1.8) | Severity (head injury criteria (HIC)). | IG1: Wearing headband-style headgear.<br>IG2: Wearing cap-style headgear.<br>CG: No headgear. | HIC: No interaction between sex and headgear for HIC (p=0.069, power=0.532).<br>Note: HAE was explored, but only for sex comparisons. No female-only comparisons between IGs and CG were completed. | 13 |
| van Iersel 2021<br>Canada; Cohort<br>FWG: 27%‡<br>Paediatric: Y | PPE | Multiple sport<br>IG: n female=80<br>CG: n female=193 | Concussion severity (Post Concussion Symptom Inventory (PCSI)). | IG: Wearing a mouthguard.<br>CG: Not wearing a mouthguard. | PSCI change score of wearing a mouthguard on symptoms at baseline and weeks 1, 2 and 4 (Estimate (95% CI); p value):<br>Baseline: 0.22 (–0.04 to 0.48); p=0.098<br>Week 1: 0.29 (0.01 to 0.56); p=0.039<br>Week 2: 0.22 (–0.06 to 0.51); p=0.128<br>Week 4: 0.08 (–0.20 to 0.36); p=0.581<br>Models were adjusted for covariates of interest; see online supplemental material 5) for complete list | 15 |
| Willmott 2022<br>Australia; case cross-over<br>FWG: 62%‡<br>Paediatric: Y | PPE | Australian Football; Under-12, Under-14<br>Under-14 female (Div 1 N=1 team; Div 2 N=1 team)<br>n female=25<br>age (mean, SD): 13.04 (1.14) | Head contact (physical contacts to the head/neck (count)) | IG: Use headgear.<br>CG: Do not use headgear. | Frequency of head/neck contact events/player:<br>IG versus CG: p=0.896 | 14 |
| Pierpoint 2018 USA; Cohort<br>FWG: 100%<br>Paediatric: Y | Manage-ment | Soccer, basketball; High school<br>All female<br>IG: N=100 schools; CG: N=36 schools<br>Total Athletic exposures:<br>IG: 1 082 985; CG: 126 266 | Concussion. | IG: Athletic trainers in schools.<br>CG: No athletic trainers in schools. | Soccer RR (95% CI): 8.05 (2.00 to 32.51)<br>Basketball RR (95% CI): 4.50 (1.42 to 14.16) | 11 |

*FWG: proportion of sample that is female/woman/girl.
†Paediatric: Inclusive of paediatric (≤18 years old) population yes/no.
‡Studies contain aggregated female/woman/girl and male/man/boy data and/or male/man/boy-specific estimates. These results are presented in Supplemental Material 3, where results of all included studies are reported.
FIFA, Fédération Internationale de Football Association; NR, not reported; PAV, peak angular velocity; PLA, peak linear acceleration; PRA, peak rotational acceleration; PRV, peak rotational velocity; RCT, randomised controlled trial.

requiring forceful contact, 2011 rule) did not change head contact rates across female/woman/girl weight divisions (ages >15; IRR=2.2, 95% CI 0.69 to 6.49).[47] In contrast, the 2000 World Karate Federation rule changes (ie, updated scoring system, stricter rules against prohibited behaviour, and standardising the size and shape of protective gloves) contributed to lower SRC rates for females/girls (ages <18; IRR=0.22, 95% CI 0.12 to 0.39), but not for females/women (ages ≥18; IRR=0.90, 95% CI 0.49 to 1.67).[50] Similarly, implementation of fair play programmes (ie, extra point awarded to team standings for staying below a predetermined number of game-penalty minutes) in female/girl under-14 ice hockey tournaments was not associated with differences in SRC (RR=2.38, 95% CI 0.10 to 50.00) or head contact rates (RR=0.79, 95% CI 0.05 to 12.50).[53] Interestingly, there was an increase in SRC relative to other injuries among female/girl soccer players (unadjusted OR=1.31, 95% CI 1.01 to 1.69) after the US Soccer Federation banned heading for players ages <10, adopted heading restrictions during practice for players ages 11–13, and required concussion education and management improvements.[49]




A*: Intent-to-treat combined match and training **headgear** meta-analysis with concussion outcome and athlete-exposure exposure time for girls, women, and/or females. B*: As-treated combined match and training **headgear** meta-analysis with concussion outcome and athlete-exposure exposure time for girls, women, and/or females. C: Combined match and training **eyewear** meta-analysis with concussion outcome and athlete-exposure exposure time for girls, woman, and/or females.
* One study (McGuine 2020) reported intent-to-treat and as-treated analyses. Both analyses were considered for meta-analyses and ran as a sensitivity analysis.

**Figure 2** Meta-analyses of prevention strategies when ≥3 studies when with similar intervention or MRF and outcomes.

### Personal protective equipment (PPE)

PPE use was evaluated in 25/67 (37%) studies.[56–80] 10 studies (10/25 (40%)) included female/woman/girl-specific estimates;[57 59 64 67–69 73 77 78 80] six (6/25 (24%)) were female/woman/girl-only evaluations.[57 59 64 67–69]

### Headgear use

There was very low certainty of evidence in adolescent lacrosse and soccer that headgear for female/woman/girl athletes may reduce SRC IR by 30–39% (intent-to-treat IRR=0.70; 95% CI 0.50 to 0.99; $I^2$=27.6%; p=0.251 (representing heterogeneity that may not be important); as-treated IRR=0.61; 95% CI 0.44 to 0.85; $I^2$=0.0%; p=0.541 (representing heterogeneity that may not be important)) (figure 2).[57 64 73] 6 of the 10 female/women/girl PPE studies (60%) explored the effectiveness of headgear in reducing SRC (two cohort, 1 RCT), HAEs (1 cohort, 1 RCT) and head contacts (1 case cross-over study) for females/women/girls.[57 59 64 73 77 80] There are limited data to support a relationship between headgear (in unhelmeted sports) and head acceleration events.

### Protective eyewear use

There was very low certainty of evidence of no significant relationship between protective eyewear use and SRC rates (IRR=1.08; 95% CI 0.69 to 1.68; $I^2$=79.0%, p=0.008 (representing considerable heterogeneity)), based on data from three cohort studies from female/girl-only adolescent field hockey and lacrosse (figure 2; table 2).[67–69]

### Mouthguard use

10 studies examined mouthguards,[38 56 58 60 66 74–76 78 79] with 10–25% female/woman/girl athletes per study, and only 1 of the 10 studies (10%), a cohort study, included female/woman/girl-specific estimates.[78] At the time of SRC, females/girls who wore a mouthguard (across multiple sports) reported significantly higher symptom scores 1 week post-SRC compared with non-wearers; however, symptom scores did not differ at 48 hours, 2, 3 or 4 weeks post-SRC.[78]

### Management (secondary prevention)

Management strategies were evaluated in 11 (11/67; 16%) studies.[81–91] Three studies (27%; $\eta^2$ 3/11) examined the use of healthcare personnel,[84 86 88] four studies (4/11; 36%) examined law or policy,[81 87 89 90] and four studies (4/11; 36%) examined time to return to play (RTP).[82 83 85 91] One cohort study (9%; 1/11) included female/woman/girl-specific estimates, reporting that schools with athletic trainers reported higher SRC rates than those without for soccer (RR=8.05, 95% CI 2.00 to 32.51) and basketball (RR=4.50, 95% CI 1.42 to 14.16).[88]

## Modifiable risk factors (MRF)

In total, 41/108 (38%) studies evaluated MRFs,[6–8 92–129] with 21/41 (51%) presenting female/woman/girl-specific estimates.[6–8 93 95 98 100 103 105 107–111 113 115–117 122 128 129] Of those 21 studies, 7/41 (17%) were female/woman/girl-only evaluations.[7 8 107 109 110 115 116] Soccer was the most common sport evaluated in MRF studies, identified in 20 (49%;

**Table 2** GRADE summary for pooled estimates of prevention strategies and modifiable risk factors for female/woman/girl sport-related concussion

| Prevention strategy | Injury type | # of Studies | Participants/ athlete-exposures* | Phase of investigation | Study limitations | Inconsistency | Indirectness | Imprecision | Publication bias | Upgrading factors | Modified GRADE rating | Confidence Statement |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Headgear | Concussion | 3 | 2030 participants<br>1 062 805 athlete-exposures | Phase 2 (2 studies)<br>Phase 3 (1 study) | XX | X | ✓ | ✓ | ✓ | X | + | Minimal confidence headgear use is associated with **lower** SRC rates |
| Eyewear | Concussion | 3 | 9430 participants<br>954 404 athlete-exposures | Phase 2 (3 studies) | XX | X | ✓ | X | ✓ | X | + | Minimal confidence of an **unclear** association between eyewear use and concussion |
| Risk Factor | **Injury Type** | **# of Studies** | | **Phase of Investigation** | **Study Limitations** | **Inconsistency** | **Indirectness** | **Imprecision** | **Publication Bias** | **Upgrading Factors** | **Modified GRADE Rating** | **Confidence Statement** |
| Field type | Concussion | 3 | 154 participants<br>2682 team-matches<br>797 matches | Phase 2 (3 studies) | X | X | ✓ | X | ✓ | X | + | Minimal confidence of an **unclear** association between artificial turf and grass playing fields |

X serious limitations, XX very serious limitations, ✓ no limitations, ++++ (high quality), +++ (moderate quality), ++(low quality), + (very low).
*Not all studies reported participant numbers; studies reported participants, athlete-exposures, team-matches, matches.

**Table 3** Risk factor summary table

| | Intrinsic | | Extrinsic | |
|---|---|---|---|---|
| | *Girl, woman, and/or female-specific estimates* | *Aggregate* | *Girl, woman, and/or female-specific estimates* | *Aggregate* |
| Anthropometric properties | Body mass[113] | Body mass index[124]<br>Neck girth/circumference[97 106 120] | None identified | None identified |
| Lifestyle factors | Hormonal contraceptive use[109]<br>Narcotic use[100] | ADHD medication[92]<br>Alcohol use[101 123]<br>Cigarette use[101 123]<br>E-vape use[123]<br>Recreational marijuana use[101]<br>NSAID use[127]<br>Physical inactivity[123]<br>Sleep[118 121]<br>Sports team participation[123]<br>Steroid use[125] | None identified | None identified |
| Training factors | Sport specialisation[116 129] | Sport specialisation[96] | Level of contact during scrimmage[128] | None identified |
| Competition factors | None identified | None identified | Karate competition categories with/without weight bands[93]<br>Continued participation after SRC event[103]<br>Soccer heading game scenarios[7 111] | Karate competition categories with/without weight bands[94]<br>Mixed martial arts bout length[99]<br>Referee experience[99]<br>Use of matchmaker[99] |
| Skill & technique | Heading technique[107]<br>Tackle characteristics[8]<br>Preparedness and body position into contact[122] | Blocking skill used[112]<br>Head-to-torso range of motion and torso range of motion[97] | None identified | None identified |
| Environmental factors | None identified | None identified | Surface type<br>Field type[105 108 115]<br>Flooring[128] | Altitude[114 126] |
| Muscle function characteristics | Neck muscle strength[95 110] | General strength[119]<br>Neck muscle strength[6 97 102 104 120 162] | Not identified | None identified |
| Ball characteristics | None identified | None identified | Ball size, mass, pressure[117] | None identified |
| Coaching factors | None identified | None identified | None identified | Highest level of education for coaches[124] |

ADHD, attention deficit hyperactivity disorder; NSAID, non-steroidal anti-inflammatory drugs.

20/41) MRF studies. After considering the studies investigating relationships between a unique MRF and SRC, mTBI, head impact or HAE, plus availability of female/woman/girl-specific estimates and estimate type (eg, IRR, OR, HR) reported, a meta-analysis and semi-quantitative analysis was performed for one MRF (field type: natural grass vs artificial turf). No semi-quantitative analyses were performed for non-pooled data due to heterogeneity of outcomes and MRFs.

MRFs included anthropometric properties, lifestyle, training, coaching, competition, skill and technique characteristics, environment, muscle function and ball characteristics. All categories included female/woman/girl estimates except coaching factors. Risk factors are summarised by intrinsic and extrinsic factors for studies that reported female/woman/girl-specific estimates and aggregated female/woman/girl and male/man/boy estimates (table 3).

### Anthropometric properties

Five studies examined anthropometric measurements, including body mass, BMI and neck size.[97 106 113 120 124] Only one study (cohort) included female/woman/girl-specific estimates, where a higher body mass was associated with a higher risk of experiencing prolonged SRC symptoms compared with lower body mass among ice hockey athletes (OR=1.07, 95% CI 1.00 to 1.14).[113]

### Lifestyle factors

Nine studies examined lifestyle MRFs (eg, hormonal contraceptives, narcotics, ADHD medication).[92 100 101 109 118 121 123 125 127] One study (cohort) evaluated hormonal contraceptive use and one cross-sectional study evaluated narcotics use, included female/woman/girl-specific estimates.[100 109] There was no difference in time to recovery from SRC between females/women/girls who did or did not take hormonal contraceptives ($p>0.05$).[109] Higher symptom severity scores were reported for females/women/girls who had sustained a SRC and did not take hormonal contraceptives compared with those taking hormonal contraceptives ($F_{(1,47)}=5.142$, $p<0.05$).[109] Considering narcotics use, females/girls who participated in softball (OR=3.52 ($p<0.05$)), soccer (OR=3.10 ($p<0.05$)), track (OR=3.21 ($p<0.05$)) or cheerleading (OR=3.55 ($p<0.05$)) had greater odds of one or more previous concussion when they had previously used narcotics one or two times.[100] Females/girls who participated in basketball ($OR_{1-2x}=3.80$ ($p<0.05$); $OR_{\geq 3x}=3.02$ ($p<0.05$)) or volleyball ($OR_{1-2x}=3.89$ ($p<0.05$); $OR_{\geq 3x}=2.87$ ($p<0.05$)) had greater odds of SRC history when they had previously used narcotics one or more times.[100]

### Training factors

Four studies (cross-sectional) reporting female/woman/girl-specific estimates[116 128 129] included sport specialisation[96 116 129] and contact level in scrimmage[128] as potential MRFs. In a multisport context (aggregate data), there were conflicting results regarding the association between sport specialisation and SRC with two studies demonstrating no association and one reporting higher odds of concussion in adolescents specialised (≥4/6-point scale) vs nonspecialized (≤3/6) (OR=4.74, 95% CI 1.92 to 11.71; $p<0.01$).[116] In roller derby, full-contact scrimmage was not associated with SRC (cohort 90% females/women/girls).[128]

### Competition factors

Six studies examined MRF related to competition, including type of weight categories,[93 94] order of matches,[99] ongoing sport participation following a suspected SRC,[103] and game scenarios for soccer heading.[7 111] Four studies (three cohort, one cross-sectional) included female/woman/girl-specific estimates.[7 93 103 111] In karate, no significant differences were observed for females/women/girls for SRC when fights occurred in a strict weight class compared with a free-weight team competition.[93] In an evaluation with multiple sports, female/woman/girl athletes continuing to participate in sport following a suspected SRC were more likely to report more severe affective ($R^2=0.06$, $p=0.006$) and cognitive-ocular symptoms ($R^2=0.03$, $p=0.02$) than those who stopped participating.[103] Within elite female/woman/girl soccer players, significant differences were reported for linear and rotational HAEs for headers resulting from different game scenarios.[7 111]

### Skill and technique characteristics

Five studies examined technical characteristics in relation to SRC.[7 8 107 112 122] Three studies (soccer heading technique (one cross-sectional), lacrosse body preparedness before contact (one cohort), rugby league tackle characteristics (one case-control)) included female/woman/girl-specific estimates.[8 107 122] In female/woman/girl soccer, better heading technique was associated with decreased peak head kinematics, lower rotational HAEs during games and increased rotational head acceleration events during practices.[107] In women's lacrosse, no interaction was observed between HAEs and preparedness/anticipation of impact (ie, good body position).[122] Within women's rugby league, head impacts were associated with body positioning into the tackle, location of body contact and proximity location of head to the opposing player.[8]

### Environmental factors

Six studies examined environmental factors,[105 108 114 115 126 128] with four (three cohort, one cross-sectional) including female/woman/girl-specific estimates and one of the four a female/woman/girl-only evaluation.[105 108 115 128]

There was very low certainty of evidence of no significant difference in SRC rates based on field type (artificial turf vs grass) used for adult female/woman soccer players (IRR=0.95; 95% CI 0.62 to 1.45; $I^2=0.0\%$, $p=0.985$) from three cohort studies (figure 3; table 2).[105 108 115] Furthermore, one study with women, men, non-binary/other and trans roller derby athletes reported no association between floor surface type and SRC.[128]

### Muscle function characteristics

Nine studies evaluated muscle function.[6 95 97 98 102 104 110 119 120] Eight of these[6 95 97 98 102 104 110 120] explored neck muscle strength or endurance as a MRF for SRC (n=2)[95 98] and head impact magnitude (acceleration and/or velocity) (n=6; including two during soccer heading).[6 97 102 104 110 120] One study explored general strength.[119]

Four studies (three cohort, one cross-sectional) reported female/woman/girl-specific estimates.[6 95 98 110] In one cohort study (lacrosse, soccer, basketball), neck strength was not associated with SRC.[98] In another study, there was no difference in deep neck flexor endurance between female/woman/girl athletes (hockey, soccer, basketball) who did or did not sustain an SRC.[95] Two (one cohort (rugby), one cross-sectional (soccer)) studies explored neck muscle function and head impact magnitude and included female/woman/girl-specific estimates and one of the two studies reported a negative correlational association.[6 110]

### Ball characteristics

One cross-sectional study in female/girl soccer players examined ball characteristics (size, mass, pressure) during heading and reported lower ball pressure was significantly related to lower peak linear head acceleration ($r^2=0.38$, $F=103.55$, $p<0.001$) and lower ball mass was significantly associated with lower angular head velocity ($r^2=0.56$, $F=217.93$, $p<0.001$).[117]

## Risk of bias

Individual risk-of-bias scores are reported in online supplemental material 6. For studies that reported female/woman/girl estimates, a median DBQAT score of 14 (range 6–21) for prevention strategies and 12 (range 7–18) for risk factor studies was observed. Substantial heterogeneity existed in prevention strategy type and SRC, head impact and HAE outcomes for female/woman/girl studies. Confounding variables were controlled for to some degree in 43% of female/woman/girl studies.

## Protocol deviations

There were protocol deviations to the study quality and risk-of-bias instrument. The protocol included the use of the National Institutes of Health suite of Study Quality Assessment tools.[130] To ensure rating consistency across the broad range of study designs included, the DBQAT was used instead.[22] The DBQAT can be used across multiple study designs and includes items that

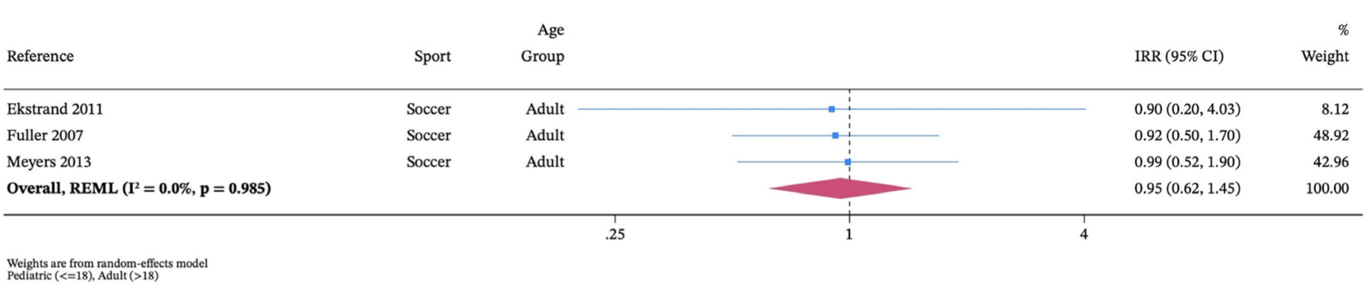



**Figure 3** Match field type (artificial turf vs grass) meta-analysis with concussion outcome and player-hours exposure time for girls, women and/or females.

rate internal validity (study design, selection and misclassification bias, potential confounding), external validity (generalisability), and reporting methods.

## DISCUSSION

This review examined the current evidence for SRC and head impact/HAE prevention strategies and MRFs in female/woman/girl athletes. The evidence for SRC prevention for female/woman/girl athletes is limited, and heterogeneity exists across prevention strategies, MRFs and outcomes of interest.

### Training

There is inconsistent evidence about the efficacy of training strategies to reduce female/women/girl SRCs and head impacts/HAEs.[27 30 32 33] These findings align with previous systematic reviews' aggregated sex/gender data.[13] Variations in training programme components, sports assessed and/or player positions may help to explain the inconsistencies across studies.[13] For example, all training programme strategies studies with female/woman/girl estimates focused on a single sport (soccer), but different training programme approaches (eg, neck and core strengthening vs vision training) were used. A synthesis of data evaluating neck training to reduce HAEs highlighted the heterogeneity of the current evidence base.[131] For example, interventions ranged from 5 to 27 weeks and ranged from two to four sessions per week.[131] Similarly, this review observed heterogeneity across intervention duration (6 weeks to one season) and outcomes (eg, SRC, HAE).

In community male/man/boy rugby (ages 14–18), a neuromuscular training warm-up programme performed ≥3 times per week reduced SRC rates.[132 133] Although there are no female/woman/girl-specific rugby studies, there is emerging evidence that training warm-up programmes may reduce overall injury rates in female/woman/girl soccer athletes.[134] Future training interventions assessing effect on SRC and head impacts and/or HAEs are needed.[135] Future studies should use consistent methodology and outcome measures to facilitate comparison and synthesis between studies for female/woman/girl athletes.

### Policy/rule changes

Policy/rule change evaluations, which show potential benefit in some sports, continue to be primarily conducted in predominantly male/man/boy cohorts (eg, disallowing body checking in ice hockey, lowering the legal tackle height in rugby, limiting head impact exposure during American football training),[39–41 48 136 137] and thus their applicability to female/woman/girls is unknown. Based on aggregate data, there is cohort study evidence that policy disallowing body checking in paediatric ice hockey does not lead to higher rates of SRC in age groups where body checking is allowed.[39–41]

Despite that female/woman/girl-only ice hockey leagues not permitting body checking, female/woman/girl athletes are still at a higher risk of sustaining an initial and a recurrent SRC compared with male/man/boy competitions that permit body checking; moreover, girls can play with boys in leagues allowing body checking.[38 55 138] Initially, head contact rule changes did not reduce SRC or head impact rates within a male/boy cohort.[54 139] However, within a similar cohort, increasing the severity of head contact penalties was associated with lower direct head contact rates.[55] Training referees to identify and penalise head contacts may be a potential opportunity for future prevention intervention evaluation within female/woman/girl cohorts.[13]

To reduce SRC in rugby union, lowering the maximum legal tackle height was suggested to decrease the likelihood that the heads of the tackler and ball-carrier would result in head-to-head contact.[136 137] This rule change was based on professional male/man evidence.[136 137 140–143] Lowering the tackle height and reducing shared head-space between tackler and ball-carrier are equally relevant in female/woman/girl's rugby. Although no data exists within rugby union, early evidence within a professional female/women's rugby league cohort suggests a greater risk of a head injury event to both the tackler and ball-carrier when head proximity to the opposing player is above the sternum.[8] Two male/man cohorts provide limited evidence for reducing the legal tackle height to the level of the armpit.[136 137] Further research to evaluate this type of rule change in female/woman/girl athletes is warranted as differences in tackle characteristics may exist between female/woman/girl and male/man/boy rugby players.[140 144 145] Given the emerging knowledge surrounding tackle characteristics as a MRF, such a rule change could be evaluated in female/woman/girl rugby to ensure the consideration of sex/gender-specific factors.

There is a notable rise in female/woman/girl contact and/or collision sport participation, such as in rugby, Australian football and American football.[14–17] As such, exploring policies to reduce head impact/HAE exposure while still undergoing appropriate tackle training may be an opportunity to reduce SRC rates in female/woman/girl athletes. Policies limiting the number and duration of contact practices during American football led to reduced SRC and head impact/HAE rates in males/boys;[146–149] however, similar policies were not as effective in collegiate American football males/men adults.[150–152] With no evidence to date, evaluation of contact training skill development in female/woman/girl collision sports aimed to reduce SRCs and head impacts/HAEs should be evaluated.

### Personal protective equipment (PPE)

Using PPE may be a relatively efficient solution for SRC prevention. Presently, headgear (hard-shell or soft-shell), eyewear and mouthguards have been evaluated within female/woman/girl cohorts. Headgear is an alternative to traditional helmets (eg, American tackle football, ice hockey) and can be used in rugby, lacrosse, Australian football and soccer. In females/women/girls lacrosse, a policy mandating headgear (hard-shell) use demonstrated lower SRC rates following its introduction,[57 64] despite concern from the lacrosse community regarding potential impacts on game performance.[153] Soft-shell headgear use in soccer across aggregated and disaggregated female/women/girl studies demonstrated inconsistent findings for protection against SRC.[61 73] Given the lack of evidence to date in female/woman/girl cohorts, hard-shell and soft-shell headgear were combined for the purposes of a meta-analysis to inform the association between headgear use and SRC. However, combining these two types of headgear should be interpreted with caution given differences in materials for these types of headgear and mechanistic implications of their protection against SRC and their use in their respective sports. Use in rugby (union, 7s) and Australian football with aggregated female/women/girl and male/man/boy groups demonstrated no protective effect on SRC[70 72 154] or SRC severity for rugby players.[70] Moreover, headgear use in male/man/boy adolescent and professional rugby union showed no significant protective effect for SRC.[13 155 156] Although the current meta-analysis displayed a potential protective effect with headgear use against SRC for female/girl athletes, the level of certainty surrounding the evidence was very low and the heterogeneity across the studies included in the meta-analysis varied considerably. These findings are very likely to change with future high-quality research and should be interpreted with caution.

In high school female/girl's field hockey, there was no association between eyewear protection mandates and SRC rates.[67 68] Conversely, in female/girl's lacrosse, an eyewear policy may increase concussion rates.[69] Importantly, in both studies, lower rates of eye, head and face injuries were reported when eyewear protection was mandated.[67–69] Based on the current evidence, use of protective eyewear cannot be recommended for protection against SRC, but may be recommended for protection against eye and other head/face injuries.

Wearing a mouthguard is effective to prevent dental and/orofacial injuries across multiple sports, settings and populations.[157] However, for SRC, findings indicating protective effects are inconsistent.[157] Aggregate data (sex/gender) of adolescent and collegiate ice hockey players demonstrated mouthguard use was protective of SRC.[60 66 79] Without disaggregated female/woman/girl-specific data, it is uncertain if there would be similar findings in a female/woman/girl population. One study suggests higher symptom scores at 1 week post-SRC;[78] however, individuals with SRC history may be more likely to wear a mouthguard, which might explain these findings. Neck muscle strength and activation are postulated to play a role in mouthguard effectiveness against SRC (via teeth clenching).[158–160] Female/woman/girl neck strength may be weaker than male/man/boy neck strength.[6] Therefore, it is critical to explore the female/woman/girl-specific relationship between mouthguard use and SRC prior to making recommendations for mouthguard use in female/woman/girl athletes.[13]

Hard-shell helmets protect against all types of traumatic brain injuries (including SRC) across many sports,[13] albeit primarily evaluated in male/man/boy cohorts in ice hockey and American football. A structured helmet fit criteria (aggregate data) designed for youth ice hockey players showed that missing two or more (of 12) helmet fit criteria was associated with increased SRC odds,[63] but helmet age was not associated with SRC risk.[66] Helmet fit criteria should be evaluated in a female/girl-specific ice hockey context.

## Management

There are studies highlighting aggregate data examining the effectiveness of policy inclusive of concussion education, protocols and medical coverage on reducing recurrent concussion rates and improving time to recovery based on aggregate data across female/woman/girl and male/man/boy athlete data.[81–87 89–91] In some studies, a reduction in recurrent concussion rates and reduced time to recovery is observed. However, the presence of medical personnel may lead to higher detection based on reporting behaviours associated with presence of medical personnel.[88]

## Modifiable risk factors

This systematic review found mixed evidence for potential MRFs for SRCs and head impact/HAEs. Of the 34 risk factors identified, only field surface type was explored across three or more studies with a similar outcome for female/woman/girls,[105 108 115] and thus only one meta-analysis and semi-quantitative MRF analysis was conducted. Within this meta-analysis, there was no association observed between SRC and surface type (artificial turf vs grass). In contrast to our findings, a previous systematic review and meta-analysis which included primarily male and adult athlete populations reported a protective effect across American football, soccer and rugby demonstrating 40% lower rates of concussion on turf (IRR=0.6, 95% CI 0.47 to 0.76).[13] Currently, no mechanism for this difference could be postulated. However, a greater understanding of the implications of surface type and SRC across female/woman/girl sport is needed given the lack and heterogeneity of evidence.

### Neck muscle function characteristics

The MRF most commonly examined in this review was neck muscle function. However, these studies had high levels of heterogeneity for outcome measurement and small sample sizes (<25 female/woman/girl athletes in some studies).[102 104 110 120] Differences in maximal isometric neck strength assessment (eg, technique—push or pull, testing position—seated or quadruped) made it challenging to compare data between studies. Factors related to symptoms of neck pain and neck function (eg, joint position sense, craniocervical flexion, strength, endurance, timing of activation) may affect SRC rates, as has been reported with cervical spine measures worsening following SRC.[161] Before neck muscle outcomes can be confidently considered as a MRF for SRC (in females/women/girls or males/men/boys), more evidence is required using standardised testing protocols that include muscle strength and muscle activation outcome measures.

## Strengths and limitations

This systematic review provides a comprehensive evaluation of SRC prevention and MRF literature for female/woman/girl athletes. Given the paucity of female/woman/girl athlete-specific data, we were inclusive of studies reporting aggregate data (female/woman/girl and male/man/boy) to ensure we captured all available data informing appropriate recommendations for female/woman/girl athletes. Despite this effort, only 37% (40/108) of included studies contained female/woman/girl-specific estimates, with the remaining reporting aggregated data only. Within the studies that disaggregated female/woman/girl data, there was large heterogeneity of study outcome definitions across SRC and head impact/HAE, data collection methodology and exposure time. Within the studies that considered female/woman/girl estimates, a limited number of sports were evaluated, presenting an underrepresentation of sports within the female/woman/girl concussion prevention literature. Additionally, several studies contained very small sample sizes and some did not report the number of study participants (reported athlete-exposures only). Many studies were subject to potential selection bias given convenience sampling. Most studies did not evaluate potential effect measure modification, control for confounding variables (eg, previous concussion history, level of play), or consider clustering effects (eg, team, individual (when competing in several seasons)). In keeping with the findings from the International Consensus Statement on Concussion in Sport[10] there were no studies retrieved that included female/woman/girl Para sport athletes. Further attention and future research examining this understudied population is critical. Finally, the number of reviewers involved in screening and data extraction carries a small risk of error in data charting and interpretation.

## Practical implications

This systematic review highlights the need for female/woman/girl-specific prevention strategies and MRFs. Evidence supports recommendations in adolescent female/woman/girl lacrosse and soccer athletes that headgear may reduce SRC incidence rates.

There are discrepancies in the literature evaluating the association between neck strength and (1) SRC or (2) head impact/HAEs in soccer and rugby. Interventions and outcome variability highlight the need for future research specifically evaluating the role of neck strength and function. Given the variability in injury definitions across prevention and MRF studies, research findings should be interpreted with caution and standardised definitions should be prioritised in future research.

## Research implications

In summary, there are many gaps in the literature evaluating prevention strategies aimed to reduce concussion, head impacts, and/or HAEs in female/woman/girl athletes. Specifically, training strategy evaluations are limited in scope to muscle strength training strategies (eg, neck and core strengthening) in female/woman/girl soccer with heterogeneity of outcomes. To date, neuromuscular training warm-ups have only been evaluated in a male/man/boy rugby context. As such, there is a need for research evaluating female/woman/girl-specific training strategies (eg, neuromuscular training, tackle training) across a diversity of female/woman/girl contact and collisions sports (eg, ice hockey, rugby, lacrosse) aimed to reduce concussion. Regarding policy and rules, currently, all research is based on male/man/boy and/or aggregate data (eg, body checking policy in ice hockey, height of the legal tackle in rugby) and there is a need to consider rules of the game across multiple female/woman/girl sports. Research evaluating PPE in female/woman/girl athletes is limited to headgear as discussed in soccer and lacrosse. Female/woman/girl-specific data are needed to evaluate the effectiveness of mouthguards specifically in female/woman/girl collision sport (eg, ice hockey, rugby) where recommendations are currently based on effectiveness in male/boys ice hockey. Evaluation of helmet-fit criteria in female/woman/girl helmeted sports (eg, ice hockey, ringette) is also a significant gap.

Future research recommendations for evaluation of SRC and/or head impact/HAE prevention and SRC MRFs include prioritising disaggregated data for female/woman/girl-specific effect estimates. Priorities should also consider a focus on Para athletes, considerations across other equity-deserving athlete groups (eg, lower-middle income countries, rural communities, age groups), stronger experimental study designs, consideration of effect measure modification, adjustments for confounding and cluster(s) in analyses, and reporting of unintended consequences. In addition, future research should consider multifaceted approaches to evaluate SRC and head impact/HAE prevention strategies through adequately powered studies and the combined use of validated concussion and injury surveillance, video analysis and wearable technologies (eg, instrumented mouth guards).

## CONCLUSION

There is minimal evidence for female/woman/girl athlete-specific SRC and head impact/HAE prevention strategies and MRFs and is limited to supporting headgear use in adolescent soccer/lacrosse. To make appropriate recommendations and to better inform prevention strategies for female/woman/girl athletes, evidence for female/women/girl-specific SRC prevention and MRFs is needed. The development, implementation, and evaluation of female/woman/girl-specific SRC prevention strategies are needed to reduce the SRC burden in this under-researched sport population.

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