Systematic review

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Prevention strategies and modifiable risk factors for upper extremity injury: a systematic review and meta-analysis for the Female, woman and/or girl Athlete Injury pRevention (FAIR) consensus

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ABSTRACT

Objectives To examine injury prevention strategies and potentially modifiable risk factors (MRFs) for upper extremity (UE) injuries in female, woman and/or girl athletes (female/woman/girl).

Design Systematic review with meta-analysis, semiquantitative analyses and Grading of Recommendations Assessment, Development and Evaluation in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

Data sources MEDLINE (Medical Literature Analysis and Retrieval System Online), CINAHL (Cumulative Index to Nursing and Allied Health Literature), APA PsycINFO (American Psychological Association Psychological Information Database), SPORTDiscus (Sports Discus Database), EMBASE (Excerpta Medica Database), and ERIC (Education Resources Information Center) (30 October 2023) and Cochrane Systematic Review Database and the Cochrane Central Register of Controlled Trials (CENTRAL) (25 November 2023).

Eligibility Primary data studies with comparison group(s) assessing the association of prevention strategies and/or MRFs for sport-related UE injury, with ≥1 female/woman/girl in each study group.

Results 55 studies (n=20 intervention, n=35 MRF) were included with 33 228 athletes (8642 female/woman/girl; 26%). Of these, 17 (31%) reported female/woman/girl-specific estimates and included five injury locations (n=3 general UE, n=12 shoulder, n=3 elbow, n=3 wrist/hand). One prevention strategy (n=5 shoulder-specific exercise programmes) and seven MRFs were identified, including less range of motion (n=6), less shoulder muscle strength (n=8), high training load (n=1), presence of scapular dyskinesis (n=3), high sport specialisation (n=2), equipment differences (n=1) and less sport-specific conditioning (n=1). Pooled data from three studies suggest that shoulder exercise programmes consisting of strength, stability/control and sport-specific exercises reduce shoulder injury rates by 51% (95% CI 0.30 to 079; I^2 0.0%; very-low certainty evidence) across paediatric (≤18 years) and adult handball and volleyball players.

Conclusions Our understanding of female/woman/girl UE injury prevention is limited by heterogeneity across injury outcomes, interventions, MRFs and limited female/woman/girl athlete-specific data. Shoulder-specific strengthening and stability exercise programmes may be beneficial to reduce shoulder injury rates in female/woman/girl handball and volleyball players. Future research should prioritise female/woman/girl athletes to reduce the burden of UE injuries.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Sport participation among female, woman and/or girl athletes is on the rise, yet little is known about sex- and/or gender-appropriate upper extremity injury prevention strategies or modifiable risk factors.

⇒ Upper extremity injuries represent up to 28% of female/woman/girl athlete sport-related injuries, but it is unclear if there are sex- and gender-specific upper extremity injury prevention approaches or modifiable risk factors.

WHAT THIS STUDY ADDS

⇒ Female/woman/girl athletes make up only 26% of participants in studies evaluating upper extremity injury prevention strategies and potential modifiable risk factors, with only 31% of studies reporting female/woman/girl-specific estimates.

⇒ Exercise-based programmes (including strength, stability/control and sport-specific exercises) reduce upper extremity injuries by 51% across female/woman/girl handball and volleyball players (very low certainty of evidence from three studies including 620 female/woman/girl athletes).

⇒ Decreased shoulder muscle strength may be associated with shoulder injury (very low certainty of evidence from four studies including 474 multisport female/woman/girl athletes).

⇒ There is an unclear association between range of motion and shoulder injury in female/woman/girl athletes (very low certainty of evidence from five studies including 502 multisport female/woman/girl athletes).

⇒ Despite shoulder injuries being the most common injury among wheelchair athletes, no studies have assessed upper extremity prevention strategies in female/woman/girl Para athletes.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Identifies critical evidence gaps in upper extremity injury prevention for female, woman, and/or girl athletes, including Para athletes.
⇒ Emphasises the need for high-quality studies with adequate female/woman/girl representation and sex- and gender-disaggregated reporting.
⇒ Suggests clinicians and coaches implement exercise-based prevention programmes (strength, stability/control, sport-specific) while acknowledging limited evidence.
⇒ Calls for policy and funding initiatives that prioritise equitable inclusion and reporting in injury prevention research and surveillance.

PROSPERO registration number PROSPERO CRD42024494967.

INTRODUCTION

Female, woman and/or girl (hereafter female/woman/girl) athletes' sport participation has increased substantially over the last three decades.[1–3] Female/woman/girl athletes are at a high injury risk, with combined injury rates ranging from 2.5 to 39.0 injuries per 1000 athlete exposures across sports and high school, university and professional levels.[4–6] The upper extremity (UE) represents 19%–28% of these injuries, with variable injury mechanisms reflecting differing sport-specific demands.[5 7–9] UE injuries pose a significant economic burden, leading to 2.3 million annual emergency department visits for children[10] and substantial medical costs globally, including $79 million annually in New Zealand.[11] In addition to impairing sport performance, the long-term consequences of UE injury include persistent pain,[12 13] decreased function[14 15] and post-traumatic osteoarthritis.[16]

With the goal to prevent UE injuries and their consequences, researchers have sought to identify potential modifiable risk factors (MRFs) to inform prevention strategies, primarily within male/man/boy sport contexts.[17–19] These efforts suggest that MRFs vary across sports (ie, collision vs throwing) and may include tissue extensibility,[17] muscle strength,[18–20] proprioception,[21] training load,[22] tackle techniques[23] and biomechanical factors.[24] This information has informed many UE injury prevention strategies, including exercise-based interventions,[25] policy/rule changes,[26] and protective equipment.[27]

Historically, female/woman/girl athletes have been under-represented in UE injury prevention and MRF studies despite differences in tissue extensibility,[28] strength profiles,[29] bony morphology[28] and neuromuscular control[30] compared with male/man/boys, which may be influenced by different training environments, rules and sociocultural factors.[31] These between-sex/gender differences underscore the need to develop sex- and gender-specific preventive interventions. Studying sport injuries in female/woman/girl athletes also presents broader challenges, including limited sample sizes, underfunding and inequities in sport. Many studies fail to disaggregate results by sex or gender, and research designs often reflect gender biases that limit their generalisability. Additionally, physiological and hormonal factors, as well as disparities in training access and medical support, complicate the application of results from male/man/boy athletes. An important first step in this process is to aggregate and synthesise the current evidence base specific to female/woman/girl athletes' UE injury prevention strategies and MRFs.

This systematic review addresses the following research questions: (1) what sport-related injury prevention strategies (e.g., training strategies, policy/rule changes, equipment) have proven benefits for reducing UE injury rates in female/woman/girl sport, and are there any unintended consequences (eg, decreased performance, increased injury risk beyond targeted injury focus) and (2) what are the potential MRFs for female/woman/girl sport-related UE injuries? Our findings will help to inform clinicians and sport partners as they make decisions on the most appropriate injury prevention strategies for female/woman/girl athletes, teams and sport organisations and future research directions.

METHODS

Registration

The systematic review protocol was registered in the PROSPERO registry (International Prospective Register of Systematic Reviews; 1 January 2024; CRD42024494967).

Framework

The Cochrane Handbook[32] and Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines for reporting the review (supplemental checklist)[33 34] informed the conduct and reporting of this review. Equite, 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), Embase (OVID), APA PsycInfo (OVID), CINAHL Plus with Full Text (Ebsco), SPORTDiscus with Full Text (Ebsco) and ERIC (Ebsco), Cochrane Database of Systematic Reviews (OVID), Cochrane Central Register of Controlled Trials). An expert health sciences librarian (KAH) developed the search, which was reviewed by the author team. The search strategy (online supplemental table S1) consisted of three concepts: sports, prevention or MRF and UE injuries, with limits for publication year (2001–current). The concepts for 'sports' and 'prevention' were adapted from searches conducted for the Consensus Statement on Concussion in Sport.[35] Each concept included both subject headings and keywords. The injury concept was peer-reviewed by an external expert health sciences librarian. KAH performed all the searches (30 October 2023, CENTRAL and Cochrane Systematic Review Database 23 November 2023) and transferred records to an online screening platform (Covidence, Veritas Health Innovation). The Cochrane Systematic Review Database was searched to enable hand searching of systematic reviews reference lists.

Eligibility

Included studies met the following criteria: (1) written in the English language, (2) human participants, (3) original data, (4) sport-related UE injury outcome (eg, shoulder injury), (5) specific prevention intervention or MRF, (6) a comparison group (eg, randomised controlled trial (RCT), quasi-experimental, cohort, case-control, cross-sectional) and (7) at least one female/woman/girl (adults or paediatric ≤18 years) participant in each study group. Review articles, commentaries, non-sport-related UE injuries and non-systematic review articles, pre-experimental, case-series and case-study reports were excluded. Only studies reporting female/woman/girl disaggregated data are presented in this systematic review, but all studies meeting the above criteria are included in online supplemental table S4 and S5.

Box 1 Equity, diversity and inclusion statement

Female, woman and girls: 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 that the terms are not synonymous and may mean different things to different people. 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.

Review planning and design: The FAIR Consensus Steering Committee planned and designed this review. This group (n=24, 80% women; n=17, 71% affiliated with one of 11 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; 8%) and career stage (n=7 late-career, n=9 mid-career, n=8 early career) from four continents, who are mostly white and from well-resourced countries.

Authors: Authors were chosen by the expert group based on relevant and diverse experiences, backgrounds, expertise and professions. Reflecting these intentional efforts towards diversity, the authors were 71% women (n=15); 90% white (n=19) and 10% identified with diverse abilities (n=2), with self-reported lived experience as an athlete (n=14; 67%), coach (n=13; 62%), referee (n=2; 10%), health, medical or exercise practitioner (n=16; 76%) and member of a sport organisation (n=9; 43%), government (n=5; 24%), healthcare (n=6; 29%) or industry (n=1; 5%) committees across paediatric (n=19; 91%), adult (n=18; 86%) and Para sport (n=13; 62%) spanning four continents (n=11 North America, n=6 Europe, n=2 Asia, n=2 Oceania) and career stage (n=4 trainee, n=4 early, n=5 mid, n=7 late). Participation as an author required internet and computer access and a working knowledge of English. Author data were collected electronically.

FAIR, female, woman and girl Athlete Injury pRevention.

Study selection

After removing duplicates, we undertook a three-step screening process. First, four authors (EEH, ESG, KBF and ABM) performed a rapid screen of each title-abstract to remove any clearly irrelevant studies (ie, no English abstract, human participants, sport, UE injury or original data). This was followed by title-abstract and full-text screening by pairs of independent reviewers (EEH, ESG, KBF, MA, GSB, HF, JHL, JST, BMP, GM, RW, ABM, MM and CAE). Disagreements were resolved by a third author (EEH, ESG, MM and CAE). Before screening, inter-rater agreement was established using a random selection of 50 records where all authors were required to achieve ≥80% agreement when compared with a gold standard rating (consensus between lead (CAE) and methods author (EEH)).

Data extraction

Dyads from 14 authors (EEH, ESG, KBF, MA, GSB, HF, JHL, ABM, GM, BMP, JST, RW, MM and CAE) independently extracted data in duplicate, including study details (first author, year, location, design); participant information (sample size, age, sex/gender, sport, sport level); UE injury definition; UE injury severity definition (eg, time to medical clearance, time to UE symptom resolution); unintended consequence; comparison groups (intervention or MRF) and results, including statistical outcomes, point estimates for outcome rates and/or prevalence and effect estimates (eg, OR; incidence rate ratio, IRR or HR ratio) and measures of variability (eg, 95% CIs, SEs). Frequencies and denominators used to produce the effect estimates were also extracted. Disagreements were resolved through consensus or a third author (EEH, ESG and CAE).

Box 2 Patient and public involvement

Expert group: Our expert group (n=17) planned and designed these projects and were responsible for inviting the consensus/author groups. Our consensus group (n=108) has diverse and relevant experiences: 54 (50%) as an athlete; 43 (40%) as a coach, 78 (72%) as a health, medical or exercise practitioner, 99 (92%) serving on committees related to sporting organisations (44 (41%)); government (14 (15%)), industry (13 (12%)), and healthcare (28 (26%)).

FAIR Consensus External Advisory Committee (EAC): The FAIR EAC consists of eight 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.

FAIR, female, woman and girl Athlete Injury pRevention.

Study quality and risk of bias

Pairs from 14 authors (EEH, ESG, MDM, KBF, CLM, MA, GB, HF, ABM, GM, BMP, RW, MM and CAE) independently assessed the quality of evidence across included studies using the 27-item Downs and Black quality assessment tool (DBQAT; online supplemental table S2; maximum score possible: 32). Risk of bias (ROB) score was assigned for intervention studies using 23 items (removing items 1, 4, 6 and 8; maximum score: 28), and MRF studies included a score using 15 items (removing items 1, 4, 6, 8, 13–15, 17, 19, 23, 24 and 27; maximum score: 16). Disagreements were resolved through consensus or a third author (EEH, ESG and CAE).

Data synthesis

First, potential interventions and MRFs were identified and categorised by reported injury outcome, considering sport, study design and availability of female/woman/girl-specific data. Second, univariate OR, RR or IRR (95% CI) of injury for potential MRFs were calculated when raw data were available. Lastly, quantitative (meta-analysis) or semiquantitative syntheses were conducted, and certainty of evidence ratings were assigned. Meta-analyses or semiquantitative analyses were performed when >3 studies assessed an intervention or MRF for a reported injury outcome. Pooled effects were based on ORs, RRs, IRRs if available and injured and uninjured group means (SD) if not available.

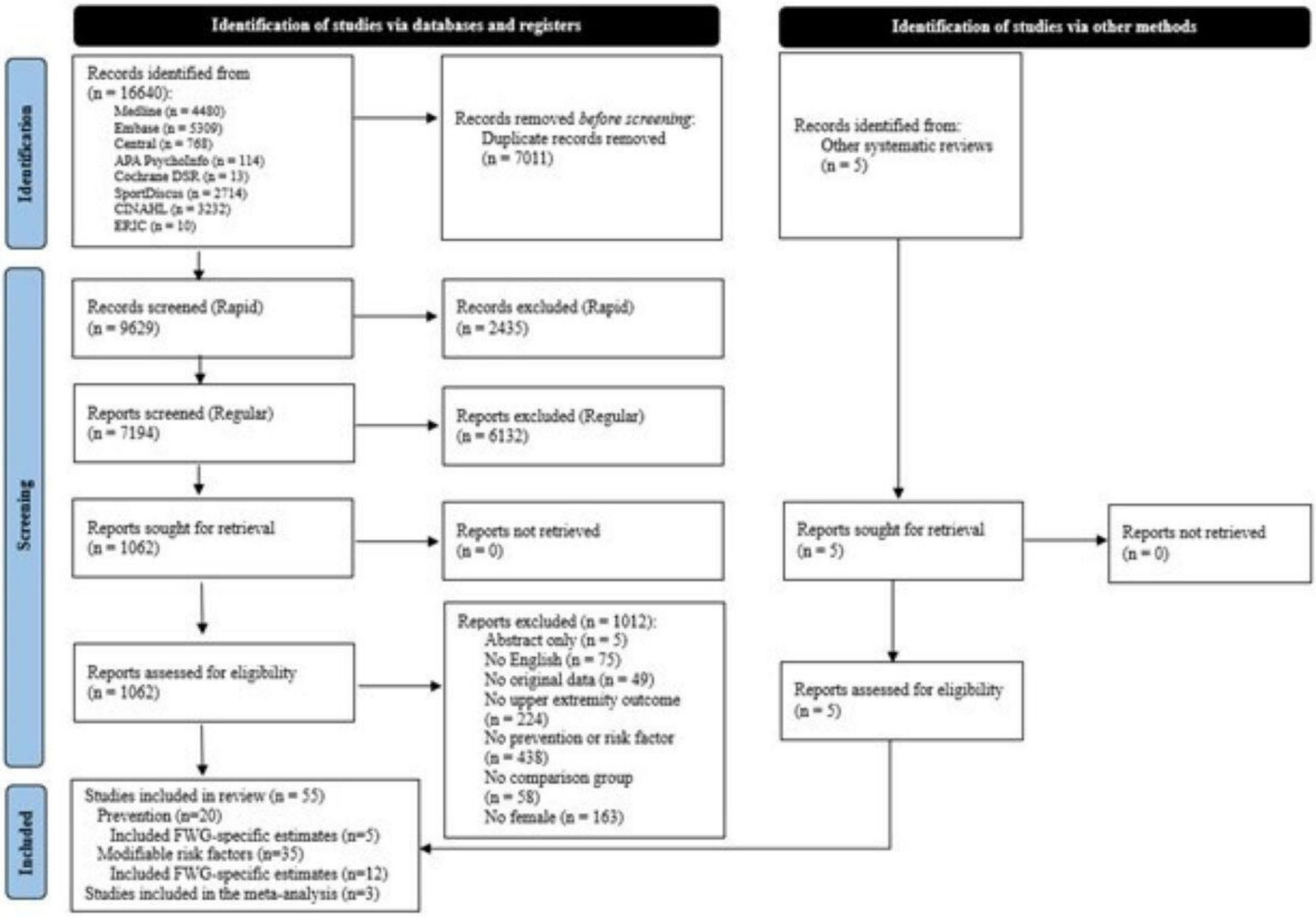

Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram for identifying studies. APA PsycINFO, American Psychological Association Psychological Information Database; CENTRAL, Cochrane Central Register of Controlled Trials; CINAHL, Cumulative Index to Nursing and Allied Health Literature; Cochrane DSR, Cochrane Systematic Review Database; ERIC, Education Resources Information Center; EMBASE, Excerpta Medica Database; FWG, female/woman/girl; MEDLINE, Medical Literature Analysis and Retrieval System Online; SPORTDiscus, Sports Discus Database.

Quantitative synthesis

Meta-analyses were conducted using a random effects model with restricted maximum likelihood to account for expected heterogeneity by study methodology (Stata V.18, StataCorp, USA). A standard Q-test was used to assess the heterogeneity between studies, and the I^2 statistic was used to measure the proportion of variance attributable to inconsistency.[36]

Following meta-analyses, the certainty of evidence for interventions and MRFs was rated as 'high' or downgraded to 'moderate', 'low' or 'very low' using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) or a modified GRADE approach for prognostic factor reviews.[37 38] Certainty ratings were cogenerated by three authors (EEH, MDM and CLM). Ratings were based on study design (RCT vs non-RCT), ROB, result heterogeneity, generalisability, estimate precision (95% CI width), publication bias (funnel plots), effect magnitude and dose-response evidence. For MRFs, study phase (from identification to confirmation of MRF pathways) replaced study design in the assessment.[39]

Semiquantitative synthesis

For non-pooled data, semiquantitative synthesis was performed. This refers to the structured application of the modified GRADE approach to evaluate the direction, consistency, and strength of the reported effects across studies to assign an overall certainty rating (see online supplemental table S3).[40] This process was used for topics where meta-analysis was not feasible due to heterogeneity or limited data.

RESULTS

A total of 16 640 studies were returned by the database. In total, 55 studies (n=20; 36% prevention strategies,[25 26 41–58] n=35; 64% MRF)[59–93] were included (figure 1; online supplemental table S4 and S5). Of the 55 studies included, 17 had female disaggregated data (n=5 prevention strategies,[41–45] n=12 MRF)[59–70] which are presented in the main results.

Prevention strategies

The five UE injury prevention studies included 828 participants (411 female/woman/girl athletes; 50%) and spanned RCTs (n=3 RCT) and quasi-experimental (n=2) studies conducted across two continents: Europe (n=4) and Oceania (n=1). Four studies (80%) included paediatric participants. Two (40%) studies included only female/woman/girl

Table 1 Characteristics of prevention studies with female, woman and/or girl data (n=5)

Author year Country Study design	Participant characteristics Sport Sample characteristics	Definition of upper extremity injury and intervention	Effect estimates (eg, IRR, OR, 95% CI or other relevant main findings) *calculated point estimate where data allowed*
Achenbach 2022 Germany Cluster RCT[41]	Handballl G: n=123 females CG: n=136 females Paediatric participants: yes	Injury: elbow (self-report) Intervention: shoulder exercise programme	Elbow injury OR: 0.583 (0.227, 1.507, p=0.334) Elbow injury (severe) OR: 0.500 (0.174, 1.440, p=0.258)
Asker 2022 Sweden Cluster RCT[42]	Handball IG: n=81 females CG: n=101 females Paediatric participants: yes	Injury: shoulder (any; self-report Oslo Sports Trauma Research Center Overuse Injury questionnaire) Intervention: shoulder exercise programme: five exercises (three on shoulder strength (elastic bands) ER+posterior shoulder/upper back, one thorax mobility, one trunk strength) to be performed 3/week during season+throwing programme off-season.	Shoulder injury IRR: 0.57 (0.24, 1.25, p=0.18)* Time loss shoulder IRR: 0.51 (0.18,1.30, p=0.19)* Substantial shoulder problem IRR: 0.72 (0.35, 1.41, p=0.39)* All shoulder problem IRR: 0.70 (0.42, 1.16, p=0.19)*
Broadbent 2016 Australia Quasi-experimental[43]	Dragon boat racing IG: n=22 females CG: n=22 females Paediatric participants: no	Injury: shoulder and wrist (self-report) Intervention: strengthening and stretching exercise programme	Shoulder: p<0.001† Wrist: p=0.031
Østerås 2015 Norway Quasi-experimental[44]	Handball IG: n=53 females CG: n=56 females Paediatric participants: yes	Injury: shoulder (gradual and acute onset pain; self-report Fahlstrom questionnaire) Intervention: strength training exercise programme: three: two elastic-band exercises (ER, IR)+push up+as part of every warm-up	Shoulder injury prevalence ratio: 0.31
Tooth 2023 Belgium RCT[45]	Volleyball IG: n=25 females CG: n=24 females Paediatric participants: yes	Injury: shoulder (self-report) Intervention: exercise programme. Warm-up programme: (1) running (2) seven shoulder exercises (ER strength, core stability, two proprioception, passing, plyometric (3) Final exercises.	Shoulder injury RR: 0.768 (0.234,2.52, p>0.05)

*Calculated from data provided.
†Indicates significant finding.
ER, external rotation; IR, internal rotation; IRR, incidence rate ratio; RCT, randomised controlled trial; RR, risk ratio.

participants, with the remaining three reporting female-separated data (table 1). No studies reported unintended consequences. Handball was the most frequently investigated sport (n=3), followed by volleyball (n=1) and dragon boat paddlers (n=1). No prevention studies reported on Parasport athletes. Shoulder injuries were the most common injury investigated (n=5), followed by wrist/hand and elbow (n=1 each). UE injury prevention strategies only included exercise-based interventions, with one meta-analysis being performed.

Study quality and risk of bias

The median ROB score was 14 (range 4–22) out of a maximum of 28 (online supplemental table S6). Intervention types and outcomes were heterogeneous across intervention studies. There was a high risk of confounding bias across most studies. Selection bias was a concern across most studies, and the generalisability of results was limited for studies evaluating prevention interventions. Low sample size increased the potential for type II error when considering female/woman/girl-specific estimates.

Exercise interventions

A meta-analysis from three studies (cluster-RCT, RCT and quasi-experimental) provides very-low certainty evidence that shoulder-specific exercise programmes (eg, strength, stability/control, sport-specific exercises) reduce shoulder injury rates by 51% (IRR 0.49; 95% CI 0.30 to 079; figure 2) in paediatric and adult athletes (online supplemental table S9).[42 44 45] Across the remaining studies with female/woman/girl-specific estimates, one cluster-RCT (handball) reported no reduction in elbow injuries with a shoulder exercise prevention programme,[41] and a quasi-experimental study (dragon boat racing) reported a lower shoulder injury rate but not wrist injuries with a strengthening and stretching prevention programme.[43]

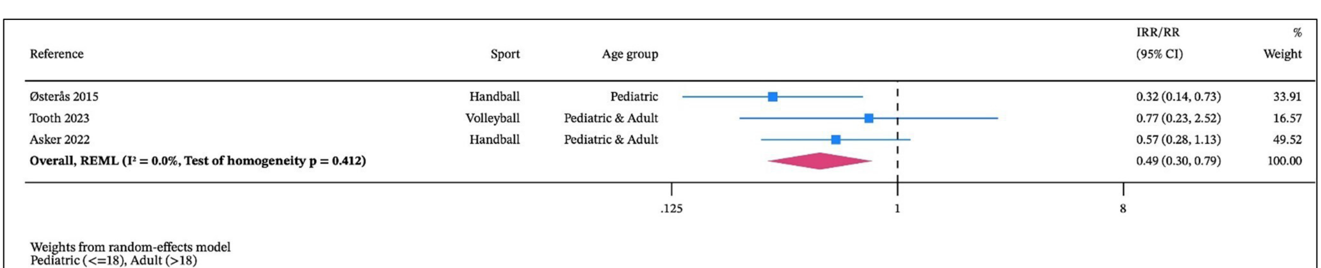

Figure 2 Random effects meta-analysis forest plot of studies evaluating the efficacy of upper extremity injury prevention programmes on shoulder injury. IRR, incidence rate ratio; REML, restricted maximum likelihood; RR, risk ratio.

Modifiable risk factors

12 UE injury MRF studies met the inclusion criteria and had female-specific data reported. Studies included a total of 2895 participants (2348 female/woman/girl athletes; 81%), and study designs included prospective cohort (n=6) and cross-sectional (n=6) studies. These studies were conducted across four continents: North America (n=6), Europe (n=4), Asia (n=1) and Oceania (n=1). Six (50%) studies included paediatric participants (≤18 years of age). Eight studies (67%) included female/woman/girl-only participants (table 2).

Most studies investigated sports involving overhead movements (n=9), including handball (n=3), softball (n=2), swimming (n=1), volleyball (n=1), baseball (n=1), cricket (n=1) and padel (n=1). Two studies examined MRFs for UE injuries in gymnastics, and one study reported on Para athletes (wheelchair basketball). Shoulder injuries were most frequently reported (n=7), followed by general UE (n=3), elbow (n=3) and wrist/hand (n=2) injuries. MRFs spanned range of motion (ROM; n=6), strength (n=8), training load (n=1), scapular dyskinesis (n=3), equipment (n=1), sport specialisation (n=2) and sport-specific conditioning (n=1), with some studies investigating multiple MRFs. We were able to perform two semiquantitative syntheses (ie, shoulder ROM and shoulder strength).

Study quality and risk of bias

The median ROB score was 9.5 (range 6–15) out of a maximum possible score of 16 (online supplemental table S7). MRF types and outcomes are heterogeneous across MRF studies. There was a high risk of confounding bias and selection bias across most studies, making the generalisability of the results limited for studies identifying MRFs. Low sample size impacted the ability to disaggregate female/woman/girl-specific estimates.

Range of motion

Based on four studies reporting female/woman/girl-specific results, there is very-low certainty evidence of an unclear association between shoulder ROM (external rotation (ER)/internal rotation (IR), heterogeneous measurement techniques) and shoulder injury in female/woman/girl athletes (online supplemental table S9).[59 60 62 66]

Strength

Based on five studies, there is very-low certainty evidence of an association between lower shoulder strength (heterogeneous strength measurements) and shoulder injury rates in female/woman/girl athletes (online supplemental table S9).[59–62 66] Across eight additional studies with female/woman/girl-specific estimates, two reported higher shoulder injury rates with lower shoulder ER to IR strength ratio (ER:IR),[61 66] one study reported a higher shoulder injury rate with lower isometric shoulder ER and IR strength,[60] and five studies found no association between strength and UE injury rates.[59 62 63 65 70]

Training load

Only one study reported female/woman/girl-specific estimates and reported that softball athletes playing ≥30 games/year had increased odds of shoulder and elbow injuries compared with those playing <30 games/year.[64]

Scapular dyskinesis

Three studies evaluating scapular dyskinesis (abnormal movement or positioning of the scapula) as a MRF reported female/woman/girl-specific estimates. These studies observed no association between shoulder injuries and scapular dyskinesis in handball or cricket.[59 60 66]

Sport specialisation

With respect to sport specialisation, one study with female/woman/girl-specific data reported higher odds of UE injury for softball athletes who played <8 months yearly or pitched <8 months yearly, but not by high or moderate specialisation.[64] A second study with female-specific data reported higher odds of arm and elbow injuries in beginner and intermediate volleyball players compared with multisport athletes, but no difference for advanced volleyball players.[69]

Equipment

Across studies that evaluated equipment as an MRF, one with female/woman/girl-specific data reported a lower rate of padel hand injuries by racket shape (round vs diamond or teardrop) and racket type (soft vs hard).[67] In contrast, racket type (round vs diamond or teardrop) was associated with higher rates of elbow injury, while racket weight was not.[67]

Sport-specific conditioning

With respect to sport-specific conditioning, one study reported no association between conditioning (eg, rope climb, vertical jump and hanging pikes) and UE injury odds in female/woman/girl gymnastics.[65]

Protocol deviations

There were protocol deviations to the eligibility criteria and the risk-of-bias instrument. The protocol indicated that 'records where sex/gender-specific results are not reported or cannot be extracted' would be excluded. Concerned there would be limited studies with female/woman/girl-specific estimates, we included all studies with data from at least one female/woman/girl athlete in each study group, regardless of the reporting of sex/gender-specific results, while still basing all meta-analyses and semiquantitative analyses on female/woman/girl-specific data. This decision resulted in a larger number of studies being included and potential hypothesis-generating data to inform future studies. Only those with female/woman/girl disaggregated data were included in the results, with the aggregate data presented in supplementary tables.

To ensure consistency in study quality and risk-of-bias ratings across the broad range of included study designs, we used the DBQAT[94] over the National Institutes of Health Study Quality Assessment tools.[95] The DBQAT can be used across multiple study designs and includes items that rate internal validity (study design, selection and misclassification bias and potential confounding), external validity (generalisability) and reporting. The DBQAT inherently assigns lower scores to studies representing lower-level evidence of causation (eg, cross-sectional, case-control and quasi-experimental studies) and higher scores to studies representing higher-level evidence of causation (eg, cohort studies and RCTs that account for confounding), given that some questions are not relevant to all study designs.[94] Despite its flexibility, we recognise that the DBQAT was not designed and does not independently assess risk-of-bias.

Table 2 Characteristics of modifiable risk factor (MRF) studies with female/woman/girl-specific data (n=12)

Author year Country Study design	Participant characteristics Sport sample characteristics	Definition of upper extremity injury and intervention	Effect estimates (eg, IRR, OR, 95% CI or other relevant main findings) *calculated point estimate where data allowed*
Achenbach 2020 Germany Cohort (prospective)[59]	Handball n=68 girls Paediatric participants: yes IG: n=16 (men and women) UG: n=122 (men and women)	Injury: shoulder (overuse, self report) MRF: ROM, strength	Normalised muscle strength—eccentric ER <2.90 N/kg OR 1.38 (0.1, 13.3, p=n.s.) Passive glenohumeral range of motion—GIRD >7.5° OR 12.50 (1.4, 114.6, p=0.014)* ER gain >7.5° OR 15.20 (1.1, 185.3, p=0.025)*
Asker 2020 Sweden Cohort (prospective)[60]	Handball n=180 female Paediatric participants: yes IG: n=26 females UG: n=154 females	Injury: dominant shoulder (first incidence, self report) MRF: ROM, strength, scapular dyskinesis	Strength, N/kg—isometric ER HRR 2.37 (1.03, 5.45), aHRR 2.37 (1.03, 5.44)* Isometric IR HRR 2.43 (1.06, 5.58), aHRR 2.44 (1.06, 5.61)* Eccentric ER HRR 1.25 (0.58, 2.71), aHRR 1.21 (0.57, 2.62) Isometric abduction HRR 1.14 (0.53, 2.47), aHRR 1.10 (0.50, 2.38) Isometric ER/isometric IR <0.75 HRR 0.87 (0.40, 1.87), aHRR 0.85 (0.39, 1.83) Eccentric ER/isometric IR <0.75 HRR 0.45 (0.11, 1.88), aHRR 0.41 (0.10, 1.73) ROM, deg—ER HRR 0.71 (0.33, 1.55), aHRR 0.74 (0.34, 1.62) IR HRR 1.56 (0.70, 3.51), aHRR 1.59 (0.70, 3.54) Total ROM HRR 0.70 (0.32, 1.53), aHRR 0.70 (0.32, 1.53) Total ROM (dominant/nondominant) HRR 1.21 (0.56, 2.62), aHRR 1.30 (0.59, 2.83) Scapular dyskinesis—during flexion HRR 0.50 (0.17, 1.45), aHRR 0.49 (0.17, 1.44) During abduction: HRR 1.65 (0.39, 6.98), aHRR 1.53 (0.36, 6.52) Join position sense—mean error from target angle HRR 1.06 (0.49, 2.29), aHRR 1.06 (0.49, 2.29)
Augustsson 2023 Cross-sectional Sweden[67]	Padel n=104 women Paediatric participants: no IG: NR (177 injuries) UG: NR	Injury: shoulder, hand/wrist/forearm, elbow (time loss) MRF: equipment	Racket shape (round vs diamond and teardrop)—hand injury: p=0.02* Racket type (soft vs hard)—hand injury: p=0.04* Racket type (soft vs hard)—elbow injury: p=0.01* Racket weight—elbow injury: p=0.64
Edouard 2013 France Cohort (prospective)[61]	Handball n=16 females Paediatric participants: yes IG: n=9 females UG: n=7 females	Injury: shoulder (time loss) MRF: strength	Dominant side deficit: in concentric (at 60, 120 or 240°/s) RR 1.88 (0.71, 3.04) in eccentric (at 60°/s) RR 1.24 (0.76,1.72) Conventional Ratios: ERcon/IRcon at 60°/s <0.63 RR 1.76 (0.95, 2.57) ERcon/IRcon at 120°/s <0.64 RR 1.24 (0.76, 1.72) ERcon/IRcon at 240°/s <0.69 RR 2.57 (1.60, 3.54)* Functional ratios: ERecc/IRcon at 60°/s <0.67 RR 1.50 (0.83, 2.17) IRecc/ERcon at 60°/s >1.61 RR 2.08 (1.18, 2.98)* Muscle imbalance criteria: at least two of the previous parameters RR 2.57 (1.60, 3.54)*
Harrington 2014 USA Cross-sectional[62]	Swimming n=37 females (74 shoulders) n=2 NCAA I programmes Paediatric participants: no IG: n=26 shoulders UG: n=48 shoulders	Injury: shoulder (self report) MRF: ROM, strength	Dominant arm: ER ROM 0.30 (p=0.40) IR ROM 0.44 (p=0.21) IR strength: 0.11 (p=0.76) ER strength: 0.14 (p=0.68) Non-dominant arm—ER ROM 0.10 (p=0.76) IR ROM 0.49 (p=0.16) IR strength: 0.09 (p=0.79) ER strength: 0.14 (p=0.71)
Heck 2021 USA Cohort (prospective)[63]	Gymnastics n=15 females (31 gymnast seasons) Paediatric participants: no IG: 12 females UG: 19 females	Injury: UE (medical attention and/or time loss) MRF: ROM, strength	Wrist extension—D: 0.7, n.s.; ND: 0.1, n.s. Elbow extension—D: 0.1, n.s.; ND: 0.2, n.s. Shoulder ER—D: 0.5, n.s.; ND: 0.3, n.s. Shoulder IR—D: 0.3, n.s.; ND: 0.2, n.s. Shoulder flexion—D: 0.3, n.s.; ND: 0.4, n.s. Shoulder ER strength—D: 0.2 n.s.; ND: 0.1 n.s. Shoulder IR strength - D: 0.1 n.s.; ND: 0.2 n.s. Shoulder scaption—D: 0.1 n.s.; ND: 0.2 n.s. Lower trapezius—D: <0.1, n.s.; ND: 0.1 n.s. Middle trapezius—D: 0.1 n.s.; ND: 0.2 n.s. Shoulder ER:IR—D: 0.5, n.s.; ND: 0.2, n.s.
Lear 2023 USA Cross-sectional[64]	Softball n=1309 females Paediatric participants: yes IG: n=572 females UG: n=737 females	Injury: shoulder, elbow (time loss) MRF: sport specialisation, training load	Playing >30 games per year aOR 1.74 (1.26, 2.40)* Playing ≤8 months of softball per year aOR 4.00 (1.96, 8.33)* Pitchers ≤8 months of softball per year aOR 3.03 (1.04, 9.09)* High specialisation aOR 2.33 (0.97, 5.60) Moderate specialisation aOR 0.39 (0.17, 0.92)

Continued

Table 2 Continued

Author year Country Study design	Participant characteristics Sport sample characteristics	Definition of upper extremity injury and intervention	Effect estimates (eg, IRR, OR, 95% CI or other relevant main findings) *calculated point estimate where data allowed*
Ling 2020 USA Cohort (prospective)[65]	Gymnastics n=100 females Paediatric participants: no IG: n=78 females UG: n=22 females	Injury: UE (time loss) MRF: strength, sport-specific conditioning	Total score OR 1.00 (0.95,1.05, p=0.99) Rope climb OR 1.05 (0.88,1.25, p=0.57) Vertical jump OR 1.07 (0.87,1.31, p=0.54) Hanging Pikes OR 0.93 (0.75,1.15, p=0.50) Shoulder flexibility angle OR 1.00 (0.90, 1.11, p=0.99) Agility Sprint time OR 0.97 (0.77, 1.22, p=0.70) Over-grip pullups OR 1.02 (0.84, 1.24, p=0.82) Split sum OR 0.98 (0.87, 1.10, p=0.70) Push-ups OR 1.06 (0.88,1 .27, p=0.55) 20-yard sprint OR 0.93 (0.68, 1.27, p=0.65) 20-yard sprint OR: 0.93 (0.68, 1.27, p=0.65) Handstand hold time OR 0.93 (0.84, 1.02, p=0.13)
Murphy 2020 Australia Cohort (prospective)[66]	Cricket n=115 females Paediatric participants: no IG: n=14 females UG: n=111 females	Injury: dominant shoulder (time loss) MRF: ROM, strength, scapular dyskinesis	Shoulder IR:ER rotation strength ratio OR 1.84 (1.16, 2.93, p=0.010)* Hip ABD strength OR 0.97 (0.95, 1.00, p=0.049)* Hip ADD:ABD strength ratio OR 1.44 (1.01, 2.06, p=0.047)* Adjusted OR (adjusted for the three significant results from univariate analysis): shoulder IR:ER rotation strength: 1.79 (1.12, 2.88, p=0.016)*
Shanley 2011 USA Cross-sectional[68]	Softball n=103 females Paediatric participants: yes IG: n=9 females UG: n=94 females	Injury: Shoulder, elbow (all complaint) MRF: ROM	Passive IR loss, degrees: p=0.72 Passive total rotation loss, degrees: p=0.75
Wasser 2021 USA Cross-sectional[69]	Volleyball n=276 females Paediatric participants: yes IG: n=188 females UG: n=88 females	Injury: arm, elbow, fingers (time loss) MRF: training load	Beginner-intermediate players only playing volleyball (compared with multisport) arm and elbow OR 4.75 (1.27, 17.73, p=0.02)* Advanced players only playing volleyball (compared with multisport)—fingers OR 1.85 (0.99, 3.45, p=0.05)
Yuine 2023 Japan Cross sectional[70]	Wheelchair Basketball n=9 females (18 wrists) Paediatric participants: no IG: n=7 wrists UG: n=11 wrists	Injury: wrist (MRI findings) MRF: strength	Applied Force (N): r=−0.37 (p=0.13) Grip Strength (N): r=−0.01 (p=1.0)

*Denotes significant finding.
ABD, abduction; ADD, adduction; aHRR, adjusted HRR; aOR, adjusted OR; BF, biceps femoris; BW, body weight; D, dominant; ER, external rotation; EXT, extension; FLE, flexion; GIRD, glenohumeral internal rotation deficit; HRR, hazard rate ratio; IR, internal rotation; IRR, incidence rate ratio; N, Newton; NCAA, National Collegiate Athletic Association; ND, non-dominant; n.s., non-significant; ROM, range of motion; UE, upper extremity.

DISCUSSION

This is the first systematic review to examine prevention strategies and MRFs for UE injuries in female/woman/girl athletes. We identified very-low certainty evidence that shoulder exercise programmes consisting of strength, stability/control, and sport-specific exercises reduce shoulder injury rates by 51% across paediatric and adult handball and volleyball. There is also very-low certainty evidence that lower shoulder muscle strength is associated with higher shoulder injury rates and an unclear relationship between shoulder ROM and shoulder injury rates. Our findings expose important knowledge gaps and can serve as an important foundation for future efforts to reduce the burden of female/woman/girl athlete UE injuries.

Preventing female/woman/girl athlete's UE injuries

Our meta-analysis demonstrated a 51% reduction in shoulder injuries among female/woman/girl handball and volleyball athletes who completed a shoulder-focused exercise intervention. All three studies in this meta-analysis were exercise-based warm-up programmes with interventions including 3–7 exercises focusing on shoulder external rotation strength,[42 44 45] scapular control/posterior upper body strength,[42 44 45] shoulder internal rotational strength[44] and a throwing component, either as part of the warm-up[45] or a preseason programme.[42] Programmes were performed as part of every warm-up routine[44 45] or at least three times per week.[42] Although prevention strategies often involve policy/rule changes, equipment modifications and/or education, none of the included studies reported female/woman/girl-specific data for these approaches. This highlights the need for high-quality studies to evaluate the effectiveness of other interventions for female/woman/girl athletes.

MRFs for female/woman/girl athletes' UE injury

This review included 12 studies that evaluated several MRFs for UE injuries, including ROM, strength, training load, scapular dyskinesis, equipment, sport specialisation and sport-specific conditioning. As the certainty of evidence across these MRFs was very low, it is highly likely that our understanding of their relationship with female/woman/girl athletes' UE injuries will change as higher-quality evidence becomes available.

Shoulder ROM is inconsistently associated with shoulder injury in female/woman/girl athletes. Significant associations between ER and IR ROM deficits and shoulder injuries were reported in some, but not all, studies. Similarly, strength measures, particularly ER:IR strength ratio, showed mixed results in terms of shoulder injury risk, requiring clarification in future well-designed, rigorous studies. Sport specialisation, a potential MRF, was not consistently associated with increased risk for UE injuries.

Training load emerged as a potential MRF in this review. The relationship between training volume and UE injuries appears complex and variable. For example, some studies indicated that increased training load (eg, higher weekly training hours, weekly throw numbers) is associated with a higher risk of shoulder and elbow injuries, while others found no significant association. Inconsistent findings likely highlight the multifactorial nature of training load that encompasses various physical demands and training activities across sports and the physiological and psychological adaptations to load and recovery.[96 97] Additionally, studies use a range of training load definitions and measures, making it difficult to combine data and compare across studies. Further, an increased susceptibility to changes in training load may be related to tissue capacity differences.[96] For instance, ligament tissues might tolerate changes in training volume differently than tendon tissues, underscoring the need to distinguish between acute and gradual onset/overuse injuries. Finally, factors like reduced strength likely influence the tissue-specific training load tolerance.[84] The influence of other MRF factors on the training load–injury relationship should be further investigated.

Overall, this review highlights the need for well-designed prospective studies with female-specific data to better understand the impact of MRFs on UE injuries. Future research should aim for standardised assessment methods, sport- and sex-specific analyses and rigorous study designs to improve the quality of evidence. These studies should consider the complex and multifactorial nature of injuries by applying theory-driven 'a-priori' approaches that attempt to explain how and why changes in an MRF lead to changes in injury incidence rates (ie, causal model), with consideration of potential modifiers and interactions between modifiable and non-MRFs based on past evidence (eg, directed acyclic graphs)[98] and the gendered environments that female/woman/girl athletes develop, train and compete.[99] Additionally, injury mechanisms are likely influenced by the interaction of MRFs (eg, strength, ROM) with non-modifiable factors (eg, age, level of sport). These interactions may vary by sport and developmental stage, highlighting the need for multifactorial risk profiling in future studies.

Female/woman/girl Para athlete UE injury

Little is known about UE injury prevention and MRFs for female/woman/girl Para athletes. The only study in wheelchair basketball with female-specific data found no association between strength and wrist injuries, leaving a significant void in our understanding of UE injury risk in this population. Given that Para athletes often experience unique biomechanical demands and injury mechanisms due to mobility impairments, prosthetic or assistive device use or sport-specific adaptations, targeted research is critical.[100 101]

While it is possible that similar factors (such as training load, ROM deficits, strength imbalances and scapular dyskinesis) also influence UE injury risk in female/woman/girl Para athletes, Para-specific MRFs, such as the type of assistive equipment used, level of limb function and classification within sport, must also be considered.[100 101] Without dedicated research, it remains unclear whether existing prevention programmes for UE injuries are effective or appropriate for female/woman/girl Para athletes.

Future research should prioritise inclusive study designs that specifically evaluate UE injuries in female/woman/girl Para athletes, considering sport-specific demands and unique MRFs. Additionally, there is a need to develop evidence-based injury prevention strategies tailored to Para athletes, including training programmes, policy/rule changes and equipment modifications. Ensuring that female/woman/girl Para athletes are adequately represented in injury prevention research will be crucial for developing targeted strategies to support their long-term health and performance.

Strengths and limitations

We employed *a priori* methodology, a librarian scientist's comprehensive search, duplicate independent record screening, data extraction and ROB assessment, biostatistician-led quantitative synthesis, semiquantitative synthesis and certainty of evidence ratings and a broad team of expert researchers, clinicians and those with lived experience (see equity, diversity and inclusion statement). A limitation of this review is the large number of authors involved in the title/abstract screening, full-text review, data extraction and ROB assessment. While a large review team was necessary to manage the scope of the review, it introduces the potential for variability in the decision-making and interpretation between pairs of reviewers. To mitigate this, we included several consistency measures, including agreement processes as described in the methods, detailed reviewer guidelines and regular meetings throughout each stage of the review. All disagreements were resolved through a third lead author to ensure consistency in the final decisions. Across the searches, we also acknowledge the limitation that 75 studies were excluded at full text that were not English, which accounted for 7% of all studies excluded based on all exclusion criteria.

Considering all prevention and MRF studies, several important knowledge gaps remain. Less than one-third of these studies reported female/woman/girl-specific effect estimates (31%). A recent meta-analysis highlights that injury risk profiles for female athletes differ from their male athlete counterparts,[102] underlining the need for innovative, targeted prevention strategies that are sport- and female/woman/girl-specific. Additionally, no prevention studies and only one MRF study reported on Para athletes, highlighting the significant need for further research in this population, in particular, considering wheelchair sports. We acknowledge that the use of aggregate data, including female/woman/girl athletes, limits the specificity of recommendations for female/woman/girl athletes.

Considering the common goal of reducing UE injuries through ameliorating the effects of potential MRFs, another overarching limitation was heterogeneity in study designs, data collection protocols, injury outcomes and injury definitions. A lack of unified methodology and data collection protocols limits our ability to draw comparisons between studies and sports. Sources of heterogeneity included variability in injury definitions used (eg, self-report, medical attention, time-loss, all-complaint, hospital records, prolonged pain), acute and overuse injury definitions and body segments selectively reported (eg, shoulder, wrist). Of the studies that did explore MRFs, it is also notable that specific MRFs were typically analysed independently. As injury aetiology and mechanisms are multifaceted,[103] future studies are needed to determine precise UE injury mechanisms across diverse sporting contexts.

While this review includes studies spanning paediatric through adult athlete populations, differences in developmental stage may impact injury risk and prevention effectiveness. Due to limited disaggregated data, age-specific analyses were not consistently possible, highlighting the need for future chronological and biological age-stratified research in female/woman/girl athletes.

Practical implications

It is clear that sport-specific and sex-/gender-informed UE injury prevention strategies are needed. Shoulder exercise programmes (eg, strength, stability/control and sport-specific exercises) can reduce shoulder injuries in paediatric and adult handball and volleyball athletes and should be recommended for use. Clinicians should be aware of the gaps in existing research and consider adapting injury prevention programmes to account for individual, potential MRFs. Additionally, given the variability in injury definitions across studies, clinicians should interpret research findings cautiously and prioritise standardised assessment tools when evaluating UE injuries in practice.

Research implications

Future research recommendations include reporting disaggregated data for female/woman/girl-specific effect estimates and a focus on Para athletes and other factors (eg, different countries, cultures). Location-specific and injury type- (acute vs gradual-onset/overuse) specific prevention strategies, stronger experimental designs, consideration of confounding and effect measure modification in analyses, clarity of injury definitions and reporting of unintended consequences should also be considered. Future studies should also consider psychological and socioenvironmental factors that might contribute to female/woman/girl upper-extremity injury risk.[99 104] Future prevention strategies should be designed with implementation in mind, including coach-delivered programmes, sport-specific adaptations and sport partner engagement to ensure uptake and sustainability across diverse levels of female/woman/girl sport.

CONCLUSIONS

This systematic review and meta-analysis summarises the current evidence on prevention strategies and MRFs for UE injuries in female/woman/girl athletes; however the overall quality and quantity of evidence are insufficient to draw firm conclusions. Shoulder-specific exercise programmes may reduce shoulder injury rates in female/woman/girl handball and volleyball players. Considering the large number of female/woman/girl athletes at risk of UE injury, there is an urgent need for focused research, with attention to high-quality study designs, larger sample sizes and standardised outcome measures. Until such studies are conducted, the development of evidence-based prevention interventions for UE injuries in female/woman/girl athletes will remain limited.

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Contributors CAE and KMC were responsible for study conceptualisation and methodology. KAH was responsible for conducting a search of the literature to retrieve the studies to be screened. Initial rapid screening was completed by EEH, ESG and KBF. Title and abstract screening, full-text review and data extraction were completed by EEH, ESG, CAE, MM, HF, JHL, JST, KBF, BMP, GM, MA, RW, GB and ABM. ROB assessments were completed by EEH, ESG, CAE, MM, HF, KBF, BMP, GM, MA, RW, ABM and CLM. Data synthesis was completed by EEH, ESG and MDM. Resources to help synthesise results were created by JLW. Initial draft was created by EEH, ESG, MDM, KBF, CLM, MM and CAE. All authors reviewed and edited the draft. Project administration was carried out by EEH, CAE and MM. Funding acquisition was from CAE and KMC. CAE and KMC are the guarantors of the review and accept responsibility for the work, including the integrity of the data and the decision to submit for publication.

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