Modifiable risk factors for lower-extremity injury: a systematic review and meta-analysis for the Female, Woman and Girl Athlete Injury Prevention (FAIR) consensus

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ABSTRACT

Objective Examine potentially modifiable risk factors (MRFs) for female/woman/girl athletes' lower-extremity injuries.

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

Data sources MEDLINE, CINAHL, APA PsycINFO, Cochrane Systematic Review Database, CENTRAL, SPORTDiscus, EMBASE, ERIC searched 30 October or 23 November 2023.

Eligibility Primary data studies with comparison group(s) assessing the association of MRFs for sport-related lower-extremity injury(s) with ≥1 female/woman/girl per study group.

Results Across 195 studies (n=115; 58.9% female/woman/girl-specific estimates) including 1 525 662 participants (2.4% females/women/girls), eight injury outcomes were assessed (n=75 general lower-extremity, n=3 groin, n=6 hip, n=17 thigh, n=88 knee, n=17 lower-leg, n=27 ankle, n=9 foot). Sixty-six MRF categories were identified. Substantial heterogeneity in MRFs and injury outcomes exists, with high risk of bias present in 37.4% of studies. Considering female/woman/girl specific estimates, we performed meta-analyses for 10 MRFs (body mass, x (BMI), weekly training distance, muscle strength, artificial turf, off-season plyometric training, readiness to return-to-sport, single-leg hop asymmetry, vertical drop jump peak knee flexion angle and ground reaction force) and semiquantitative analyses for 26 MRFs for a variety of injuries. Meta-analyses suggest no association between any lower-extremity strength outcome (g=0.01, 95% CI −0.11 to 0.14; I^2=37.3%; very low certainty evidence) or artificial turf (Incidence Rate Ratio=0.97, 95% CI 0.88 to 1.07; I^2=2.4%; low certainty evidence) and various lower-extremity injuries. Higher body mass (g=0.19, 95% CI 0.00 to 0.38; I^2=71.7%) and/or BMI (g=0.22, 95% CI 0.09 to 0.36; I^2=37.0%) are associated with several lower-extremity injuries (very low certainty evidence).

Conclusion This review synthesises a large body of exploratory research, exposes important knowledge gaps and provides a foundation for understanding MRFs for female/woman/girl athlete lower-extremity injuries.

PROSPERO registration number PROSPERO CRD42024486715.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Lower-extremity injuries represent over 60% of female/woman/girl athlete injuries.

⇒ Exercise-based training programmes are estimated to reduce female/woman/girl athlete knee injuries by 24%, anterior cruciate ligament injuries by 61% and ankle sprain injuries by 39%.

⇒ It is unclear if there are gender- or sex-specific modifiable risk factors for female/woman/girl athletes that could enhance lower-extremity injury prevention interventions.

BACKGROUND

Lower-extremity injuries account for over 60% of female/woman/girl athlete sport-related injuries across adolescent, collegiate, amateur and professional levels.[1–4] Lower-extremity injury rates are higher in some female/woman/girl sports, with more than 60% of all basketball,[5] soccer (football), volleyball,[6] gymnastics,[7] athletics[8 9] and dance[10] injuries involving the lower extremity.[1] Across injury types, knee injuries, in particular

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WHAT THIS STUDY ADDS

- ⇒ Female/woman/girl athletes make up approximately 2.4% of participants in sport-related lower-extremity injury risk factor studies.
- ⇒ Overall leg, hip abduction, knee extension and knee flexion strength do not differ between female/woman/girl athletes with and without knee injuries (low to very low certainty evidence from six studies including 1757 females/women/girls).
- ⇒ There is no difference in general lower-extremity, hip/groin, thigh, knee and ankle injury incidence rates between artificial turf and grass playing fields (low to very low certainty evidence from six studies including over 2174 females/women/girls).
- ⇒ There is conflicting evidence about the association between body mass or body mass index (BMI) and general lower extremity, thigh, anterior cruciate ligament and ankle injuries (body mass, very low certainty evidence from 20 studies including 7875 females/women/girls; BMI, 19 studies including 6973 females/women/girls).
- ⇒ Significant heterogeneity and high risk of confounding bias limit our understanding of modifiable risk factors for female/woman/girl athlete lower-extremity injuries.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ This review exposes important knowledge gaps which can guide investment and action to reduce the burden of female/woman/girl athlete lower-extremity injuries.
- ⇒ Future research must move past bio-physiological, anatomical and biomechanical characteristics to consider psychosocial and environmental factors that contribute to female/woman/girl athletes' lower-extremity injuries.
- ⇒ To advance the field, we must shift from studies that describe/identify potential risk factors to studies that assess independent risk factor-injury relationships or predict female/woman/girl athletes' lower-extremity injuries.

anterior cruciate ligament (ACL) ruptures, consistently represent the highest female/woman/girl athlete injury burden based on incidence rates and time loss.[11–13] ACL ruptures also represent one of the highest injury-related financial burdens for female/woman/girl athletes.[14] The longer-term consequences of lower-extremity injuries can be considerable, including higher fat mass index,[15] inactivity,[16] early post-traumatic osteoarthritis[17] and poorer health-related quality of life.[18 19]

Exercise-based training programmes are estimated to reduce female/woman/girl knee injury rates by 24% (incidence rate ratio; IRR=0.76 95% CI 0.56 to 1.03), ACL rupture rates by 61% (IRR=0.39 95%CI 0.25 to 0.60) and ankle sprain injury rates by 39% (IRR=0.61 95% CI 0.36 to 1.03).[20] Currently, it is unclear if there are modifiable sex or gender-specific risk factors[21] that could be targeted to boost the protective effect of lower-extremity exercise-based training programmes for female/woman/girl athletes. This lack of knowledge perpetuates misconceptions including the role of hormonal factors,[22 23] the menstrual cycle,[24] anatomical features and hormonal contraceptive use in female/woman/girl injury prevention.[25] More importantly, these gaps divert attention from environmental and contextual factors that disadvantage female/woman/girl athletes [26 27]and interfere with the development of sex- and gender-specific prevention strategies.

The objective of this systematic review was to examine and synthesise the scope and certainty of evidence on potentially modifiable risk factors (MRFs) for female/woman/girl athletes' lower-extremity injuries.

METHODS

Registration

This review was registered on PROSPERO (CRD42024486715) 1 January 2024.

Framework

The Cochrane Handbook,[28] Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines[29] and PRISMA-Search extension[30] informed the conduct and reporting of this review. Equity, diversity and inclusion, and patient and public engagement statements are provided in Box 1 and Box 2 respectively.

Box 1 Equity, diversity and inclusion statement

Female, Woman, 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 also use the term 'gender and/or sex' (gender/sex) but recognise that these constructs are not distinct and often intersect. 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 Female, Woman and Girl Athlete Injury Prevention (FAIR) Consensus Steering Committee planned and designed this review to inform the FAIR consensus meeting. This group (n=24, 80% women; n=17, 71% affiliated with International Olympic Committee 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 FAIR Steering Committee based on relevant and diverse experiences, backgrounds, expertise and professions. Reflecting these intentional efforts towards diversity, authors were 53% women (n=17); 84% White (n=27), 6% Black (African)/African American (n=2), 3% Asian (n=1) and 3% Hispanic/Latino (n=1); 16% from middle to low income birth countries (n=5); and 3% ability limited (n=1), with self-reported lived experience as an athlete (n=16; 48%), coach (n=16; 48%), referee (n=3; 9%) health, medical or exercise practitioner (n=24; 73%) and member for sport organisation (n=11; 33%), government (n=5; 15%) or healthcare (n=7; 21%) committees across paediatric (n=30; 94%), adult (n= 27; 84%) and Para sport (n=17; 53%) spanning five continents and career stage (n=2; trainee; n=10 early, n=9 mid, n=11 late). Author participation required internet and computer access, and a working knowledge of English. Author data were collected electronically.

Box 2 Patient and public involvement

Female, Woman and Girl Athlete Injury Prevention (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 Para sport experience (n=4). The EAC level of engagement is consistent with the International Association for Public Participation 'consult' or 'involve' level with tasks including reviewing an evidence synthesis from this review, and consulting on the development of the FAIR consensus and other outputs. The EAC will also participate in future knowledge translation activities.

Data sources and search

Relevant studies were identified by searching eight databases (Medline-OVID, CINAHL-EBSCOhost, APA PsycINFO-OVID, Cochrane Systematic Review Database-OVID, CENTRAL-OVID, SPORTDiscus-EBSCOhost, EMBASE-OVID, ERIC-EBSCOhost). Search strategies consisted of subject headings and text words related to lower-extremity injuries, sports, prevention and risk factors, with limits for publication year (2001-current) to prioritise evidence reflecting current techniques and technology, and conducted when standardised reporting guidelines[31–33] were available (online supplemental file 1). The concepts for 'Sports' and 'Prevention' were adapted from searches conducted for the Consensus Statement on Concussion in Sport.[34] A health sciences librarian (KAH) developed the MEDLINE search strategy in consultation with all authors and translated it for other databases. The search strategy for lower-extremity injury was peer-reviewed by an external expert health sciences librarian. A health sciences librarian (KAH) performed all searches (30 October 2023, Cochrane Systematic Review Database and CENTRAL 23 November 2023) and transferred records to an online screening platform (Covidence, Veritas Health Innovation).

Eligibility

Table 1 presents detailed eligibility criteria. While the term 'risk factor' should be reserved for situations when a causal relationship is under investigation,[35] we used a broader definition 'any factor associated with a lower-extremity injury' due to a paucity of causal research. Sport was defined as 'any physical activity involving physical exertion and skill where an individual or team competes in an event under a set of rules'. Studies reporting data from the same cohort were included if they assessed different risk factors or reported estimates at different follow-up periods. Although we excluded review articles, the Cochrane Systematic Review Database was searched to enable reference list searching of relevant reviews.

Study selection

After removing duplicates, we used a three-step screening process. First, individual reviewers (JML, AR, ER, MW) performed a rapid title-abstract screen to exclude clearly irrelevant records (ie, no English abstract, no human participants, no sport, no lower-extremity injury or no peer-reviewed primary research paper). Remaining title abstracts were screened by pairs of independent reviewers (MB, MBo, HPD, CAE, MH, JML, SM, ABM, MM, GM, OO, DP, KP, AR, ER, KT, EV, MvM, SJW, MW, JLW). Finally, the full text of remaining records was independently reviewed by AR or CAE and one other reviewer (MB, MBo, CAE, MH, JML, CLM, GM, MM, MMø, NSM, SM, OBAO, DP, KP, AR, ER, KT, MvM, EV, SJW, MW, JLW) for inclusion. If eligibility questions arose during the rapid review, a record was moved to title-abstract screening. Discrepancies at title-abstract and full-text screening were discussed by raters for consensus and/or resolved by a third reviewer (JLW, AR, CAE). Before screening, inter-rater agreement was established (≥80% agreement) among raters and senior authors (CAE) based on a sample set (50 records). Retracted studies were identified and removed.

Data extraction

Authors (MB, MBo, HPD, CAE, MAG, JML, ABM, CLM, MCM, MM, MMø, NSM, SM, JO, OBAO, DP, KP, AR, ER, KT, MvM, EV, SJW, JLW) independently extracted data in duplicate. Extracted data included study details (first author, year, location, design); participant information (size, study groups, age, sex/gender, sport, sport level, attrition); lower-extremity injury definition; MRF(s) assessed; and results (ie, statistical outcomes, point estimates for outcome prevalence/incidence/rates, unadjusted effect estimates including odds ratios; OR, IRRs, relative risk; RR and 95% CI, or raw numbers to calculate effect estimates). Participants <18 years of age were categorised as paediatric based on 18 years being commonly recognised as a legal age of majority, and division of age between high school and university/college sport. Discrepancies were discussed by raters for consensus and/or resolved by a third reviewer (JLW, AR, CAE).

Table 1 Detailed eligibility criteria

Inclusion criteria	Exclusion criteria
► English language abstract ► Human data ► Primary data (RCT, quasi-experimental, cohort, case-control and cross-sectional studies) ► Assessed the association between a potentially modifiable risk factor (extrinsic or intrinsic to an athlete) for LE injury (groin to toes) ► Comparison group (participants with no exposure to a potentially modifiable risk factor) ► Reported ≥1 female/woman/girl* in each study group	► Review articles, commentaries, letters to the editor, case-series, case study, reports, abstracts, conference proceedings, dissertations ► Only report injuries or pain from non-sport related mechanisms ► Only report injuries or pain of the spine or pelvis ► Did not report disaggregated LE injury data ► Participation in recreational activities or active transportation

*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 also use the term 'gender and/or sex' (gender/sex). 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 intending to reduce humans to their gender.
LE, lower extremity; RCT, randomised controlled trial.

Risk of bias

Pairs from 23 reviewers (MB, MBo, GB, MOD, CAE, JML, ABM, CLM, MCM, MM, MMø, NSM, SM, JO, OBAO, DP, KP, AR, ER, KT, MvM, SJW, JLW) independently assessed included studies in duplicate on criteria for transparent reporting, internal validity (study design, reporting quality, presence of selection and misclassification bias, potential confounding) and external validity (generalisability) using the 27-item Downs and Black quality assessment tool (DBQAT; online supplemental file 2). Risk-of-bias scores were assigned based on 15 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 (JLW). The percentage of items at low risk of bias (achieved maximum rating) was calculated for each study.

Data syntheses

First, unique MRFs were identified and categorised by reported injury outcome considering sport, study design and availability of female/women/girl-specific data and/or estimates. Second, univariate OR, IRR or RR (95% CI) of injury for potential risk factors assessed in studies that only reported a p value when raw data was available were calculated. Finally, quantitative (meta-analysis) or semiquantitative syntheses were conducted, and certainty of evidence ratings assigned. Meta-analyses or semiquantitative[36] analyses were performed when ≥3 studies assessed a unique MRF for a reported injury outcome with either homogenous (meta-analysis) or heterogeneous (semiquantitative) female/woman/girl athletes specific estimates (eg, p value, group mean, mean group difference, OR, RR or IRR). Pooled effects were based on ORs, RRs, IRRs as available, and standardised injured and uninjured group means (SD) if not. A level of three studies was based on best practice[28] of allowing for a tie break.[37] Certainty ratings were co-generated by one author (JLW) and confirmed by three others (AR, CLM, JML).

Quantitative synthesis

Based on female/women/girl-specific data, we performed meta-analyses by computing Hedge's g standardised mean differences (comparison of baseline features of injured and uninjured groups from cross-sectional, case-control and cohort studies) or pooled OR, IRR or RR (95%CI) using a random effects (restricted maximum likelihood) model (Stata v18, StataCorp, USA). We chose Hedge's g because it accounts for the continuous and heterogeneous nature of the outcome data and considers individual study sample sizes in the pooled SD. Weights were computed from the random effects model with each MRF summarised by its own unadjusted model. Heterogeneity between studies was assessed with a standard-Q test, and the proportion of variation attributable to inconsistency was estimated with the I^2 statistic.

After meta-analyses, the overall certainty of evidence for estimates of individual MRFs was rated as 'high' or downgraded to 'moderate', 'low' or 'very low' using the modified Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach for prognostic factor reviews.[36] Briefly, a baseline rating was assigned to each MRF based on the phase of investigation (strength study design on a continuum from identifying to confirming or understanding a MRF pathway)[38] represented across studies. This value was then up or down graded based on methodological weaknesses (risk of bias); heterogeneity of results (inconsistency in sample and methods); and generalisability of findings to the target population (indirectness), estimate precision (95%CI width), risk of publication bias (ie, consistency of the relationship between a potential intervention or MRF and a specific injury, reporting of estimates and p values, effect size and funnel plot distribution), magnitude of effect and evidence of a dose response (online supplemental file 3).

Semiquantitative synthesis

Semiquantitative syntheses involved rating the certainty of evidence for potential MRFs using the modified GRADE approach[36] adapted for non-pooled data (online supplemental file 3).[37–39] All domain ratings were considered when assigning an overall rating,[36] and a corresponding statement of certainty in the direction (considering consistency across studies), and magnitude of the MRF and injury relationship was generated.

RESULTS

In total, 195 studies were included (figure 1, online supplemental file 4). These studies involved 1 524 895 participants (36 890 females/women/girls; 2.4%), with 115 (58.9%) studies reporting female/woman/girl-specific estimates. Of the included studies, 135 (69.5%) had samples with participants under the age of 18 (online supplemental files 5 and 6), with 40 reported girl (paediatric <18 years of age) specific data. No studies reported female/woman/girl Para athlete-specific data.

Study characteristics

The 195 studies included 122 cohort, 46 case-control and 27 cross-sectional studies representing 37 countries (28 high-, eight middle- and two lower-income)[40] across six continents (Africa, Asia, Europe, North America, Oceania, South America) and 21 sports (online supplemental files 4 and 5). One hundred and ten (56.4%) studies referred to participants exclusively as females (sex), eight (4.1%) as women or girls (gender) and 77 (39.7%) used females, women or girls interchangeably. Across studies, eight lower-extremity injury outcomes were assessed (n=75 general lower-extremity, n=3 groin, n=6 hip, n=17 thigh, n=88 knee with n=49 ACL injury, n=18 lower leg, n=27 ankle, n=10 foot; online supplemental files 5 and 6). Potentially, MRFs spanned 66 broad categories (figure 2).

Meta-analyses

After considering the number of studies investigating unique MRFs and injury type associations, availability of female/woman/girl-specific estimates and reported estimate type, meta-analyses were performed for 10 MRFs (body mass, body mass index (BMI), weekly training distance, muscle strength, artificial turf, off-season plyometric training, psychological readiness to return to sport, single leg hop asymmetry, vertical drop jump (VDJ) peak knee flexion angle and vertical ground reaction force), and semiquantitative analyses for 26 MRFs across a variety of injury outcomes.

Based on meta-analyses of female/woman/girl-specific data (table 2 and online supplemental file 7), low certainty evidence suggests no difference in knee flexion *strength* (g=0.01, 95% CI −0.17 to 0.18; I^2=2.2%) or knee flexion-extension strength ratio (g=−0.18, 95% CI −0.39 to 0.02; I^2=0.0%) between female/woman/girl athletes with and without knee injuries. There was also very low certainty evidence of no difference in general leg (leg press one repetition maximum; g=−0.13, 95% CI −0.40 to 0.15; I^2=53.5%) or knee extension strength (g=0.19, 95% CI −0.09 to 0.47; I^2=55.9%) between female/woman/girl athletes with and without knee injuries, or hip abduction strength (g=−0.10, 95% CI −0.40 to 0.20; I^2=0.0%) between those with and without ACL injuries.

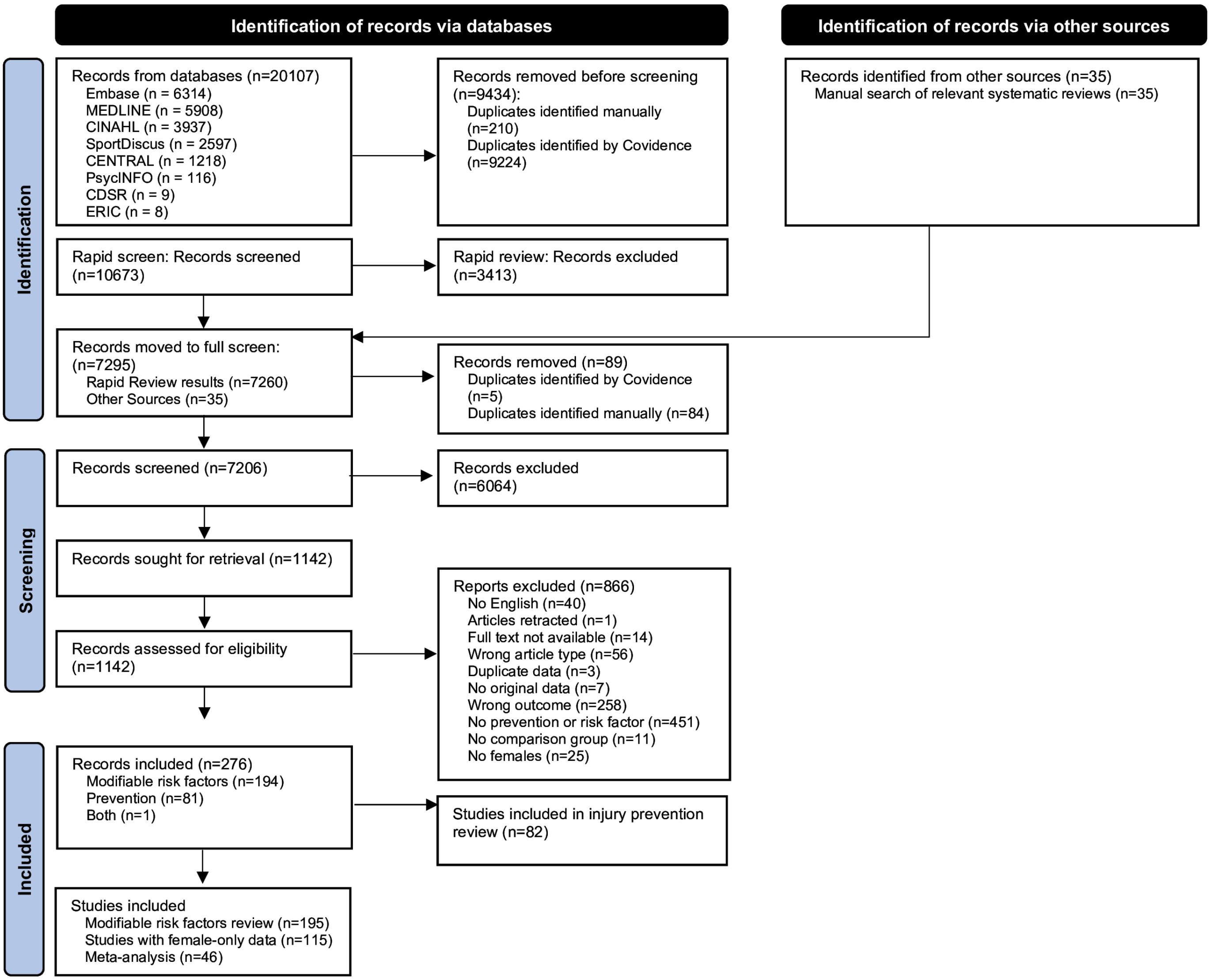

Figure 1 Preferred reporting items for systematic reviews and meta-analyses flowchart. CDSR, Cochrane Database of Systematic Reviews; ERIC, Education Resources Information Center.

With respect to *playing surface*, there is low certainty evidence of no difference in general lower-extremity (IRR=0.96, 95% CI 0.83 to 1.10; I^2=0.0%), hip/groin (IRR=0.69, 95% CI 0.44 to 1.09; I^2=0.0%), thigh (IRR=0.91, 95% CI 0.69 to 1.21; I^2=0.0%), or knee (IRR=1.09, 95%CI 0.79 to 1.49; I^2=22.8%) injury rates and very low certainty evidence of no difference in ankle (IRR=1.07, 95% CI 0.76 to 1.50; I^2=45.5%) injury rates between artificial turf and grass playing fields. Further stratification for knee injuries also revealed no difference in injury rates between playing surfaces for competition (IRR=1.02, 95% CI 0.74 to 1.41; I^2=0.0%).

Very low certainty evidence suggests that female/woman/girl athletes with ACL injuries (g=0.22, 95% CI 0.06 to 0.39; I^2=0.0%) have *higher body mass*, and those with thigh injuries (g=0.37, 95% CI 0.15 to 0.59; I^2=0.0%) have higher BMI, compared with uninjured female/woman/girl athletes. In contrast, there was very low certainty evidence of no difference in body mass between female/woman/girl athletes with and without general lower-extremity (g=0.22, 95% CI −0.15 to 0.58; I^2=87.1%) or ankle sprain (g=−0.08, 95% CI −0.45 to 0.30; I^2=0.01%) injuries and very low certainty evidence of no difference in BMI between female/woman/girl athletes with and without general lower-extremity injuries (g=0.16, 95% CI −0.05 to 0.37; I^2=58.0%) or ACL injuries (g=0.23, 95% CI −0.06 to 0.59; I^2=0.0%).

Very low certainty evidence suggests no difference in *weekly training distance* between female/woman/girl athletes with and without general lower-extremity injuries (g=0.14, 95% CI −0.02 to 0.30; I^2=0.0%) or *ACL return to sport* (RSI) scores (g=0.10, 95% CI −0.16 to 0.35; I^2=0.0%), *VDJ peak knee flexion angle* (g=−0.45, 95% CI −1.22 to 0.33; I^2=84.9%) and *VDJ vertical ground reaction force* (g=0.42, 95% CI −0.22 to 1.06; I^2=83.9%) between female/woman/girl athletes with and without ACL injuries. Finally, there was very low certainty evidence of no difference in odds of thigh/knee injuries based on *off-season plyometric training* (OR=0.95, 95% CI 0.41 to 2.23; I^2=31.0%) or *single-leg hop test scores* (OR=0.71, 95% CI −0.37 to 1.38; I^2=0.0%).

Semiquantitative analyses

Based on female/woman/girl-specific data (table 3), very low certainty evidence suggests no association between leg *strength* and general lower-extremity injuries and an unclear association

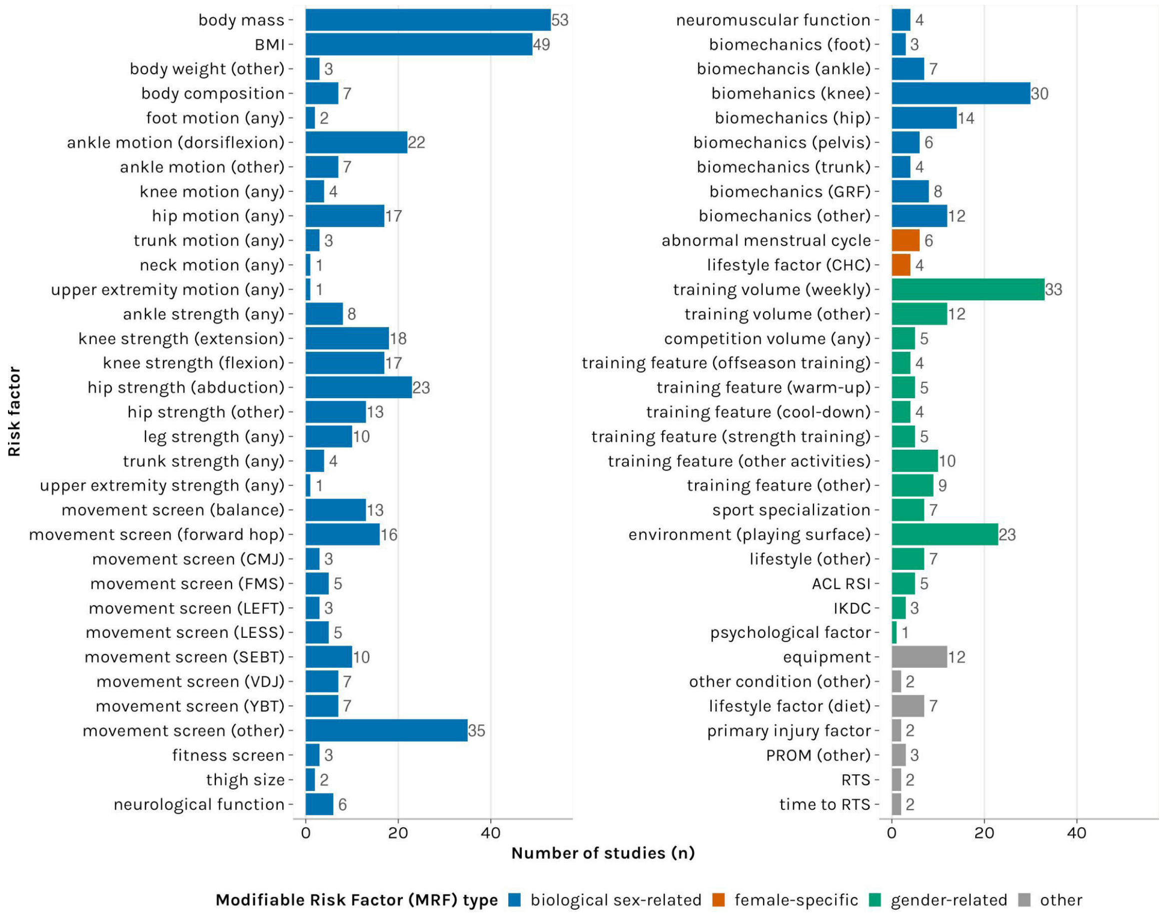

Figure 2 Summary of risk factors assessed across included studies. Blue = biological sex-related MRF, green = female-specific MRF, orange = gender-related MRF, grey = other MRF. ACL RSI, anterior cruciate ligament return to sport index; CHC, combined hormonal contraceptives; CMJ, counter movement jump; FMS, functional movement screen; GRF, ground reaction force; IKDC, International Knee Documentation Committee; LEFT, lower extremity functional test; LESS, lower extremity error scoring system; MRF, modifiable risk factor; PROM, passive range of motion; RTS, return to sport; SEBT, start excursion balance test; UE, upper extremity; VDJ, vertical drop jump; YBT, Y-balance test.

between trunk or hip abduction strength and knee injuries, or knee extension or flexion strength and general lower-extremity injuries. For *functional performance tests*, very low certainty evidence suggests an unclear association between a variety of balance or forward hopping tasks, functional movement screen (FMS), star excursion balance test (SEBT) and other screening tests/batteries and most injury types with the exception of balance or VDJ screening tests and knee injuries, where there was no evidence of an association. There was also very low certainty evidence of an unclear association between *weekly training hours* and *off-season training* and thigh or knee injuries, and *menstrual cycle abnormalities* or *diet* and general lower-extremity injuries. Finally, there was very low certainty evidence of an unclear association between any hip or knee *kinetic* or *kinematic outcomes* and a variety of lower-extremity injuries.

Risk of bias

Substantial heterogeneity in MRFs and injury/pain outcomes existed, with high risk-of-bias due to confounding (eg, amount of sport exposure, previous injury) in 64% of studies. Only 13% of studies provided information to assess for a selection bias due to participant attrition, and 26% provided sufficient information to determine the generalisability of the results (online supplemental file 8a and b).

Protocol deviations

There were protocol deviations to study eligibility and risk-of-bias instrument. The protocol stated '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/women/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 more included studies and potential hypothesis-generating data to inform future studies.

To ensure consistency in risk-of-bias ratings across the broad range of included study designs, we used the DBQAT,[41] instead of the National Institutes of Health Study Quality Assessment tools.[42] The DBQAT can be used across study designs and includes items that rate internal validity (study design, reporting quality, presence of selection and misclassification bias, 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

Table 2 GRADE summary for pooled estimates of modifiable risk factors for female/woman/girl lower-extremity injury

Risk factor	Injury/pain type	Number of studies	Participants (n)	Study design	Study limitations	Inconsistency	Indirectness	Imprecision	Publication bias	Upgrading factors	Modified GRADE rating	Confidence statement
Body mass	LE	11	1631	Phase 1 (11)	X	X	X	✓	✓	X	+	Minimal confidence of *no* difference in body mass between athletes with and without general LE injuries
	ACL injury	11	6288	Phase 1 (9) Phase 2 (2)	X	✓	X	✓	✓	X	+	Minimal confidence of *higher* body mass in athletes with ACL tears (compared with uninjured)
	Ankle sprain	3	205	Phase 1 (3)	X	✓	X	✓	✓	X	+	Minimal confidence of *no* difference in body mass between athletes with and without ankle sprains
BMI	LE	10	1848	Phase 1 (9) Phase 2 (2)	X	X	X	✓	✓	X	+	Minimal confidence of *no* difference in BMI between athletes with and without general LE injuries
	Thigh	3	368	Phase 1 (3)	X	✓	X	✓	X	X	+	Minimal confidence of *higher* BMI in athletes with thigh injuries (compared with uninjured)
	ACL injury	7	5223	Phase 1 (8) Phase 2 (1)	X	✓	X	✓	✓	X	+	Minimal confidence of *no* difference in BMI between athletes with and without ACL tears
Weekly training distance	LE	3	935	Phase 1 (2) Phase 2 (1)	XX	✓	X	✓	X	X	+	Minimal confidence of *no* difference in weekly training distance between athletes with and without general LE injuries
Leg strength	Knee	4	1389	Phase 1 (3) Phase 2 (1)	X	X	✓	✓	✓	X	+	Minimal confidence of *no* difference in general leg strength between athletes with and without knee injuries
Hip abduction strength	ACL injury	3	543	Phase 1 (3)	XX	✓	X	✓	✓	X	+	Minimal confidence of *no* difference in hip abduction strength between athletes with and without ACL tears
Knee extension strength	knee	4	1382	Phase 1 (3) Phase 2 (1)	X	X	✓	✓	X	X	+	Minimal confidence of *no* difference in knee extension strength between athletes with and without knee injuries
Knee flexion strength	Knee	4	1382	Phase 1 (3) Phase 2 (1)	X	✓	✓	✓	✓	X	++	Limited confidence of *no* difference in knee flexion strength between athletes with and without knee injuries
Knee flexion-extension strength ratio	Knee	4	1222	Phase 1 (3) Phase 2 (1)	X	✓	✓	✓	✓	X	++	Limited confidence of *no* difference in knee flexion-extension strength ratio between athletes with and without knee injury
Off season plyometric training*	Thigh/knee	3	435	Phase 1 (3)	X	✓	X	✓	✓	X	+	Minimal confidence of *no* association between off-season plyometric training and thigh/knee injury
SLH test asymmetry	Thigh/knee	3	426	Phase 1 (3)	X	✓	X	✓	✓	X	+	Minimal confidence of *no* association between SLH test asymmetry and thigh/knee injury

Continued

Table 2 Continued

Risk factor	Injury/pain type	Number of studies	Participants (n)	Study design	Study limitations	Inconsistency	Indirectness	Imprecision	Publication bias	Upgrading factors	Modified GRADE rating	Confidence statement
Artificial turf†	LE	3	2020+	Phase 1 (2) phase 2 (1)	X	✓	✓	✓	✓	X	++	Limited confidence of *no* difference in general LE injury incidence between artificial turf and grass fields
	Groin/hip	3	2020+	Phase 1 (2) Phase 2 (1)	X	✓	✓	✓	✓	X	++	Limited confidence of *no* difference in groin/hip injury incidence between artificial turf and grass fields
	Thigh	3	2020+	Phase 1 (2) Phase 2 (1)	X	✓	✓	✓	✓	X	++	Limited confidence of *no* difference in thigh injury incidence between artificial turf and grass fields
	Knee	5	4638+	Phase 1 (2) Phase 2 (3)	X	X	✓	✓	✓	X	+	Minimal confidence of *no* difference in knee injury incidence between artificial turf and grass fields
	Ankle	3	2020+	Phase 1 (2) Phase 2 (1)	X	X	✓	✓	✓	X	+	Minimal confidence of *no* difference in ankle injury incidence between artificial turf and grass fields
ACL RSI score	ACL injury	4	281	Phase 1 (4)	X	✓	X	✓	✓	X	+	Minimal confidence of *no* difference in ACL RSI scores between athletes with and without a second ACL tear
Peak knee flexion angle (VDJ)	ACL injury	3	1086	Phase 1 (1) Phase 2 (2)	X	X	✓	✓	✓	X	+	Minimal confidence of *no* difference in VDJ peak knee flexion between athletes with and without an ACL tear
Vertical GRF (VDJ)	ACL injury	3	1086	Phase 1 (1) Phase 2 (2)	X	X	✓	✓	✓	X	+	Minimal confidence of *no* difference in VDJ vertical GRF between athletes with and without an ACL tear

X serious limitations, XX very serious limitations, ✓ no limitations, ++++ (high quality), +++ (moderate quality), ++ (low quality), + (very low).
*<3 hours.
†combined training and competition injuries.
ACL, anterior cruciate ligament; ACL RSI, ACL return to sport index; BMI, body mass index; GRADE, Grading of Recommendations, Assessment, Development and Evaluation; GRF, ground reaction force; LBP, low back pain; LE, lower extremity; VDJ, vertical drop jump.

Table 3 GRADE summary for non-pooled estimates of modifiable risk factors for female/woman/girl lower-extremity injury

Risk factor	Injury/pain type	Number of studies	Participants (n)	Study design	Study limitations	Inconsistency	Indirectness	Imprecision	Publication bias	Upgrading factors	Modified GRADE rating	Confidence statement
Weekly training load	Knee	5	4997	Phase 1 (5)	X	X	X	X	✓	X	Very low	Minimal confidence of an *unclear association* between weekly training load and knee injury
Trunk strength	Knee	3	399	Phase 1 (2) Phase 2 (1)	X	X	✓	X	✓	X	Very low	Minimal confidence of *unclear association* between trunk strength and general knee injury
Leg strength	LE	3	273	Phase 1 (3)	XX	X	X	X	✓	X	Very low	Minimal confidence of *no association* between general LE strength and general LE injury
Hip abduction strength	LE	3	433	Phase 1 (3)	X	X	✓	X	✓	X	Very low	Minimal confidence of an *unclear association* between hip abduction strength and general LE injury
Hip strength (other than abduction)	Knee	3	591	Phase 1 (3)	X	X	X	X	✓	X	Very low	Minimal confidence of an *unclear association* between hip strength (other) and general knee injury
Knee extension strength	LE	4	488	Phase 1 (4)	X	X	X	X	✓	X	Very low	Minimal confidence of an *unclear association* between knee extension strength and general LE injury
Knee flexion strength	LE	4	579	Phase 1 (4)	X	X	✓	X	✓	X	Very low	Minimal confidence of an *unclear association* between knee flexion strength and general LE injury
Balance tests	Knee	3	1722	Phase 1 (2) Phase 2 (1)	X	X	X	X	✓	X	Very low	Minimal confidence of *no association* between balance tests and knee injury
	Ankle	3	215	Phase 1 (3)	X	X	X	X	✓	X	Very low	Minimal confidence of *unclear association* between balance tests and ankle injury
Forward hop tests	LE	3	197	Phase 1 (2) Phase 2 (1)	XX	X	X	X	✓	X	Very low	Minimal confidence in an *unclear association* between forward hop tests and LE injury
FMS	LE	3	399	Phase 1 (3)	XX	X	X	X	✓	X	Very low	Minimal confidence in an *unclear association* between FMS score and LE injury
SEBT	LE	4	432	Phase 1 (3) Phase 2 (1)	XX	X	X	X	✓	X	Very low	Minimal confidence in an *unclear association* between SEBT score and LE injury
VDJ	Knee	3	1100	Phase 1 (2) Phase 2 (1)	X	X	✓	✓	✓	X	Very low	Minimal confidence in *no association* between VDJ score and knee injury
Movement screen (other)	LE	10	753	Phase 1 (9) Phase 2 (1)	X	X	✓	X	✓	X	Very low	Minimal confidence of an *unclear association* between other movement screen tests and LE injury
	Thigh	3	561	Phase 1 (3)	X	✓	X	X	✓	X	Very low	Minimal confidence of *no association* between other movement screen tests and thigh injury
	Knee	8	1726	Phase 1 (8)	X	X	X	X	✓	X	Very low	Minimal confidence of an *unclear association* between other movement screen tests and knee injury
Off-season training	Thigh/knee	3	435	Phase 1 (3)	X	X	X	X	✓	X	Very low	Minimal confidence of an *unclear association* between offseason training and thigh/knee injuries
Participation in other activities	LE	3	848	Phase 1 (2) Phase 2 (1)	X	X	✓	X	✓	X	Very low	Minimal confidence of an *unclear association* between participation in other activities and general LE injury

Continued

Table 3 Continued

Risk factor	Injury/pain type	Number of studies	Participants (n)	Study design	Study limitations	Inconsistency	Indirectness	Imprecision	Publication bias	Upgrading factors	Modified GRADE rating	Confidence statement
Playing surface	LE	4	1213	Phase 1 (2) Phase 2 (2)	X	X	✓	X	✓	X	Very low	Minimal confidence of an *unclear association* between playing surface and general LE injury
Equipment use	LE	4	912	Phase 1 (4)	X	X	X	X	✓	X	Very low	Minimal confidence of an *unclear association* between equipment use and general LE injury
Menstrual cycle irregularities	LE	3	882	Phase 1 (2) Phase 2 (1)	X	X	✓	X	✓	X	Very low	Minimal confidence of an *unclear association* between abnormal menstrual cycle irregularities and general LE injury
Diet	LE	3	882	Phase 1 (2) Phase 2 (1)	X	X	✓	X	✓	X	Very low	Minimal confidence of an *unclear association* between diet and general LE injury
PROMs (other than ACL RSI)	Knee	3	268	Phase 1 (3)	X	X	X	X	✓	X	Very low	Minimal confidence of *no association* between other PROMs and knee injury
Neuromuscular function	Knee	3	184	Phase 1 (3)	XX	X	X	X	✓	X	Very low	Minimal confidence of an *unclear association* between neuromuscular function and knee injury
Hip biomechanics (cut)	ACL injury	4	212	Phase 1 (4)	XX	X	X	X	✓	X	Very low	Minimal confidence of an *unclear association* between hip biomechanics during cutting and ACL tear
Knee biomechanics (cut)	Knee	5	321	Phase 1 (4) Phase 2 (1)	XX	X	X	X	✓	X	Very low	Minimal confidence of an *unclear association* between knee biomechanics during cutting and knee injury
Hip biomechanics (VDJ)	Knee	3	415	Phase 1 (2) Phase 2 (1)	XX	X	X	X	✓	X	Very low	Minimal confidence of an *unclear association* between hip biomechanics during a VDJ and knee injury
Knee biomechanics (VDJ)	LE	4	719	Phase 1 (4)	X	X	✓	✓	✓	X	Very low	Minimal confidence of an *unclear association* between knee biomechanics during a VDJ and general LE injury
Biomechanics other	Knee	3	584	Phase 1 (3)	X	X	X	X	✓	X	Very low	Minimal confidence of an *unclear association* between other biomechanic outcomes and knee injury

X serious limitations, XX very serious limitations, ✓ no limitations, ++++ (high quality), +++ (moderate quality), ++ (low quality), + (very low).
ACL, anterior cruciate ligament; ACL RSI, ACL return to sport index; BMI, body mass index; GRADE, Grading of Recommendations, Assessment, Development and Evaluation; GRF, ground reaction force; LE, lower extremity; VDJ, vertical drop jump.

studies and randomised controlled trials), given that some items are not relevant to all study designs.[41] Despite its flexibility, the DBQAT does not independently function as a risk-of-bias instrument.

DISCUSSION

This systematic review examined MRFs for female/woman/girl athletes' lower-extremity injuries. There is low and very low certainty evidence that general leg, knee extension and knee flexion strength does not differ between female/woman/girl athletes with and without knee injuries, and knee flexion-extension strength ratio does not differ between those with and without ACL injuries. There is also low and very low certainty evidence that artificial turf playing fields are not associated with general lower-extremity, hip/groin, thigh, knee or ankle injuries compared with grass playing fields. Very low certainty evidence suggests that female/woman/girl athletes with ACL injuries have higher body mass than uninjured athletes, and female/woman/girl athletes with thigh injuries have higher BMI than uninjured athletes. In contrast, very low certainty evidence suggests no difference in body mass between female/woman/girl athletes with and without general lower-extremity or ankle sprain injuries or difference in BMI between those with and without general lower-extremity or ACL injuries. Finally, there is very low certainty evidence that weekly training, ACL RSI score, some VDJ biomechanic outcomes, off-season plyometric and single-leg hop test scores may not be important for female/woman/girl athletes' lower-extremity injury risk and prevention. The stark mismatch between the high burden of lower-extremity injuries in female/women/girl athletes and the low to very low certainty of existing evidence underscores the urgent need for prioritised investment and immediate action towards female/woman/girl athletes' lower-extremity injury prevention.

Before discussing the MRFs identified in this review, it is important to acknowledge that many included studies were designed to search for potential MRFs, not confirm or understand them, or evaluate combinations of risk factors.[38] While these exploratory studies are a necessary first step in establishing causal links, they also generate 'signal noise,' potentially obscuring the true nature of the relationship between a risk factor and injury.[35] The overabundance of exploratory studies, with conflicting results, is reflected in the low or very low certainty of evidence ratings and number 'no' or 'unclear' associations reported.

The divide between what works and why

Exercise-based training programmes targeting combinations of lower-extremity strength, balance, agility and change of direction movement patterns lower the incidence of a variety of female/woman/girl athletes' lower-extremity injuries.[20] Despite this, we found no evidence of a relationship between lower-extremity strength, movement tests or biomechanics and a variety of lower-extremity injuries. This disconnect could exist for several reasons. It could be we have been mistaken about the 'active ingredients' in exercise-based training programmes; a certain level or threshold of strength is needed before it is protective; or it is the combined effect of multiple 'active ingredients' (eg, balance or agility training) that is needed to reduce lower-extremity injuries. It is also possible that the existing evidence was not designed (eg, insufficient sample size or heterogeneity) to detect a MRF-injury relationship, or another factor such as age or sport type (contact or non-contact) is modifying or obscuring the relationship (eg, strength may be more protective at certain life stages or in non-contact sports). A similar set of arguments could be made for plyometric training, single-leg hop performance or VDJ biomechanics. Without more robust research, it will be challenging to discern the 'active ingredients', or combinations of 'active ingredients', that should be incorporated into exercise-based training programmes to enhance their protective effect for female/woman/girl athletes.

Turf wars

Our findings suggest low to very low certainty evidence of no relationship between female/woman/girl lower-extremity injuries and artificial turf playing fields (compared with grass), yet the estimated IRRs suggest artificial turf may be protective (IRR<1.0) for general lower-extremity, hip/groin and thigh injuries, while increasing risk (IRR>1) for knee and ankle injuries. The finding that artificial turf may be protective for some injuries is contrary to popular belief and player preference,[43] but in line with a 2023 meta-analysis[44] that revealed artificial turf is protective for all female/woman/girl athletes' injuries (IRR=0.83, 95% CI 0.76 to 0.91), and a 2022 systematic review (no meta-analyses or sex/gender-specific data)[45] which reported similar knee and hip injury rates between the two playing surfaces. A possible explanation for these findings could be an evolution in artificial turf quality. The studies in our meta-analysis were mostly conducted in college and elite sport settings on third generation (3G) turf. It is also plausible that female/women/girl athletes have adapted to playing on artificial turf because of their high exposure to it. Across many communities and clubs, males/men/boys have priority access to grass fields, and female/women/girls league schedules often overlap with 'shoulder' seasons where artificial turf is preferred due to inclement weather (eg, rain). It is also possible that another factor(s) (eg, grass field quality, training load, match congestion, sport-specific context including training vs competition) we were unable to account for in our analyses is obscuring the relationship between lower-extremity injury and artificial turf.

Weighing in

We found conflicting very low certainty evidence about body mass or BMI and female/woman/girl athletes' lower-extremity injury, with greater body mass linked to ACL injuries but not general lower-extremity or ankle sprain injuries and greater BMI linked to thigh injuries but not general lower-extremity or ACL injuries. This contradiction likely results from included studies not accounting for other factors that can influence the mass-injury relationship. Body mass and BMI represent muscle and adipose mass, and the optimal body mass and body composition for female/woman/girl athletes' health and performance varies by sport type and level, playing position and life stage. For example, female/woman/girl athletes who play contact sports, where there is a high incidence of injury,[46] tend to have greater muscle mass and correspondingly greater BMI and body mass. Another important consideration is whether aggressive and/or risk-taking behaviours vary by body mass or BMI, with larger and stronger athletes perhaps being more likely to tackle or take physical risks leading to injury. In contrast, little is known about the relationship between rapid weight loss and lower-extremity injury[47,48] in the context of the pressures to conform to the 'ideal female athlete' body type, and links with menstrual cycle irregularity and disordered eating associated with relative energy deficiency in sport (REDs).[49] Without a clear understanding of the relationship between body mass and female/woman/girl athletes' lower-extremity injuries, it would be premature to consider body mass and BMI as MRFs or prevention targets.

Shifting the focus

Most included studies assessed physiological, biological and performance-based MRFs (eg, body mass and composition, strength, joint motion and angles, movement patterns). Fewer studies considered psychological (eg, gender-specific stress, anxiety or depression) and socio-environmental (eg, cultural or religious norms; trivialisation of injury; uneven power dynamics) factors that might contribute to female/woman/girl lower-extremity injury risk,[26 27] and only a handful evaluated female/woman/girl-specific MRFs (eg, menstrual cycle abnormalities,[50–54] contraceptive use).[47 51 53 55] Unfortunately, no studies focused on MRFs associated with the gendered environments that disadvantage female/woman/girl athletes including access to dedicated high-quality coaching, training, competition, strength and conditioning, and medical personnel/facilities/equipment, later starting age for structured training, competition congestion or inequitable investment.[26 27]

Strengths and limitations

This review benefits from a rigorous approach to knowledge synthesis (a priori methods, peer-reviewed search strategy, duplicate independent record screening, data extraction and ROB assessment, biostatistician-led quantitative synthesis, semiquantitative vs narrative 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). It is important to highlight that 40 studies were excluded because they were not available in English, which may have introduced a selection bias, and that searches were completed in October/November 2023. Given that our conclusions are based on GRADE assessments synthesising large bodies of evidence rather than individual studies, it is unlikely that papers published since the search date would be sufficient in number and quality to meaningfully alter the certainty ratings or overall findings of this review. Beyond not describing, accounting for or assessing the effect of potential modifying and confounding variables, key challenges to synthesising the evidence related to MRFs for female/woman/girl athletes' lower-extremity injury are the variability in how MRFs were assessed (eg, different tests and units of measurement), and injury outcomes were operationalised and participant age, sport and sport level. These limitations were barriers to multivariable meta-analyses that could have provided more insight into MRF-injury relationships. Together, the heterogeneity and unadjusted statistical models make the findings of the quantitative (meta-analyses) and semiquantitative analyses vulnerable to misinterpretation. Consistent with the very low certainty evidence GRADE ratings, it is very likely that our conclusions will change with future higher-quality and more diverse research.

Implications

Practical or real-world implications: Exercise-based training programmes reduce female/woman/girl athletes' lower-extremity injuries. Based on the existing evidence, it is unclear if there are modifiable sex or gender-specific risk factors which, if addressed at the individual, interpersonal, community, organisational or societal level,[56] could boost the protective effect of these programmes. Recommendations from a transparent and rigorous consensus process[57] are the most pragmatic approach to levelling the playing field for female/women/girl athletes until high-certainty evidence about MRFs for lower-extremity injuries is available.

Validated sex- and gender-specific screening and surveillance approaches and systems that are comprehensive and feasible will accelerate our understanding of MRFs, and the burden and effectiveness of prevention interventions for female/woman/girl athletes' lower-extremity injury.[58 59] These approaches should recognise that MRFs can fluctuate over time and that a single preseason screening may not provide an accurate representation of an athlete' status.[60] Consensus-based injury definitions and diagnostic codes that facilitate reporting and registering of female/woman/girl-specific health considerations (eg, pregnancy, menstrual and life-stage experiences), and methods to measure and monitor the effect of gendered environmental factors should also be considered.[26 27] Importantly, female/woman/girl athletes must be supported and feel safe to report health concerns in order to optimise performance, prevent injury and manage long-term health.[27] Until more robust evidence is available to track[61] and understand any link between menstrual cycle stage, experiences or irregularities and lower-extremity injury risk, an individualised approach, tailored to and informed by an individual athlete and their menstrual cycle data, is appropriate.[61]

Implications for future research into MRFs for female/woman/girl athletes' lower-extremity injury include moving from exploratory studies designed to describe and identify potential MRFs to high-quality studies designed to assess and understand independent MRF-injury relationships (including non-linearity and changes over time) or predict female/woman/girl athletes' lower-extremity injuries using robust statistical models,[38] while following reporting guidelines to facilitate replication.[62] This may require large numbers of female/woman/girl athletes with lower-extremity injuries, which for some less prevalent and less studied injuries (eg, hip/groin, foot) may require multisite and international collaboration. It will also be important to broaden our focus beyond able-bodied and collegiate level athletes to accommodate the growth in professional and Para female/woman/girl sport and to consider youth and adolescence, vital life stages where female/girl athletes commonly exit sport.[63] Developing and implementing injury surveillance systems with standardised definitions that account for female/woman/girl-specific health considerations, along with rigorous approaches for measuring risk factors and potential covariates (eg, monthly ovarian hormone profiles[61]), will be essential.

The unsatisfying state of the evidence suggests that we may need to rethink our approach to MRFs for female/woman/girl athlete's lower-extremity injury. Instead of casting a wide net to capture multiple preseason individual characteristics, arbitrarily dichotomising athletes into low- and high-risk groups[64] and looking for simple correlations, it will be important to be more targeted in our approach. This targeted approach should consider the complex and multifactorial nature of injuries and involve study designs and analyses that consider continuous data and account for fluctuations in the athlete's state over time to predict the probability of injury.[60] This might include appropriately powered theory-driven 'a-priori' approaches that attempt to explain how and why changes in a MRF lead to changes in injury incidence (ie, causal model), with consideration of potential modifiers, and interactions between modifiable and non-MRFs based on past evidence (eg, directed acyclic graphs)[65] and the gendered environments that female/woman/girl athletes develop, train and compete.[66]

Important research topics include understanding the relationship between psychological and socio-environmental factors and injury risk,[27] and female/woman/girl athlete-specific health considerations including menstrual cycle experiences, REDs,[49] perimenopause and menopause transitions, and pregnancy, breast feeding and postpartum periods.[58 67 68] It is also important to consider the neurocognitive and more broad socioecological contexts of female/woman/girl athletes/ lower-extremity injuries.

CONCLUSION

This systematic review synthesises a large body of exploratory research, exposes important knowledge gaps and serves as a foundation for investment and action to reduce the burden of female/woman/girl athlete lower-extremity injuries. Future research must move past biophysiological, anatomical and biomechanical characteristics to consider psychosocial and environmental factors that contribute to female/woman/girl athletes' lower-extremity injuries.

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