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SYSTEMATIC REVIEW

Risk Factors for Lower Limb Injury in Female Team Field and Court Sports: A Systematic Review, Meta-analysis, and Best Evidence Synthesis

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Abstract

Background Identifying risk factors for lower limb injury is an important step in developing injury risk reduction training and testing for player monitoring. Female athletes are distinct from male athletes, warranting separate investigation into risk factors.

Objective To systematically review the literature and synthesise the evidence for intrinsic risk factors for lower limb injury in female team field and court sports.

Methods Five online databases were searched from inception to April 2020. To be eligible for inclusion, studies were required to be a prospective study presenting intrinsic risk factors for lower limb injury in female team field or court sport athletes. Risk of bias was assessed using the Quality of Prognosis Studies tool.

Results Sixty-nine studies, capturing 2902 lower limb injuries in 14,492 female athletes, and analysing 80 distinct factors met the inclusion criteria. Risk factors for any lower limb injury included greater body mass (standardised mean difference [SMD] = 0.24, 95% confidence interval [95% CI] 0.18–0.29), greater body mass index (BMI) (SMD = 0.22, 95% CI 0.05–040), older age (SMD = 0.20, 95% CI 0.09–0.31), greater star excursion balance test (SEBT) anterior reach distance (SMD = 0.18, 95% CI 0.12–0.24), and smaller single-leg hop distance (SMD = − 0.09, 95% CI − 0.12 to − 0.06). Lower knee injury and osteoarthritis outcome score (KOOS) increased the risk of knee injury. Anterior cruciate ligament (ACL) injury risk factors included prior ACL injury (odds ratio [OR] = 3.94, 95% CI 2.07–7.50), greater double-leg postural sway (SMD = 0.58, 95% CI 0.02–1.15), and greater body mass (SMD = 0.25, 95% CI 0.12–0.39). Ankle injury risk factors included smaller SEBT anterior reach distance (SMD = − 0.13, 95% CI − 0.14 to − 0.13), greater single-leg hop distance asymmetry (OR = 3.67, 95% CI 1.42–9.45), and slower agility course time (OR = 0.20, 95% CI 0.05–0.88). Remaining factors were not associated with injury or had conflicting evidence.

Conclusion Prior injury, older age, greater body mass, and greater BMI are risk factors for lower limb injury in female athletes. Limited evidence showed an association between KOOS, SEBT anterior reach, single-leg hop distance and asymmetry, double-leg postural sway, agility, and lower limb injury. PROSPERO ID: CRD42020171973.

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Key Points

Prior injury, older age, greater body mass, greater body mass index, and lower knee injury and osteoarthritis outcome score (KOOS) are risk factors for lower limb injury in female athletes.

Performance tests associated with injury include star excursion balance test anterior reach, single-leg hop distance and asymmetry, double-leg postural sway, and agility course time.

The majority of test/factors commonly proposed to be associated with injury have limited evidence, predominantly due to conflicting results between studies.

1 Introduction

Female team field and court sport athletes have a high incidence rate of lower limb injuries [1], resulting in sporting time loss [1], high medical costs [2], a reduction in team performance [3], and long-term health issues [4]. Females tend to sustain more severe (greater time loss) lower limb injuries than males [5], possibly due to anatomical [6], hormonal [7], and/or biomechanical differences [8]. Socio-cultural factors unique to females may also contribute to different training and competition exposure (e.g. girls generally participate in less physical activity than boys [9]) that, in turn, increases injury risk. Given the potential sex differences in injury rates and their underlying causes, it is important that injury risk mitigation strategies are targeted towards the specific needs of female athletes.

A critical step in an evidence-based injury prevention process is to first identify risk factors for injury [10, 11]. Intrinsic factors such as strength, biomechanics, physical performance, balance, and joint mobility/flexibility are of particular interest because they are modifiable with training, unlike non-modifiable intrinsic risk factors such as age and prior injury [12]. Understanding modifiable intrinsic injury risk factors is needed to inform the design of targeted risk mitigation strategies. This knowledge may also aid in the development of tests to accurately and reliably measure risk factors, an essential tool for practitioners to perform injury screening, monitor athletes over time, and assess the efficacy of training programmes [13]. Understanding the intrinsic risk factors specific to females is an important first step in reducing the rate and burden of lower limb injuries in female athletes. The aim of this paper is to systematically review the literature and synthesise the evidence for intrinsic risk factors for lower limb injury in female team field and court sports.

2 Methods

This review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [14], and was pre-registered with PROSPERO (ID: CRD42020171973) on 9th March 2020.

2.1 Literature Search

A systematic search of online databases was performed using PubMed (MEDLINE), Scopus, EBSCOhost (SPORTDiscus and CINAHL), and EMBASE from inception to 8th April 2020. A comprehensive search strategy was developed using the PICO framework for prognostic studies [15]. Population: female team sport athletes, problem: lower limb musculoskeletal injuries, prognostic factor: intrinsic injury risk factors, comparison: prospective comparison of injured and uninjured groups, and outcome: lower limb injury and associated risk estimates. The final search strategy incorporated a combination of keywords, synonyms, and Medical Subject Headings or the database equivalent, and was refined through pilot testing to maximise the chance of returning all relevant studies (see Electronic Supplementary Material Appendix S1 for search strategy). Article reference lists and citation tracking on Google Scholar were also inspected for any further relevant articles.

2.2 Study Inclusion/Exclusion Criteria

Articles were included if they (1) had a prospective cohort design; (2) presented the association between one or more intrinsic risk factors and future injury to the hip/groin, thigh, knee or ankle/foot regions; and (3) included female athletes between the age of 13 and 40 playing a team field or court sport (e.g. soccer, futsal, rugby, Australian Football, Gaelic Football, basketball, handball, volleyball, netball, field hockey, lacrosse or floorball). All injury definitions (time loss, non-time loss, contact, and non-contact) and injury reporting methods (medical staff or self-report) were included.

Studies were excluded if they (1) were not written in English; (2) were a review article, abstract, conference proceeding or non-peer reviewed journal article; (3) had a cross-sectional, retrospective or case–control study design; (4) only included extrinsic risk factors; (5) did not present an analysis of risk factors, or data were unable to be extracted;

(6) only included male participants or did not present female data independent of male participants; (7) were predominantly individual sport athletes; (8) only included water, ice or snow sport athletes; or (9) were a secondary analysis of an intervention study. Non-team field and court sports were excluded to limit the amount of heterogeneity in physical demands between sports studied.

2.3 Article Screening

Articles were imported into EndNote (version X9.2, Clarivate Analytics, Boston, US) for eligibility screening. Duplicates were removed using autodetection by EndNote and manual removal. Article screening was performed independently by three reviewers (TC, WD and MB), with at least two reviewers screening each article. The initial screening of articles was performed by checking the title and abstract, and articles that did not meet the inclusion criteria were removed (Fig. 1). Articles passing the first round of screening were subsequently pooled, and a second round of independent screening was performed using the full-text articles. Consensus on the final articles included was achieved through discussion between reviewers. Full-text articles that did not meet the inclusion criteria were removed and the reason for exclusion was recorded. Agreement/inter-rater reliability between reviewers for the final included articles was assessed using Cohen's Kappa statistic [16].

2.4 Risk of Bias Assessment

Eligible articles were assessed independently for methodological quality by two reviewers (TC and JH) using the Quality of Prognosis Studies (QUIPS) tool [17]. QUIPS provides criteria to assess each study for risk of potential bias in six areas of study design: study participation, study attrition, prognostic factor measurement, outcome measurement, study confounding factors, and statistical analysis and reporting [17]. Each potential area of bias contains three

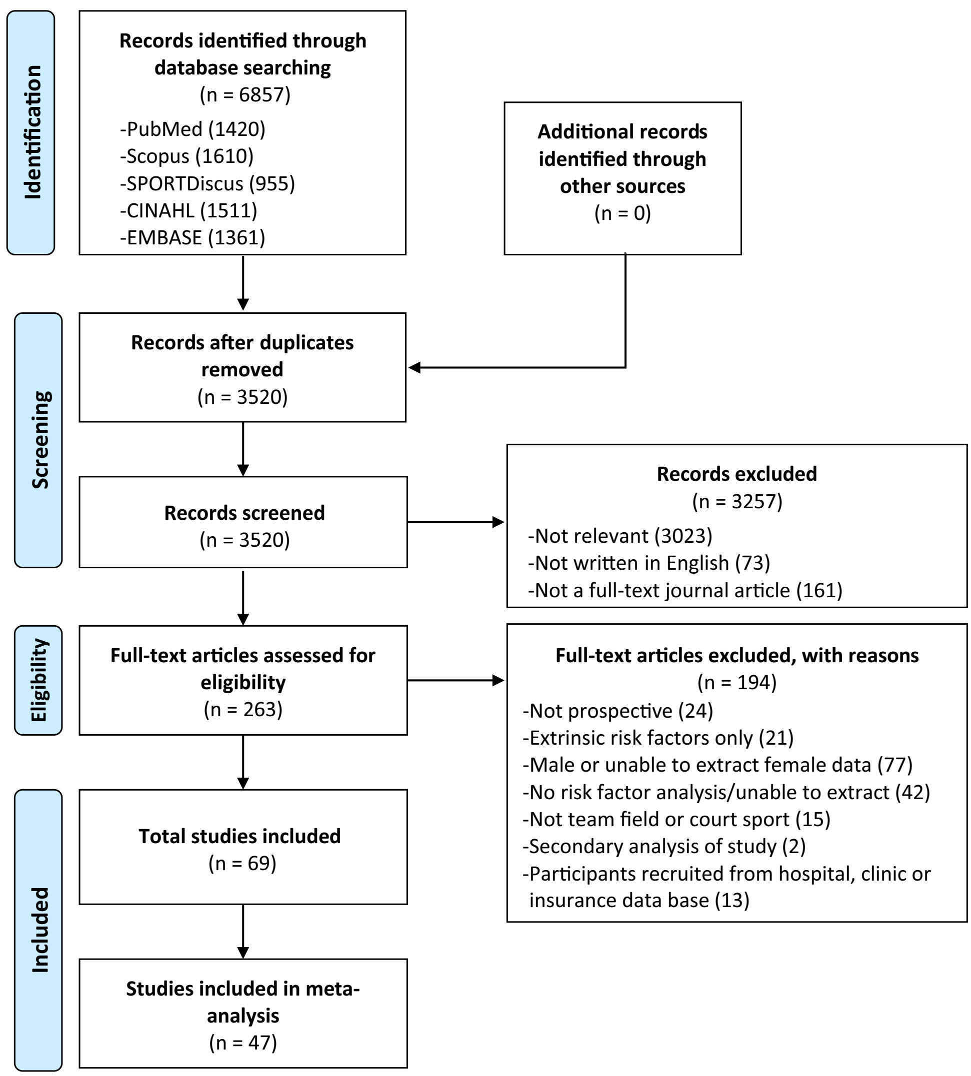

Fig. 1 PRISMA flowchart outlining the article identification, screening and selection process, with reasons for exclusion of articles, and article counts at each stage

to six individual questions, which were answered with 'not likely to increase bias' or 'may increase bias'. The complete QUIPS criteria and standards used to interpret these criteria are presented in Electronic Supplementary Material Appendix S2. For each of the six areas, 'low risk' was awarded if 75% of the questions were considered not likely to increase bias; otherwise the area of bias was deemed to be 'high risk' [18, 19]. To determine an overall risk of bias, if five out of the six areas of bias were marked as low risk, the study was awarded 'low risk'; otherwise, the study was awarded a rating of 'high risk' overall [18, 19]. This method of interpreting the QUIPS criteria provides an objective approach to determining risk of bias and was chosen for consistency with similar previous systematic reviews [18, 19]. Consensus on final ratings between reviewers was determined by discussion and where needed, consultation with a third reviewer (MB). No studies were excluded based on methodological quality or risk of bias.

2.5 Data Extraction

Study characteristics and risk factor data were extracted by one reviewer (TC) and entered into a spreadsheet database (Microsoft Excel; Washington, US). Extracted study characteristics included first author name, year of publication, country, playing level, participants' age, sport, total number of participants, length of injury follow-up period, number of injuries observed, method of recording injuries, and injury definition.

Extracted risk factor data included either continuous data (injured and uninjured group means and standard deviations [SD], number of participants injured and uninjured, and p values) or binary frequency data (number of injured and uninjured athletes, with and without a risk factor present [e.g. contingency table]). Where frequency data were not presented, the unadjusted odds ratio (OR), relative risk (RR) or incident rate ratio (IRR), the associated p value and 95% confidence interval (95% CI) were extracted. To facilitate comparison of findings between studies, univariate model estimates of risk were extracted in favour of multivariate model analyses.

Data were synthesised across studies using injury groups that were selected and defined by the included articles. These groups were predominantly based on anatomical regions instead of specific injuries and included: (1) knee injury, (2) anterior cruciate ligament (ACL) injury, (3) anterior knee pain, (4) ankle injury, (5) thigh injury, (6) hip/groin injury, and (7) any lower limb injury. Each of these groups were potentially comprised of a combination of acute, overuse, time loss or non-time loss injuries, depending on the injury definition provided by the study (Table 1).

2.6 Meta-analysis

Data analysis was performed using R studio (version 1.2.1, Boston, US). Individual random effects model meta-analyses were performed using the 'meta' package for R [20]. A random effects model was selected to account for potential heterogeneous populations due to the inclusion of studies with large variation in participant age, demographics, and sports [18, 21, 22]. Heterogeneity between studies was quantified using I^2 statistics. Meta-analyses of continuous data were performed using standardised mean differences (SMD) (Hedges' g unbiased estimates for low sample sizes) [23], as well as the mean differences in original units of measurement, with 95% CI. Where SD were not presented, confidence intervals were used to determine the SD with the equation $\mathrm{SD} = \sqrt{n} \times (upperCI - lowerCI)/2 \times t$ [24]. Where possible, odds ratios and 95% CI were calculated from binary frequency data [25]. Interpretation of SMD was as follows: 0–0.2 = trivial, 0.2–0.5 = small, 0.5–0.8 = medium, and 0.8 or higher = large [26]. For meta-analyses of SMD and mean difference, study weighting was determined using the inverse-variance method and 95% CI for overall effects were calculated using the Hartung–Knapp–Sidik–Jonkman method [27]. For meta-analyses of odds ratios, data were first log-transformed [20].

For a risk factor to be included in a meta-analysis, data had to be reported by ≥ 2 independent studies with consistent analysis and reporting methods [28]. Inconsistent analysis and reporting methods included different units, normalisation methods, expressions of risk estimates (e.g. group means, odds ratios, or relative risk), or use of different cut-off values to determine odds ratios/relative risk.

2.7 Best Evidence Synthesis

A best evidence synthesis was used to collate comparable risk factors that lacked the methodological consistency required for inclusion in a meta-analysis [29]. A best evidence synthesis provides a systematic approach for summarising the level of evidence, and strength of association between risk factors and lower limb injury risk [19, 30]. All factors with a minimum of two studies were included in the best evidence synthesis, regardless of whether they were included in a meta-analysis. The following criteria were used to establish levels of evidence for an association with injury: strong evidence: consistent results in two or more low risk of bias studies, with generally consistent findings in ≥ 75% of studies; moderate evidence: one low risk of bias study and one or more high risk of bias studies provide consistent findings, or consistent findings reported in two or more high risk of bias studies with consistent results in ≥ 75% studies; limited evidence: single study findings from either a high risk or low risk of bias study; and conflicting evidence: multiple

Table 1 Study characteristics, participant information, and data collection methods of included studies

References	*n*	Age (SD)	Sport(s)	Level	Follow-up	Injury type (*n*)	Injury def	Report method
Attenborough et al. [84]	94	20.3 (3.4)	NB	Recreational	2 seasons	Ankle (11)	TL, LIG	Medical, self
Barber Foss et al. [31]	248	12.8 (1.1)	BB	Middle school	2 seasons	Anterior knee pain (39)	PFP, AKP	Medical
Beynnon et al. [86]	67	–	S, FH, L	College	1 season	Ankle (13)	LIG	Medical
Blokland et al. [60]	114	22.4 (3.3)	S	National	1 season	Any (179), thigh (45), knee (42), ankle (22), hip/groin (15)	TL	Medical
Brumitt et al. [89]	106	19.1 (1.1)	–	College	1 season	Any (32)	TL	Medical
Brumitt et al. [62]	106	19.1 (1.1)	S, VB, BB, L, +	College	1 season	Any (24)	TL	Medical
Brumitt et al. [61]	110	19.1 (1.1)	S, BB, VB, L, +	College	1 season	Any (17), ankle (12)	TL	Medical
Brumitt et al. [64]	360	19.3 (1.4)	S, BB, VB	College	1 season	Any (73), ACL (7)	NC	Medical
Brumitt et al. [44]	119	19.2 (1.2)	S	College	1 season	Any (36)	TL, NC	Medical
Brumitt et al. [43]	82	18.9 (1.0)	VB	College	1 season	Any (15), ankle (6)	TL, NC	Medical
Brumitt et al. [45]	104	19.2 (1.2)	S, VB, +	College	1 season	Any (19)	TL	Medical
Brumitt et al. [63]	210	19.2 (1.1)	S, VB, BB, L, +	College	1 season	Any (40), ankle (15)	TL NC	Medical
Cheng et al. [46]	177	14.8 (1.8)	S	Competitive	5–9 years	Any (42)	TL	Self
Chorba et al. [90]	38	19.2 (1.2)	S, BB, VB	College	1 season	Any (19)	ALL	Medical
Clausen et al. [66]	326	15.6 (0.9)[a]	S	Recreational	1 season	Knee (34)	TL	Self
Devan et al. [32]	53	19.4 (1.3)	S, BB, FH	College	1 season	Knee (9)	OU	Medical
Dingenen et al. [68]	50	20.2 (2.9)	S, VB, HB	National	1 year	Knee (7)	TL, NC	Medical
Dingenen et al. [47]	43	20.8 (3.5)	S, VB, HB	National	1 year	Any (6)	TL	Medical
Dragoo et al. [33]	128	19.5 (1.6)	S, BB, VB, FH, L, +	College	4 years	ACL (28)	ALL	Medical
Emery et al. [91]	164	14.8 (–)	S	Competitive	1 season	Any (26)	TL	Medical
Faude et al. [48]	143	22.4 (5.0)	S	National	1 season	Any (99), ankle (33), knee (23), ACL (11)	TL	Medical
Goetschius et al. [69]	65	18.1 (1.7)	S, BB, VB, FH, L	College/H-school	3 years	ACL (20)	NC	Medical
Hartley et al. [85]	167	19.8 (1.5)	S, BB, VB	College	2 years	Ankle (21)	TL, LIG	Medical
Herbst et al. [34]	255	12.7 (0.9)	BB	Middle school	1 season	Anterior knee pain (38)	PFP	Medical
Hewett et al. [77]	205	16.1 (1.7)	S, BB, VB	High school	3 seasons	ACL (9)	NC	Medical
Holden et al. [80]	76	12.9 (0.3)	BB, FH, GF, +	High school	2 years	Anterior knee pain (8)	PFP	Self
Hopper et al. [49]	72	20.6 (3.6)	NB	Competitive	1 season	Any (22)	ALL	Medical
Kofotolis and Kellis [87]	204	24.8 (4.6)	BB	National	2 years	Ankle (32)	TL, LIG	Medical
Kosaka et al. [70]	303	15.0 (0.0)	BB, HB	High school	2 years	ACL (25)	ALL	Coach
Krosshaug et al. [71]	710	21.0 (3.9)	S, HB	National	< 7 years	ACL (42)	NC	Staff
Landis et al. [65]	187	18–25	S, BB, VB	College	1 season	Any (17), ACL (4)	TL, NC	Medical
Leetun et al. [92]	80	19.1 (1.37)	BB, +	College	1 season	Any (34)	TL, NC	Medical
Leppanen et al. [78]	171	15.4 (1.9)	BB, FB	Competitive	< 3 years	ACL (15)	NC	Staff
Leppanen et al. [79]	171	15.4 (1.9)	BB, FB	Competitive	< 3 years	ACL (15)	NC	Staff

Table 1 (continued)

References	*n*	Age (SD)	Sport(s)	Level	Follow-up	Injury type (*n*)	Injury def	Report method
Leppanen et al. [35]	258	16.0 (1.9)	BB, FB	Competitive	1 year	ACL (8)	NC	Staff
Maestro et al. [93]	23	22.5 (5.7)	S	National	1 season	Any (12)	OU	Medical
Maulder [36]	24	21.6 (3.2)	NB	National	1 season	Any (9)	TL	Self
McCann et al. [88]	43	19.7 (1.1)	S	College	1 season	Ankle (8)	TL, LIG	Medical
Myer et al. [81]	145	13.4 (1.6)	BB	Middle/H-school	1 season	Anterior knee pain (14)	AKP	Medical
Myer et al. [94]	1558	16.3 (1.7)	S, BB	College/H-school	4 years	ACL (19)	ALL	–
Naicker et al. [95]	30	23.8 (3.2)	FH	National team	1 season	Ankle (14)	ALL	Self
Nilstad et al. [50]	173	21.5 (4.1)	S	National	1 season	Any (171), thigh (35), knee (53), ankle (40)	TL	Self
Numata et al. [72]	291	15.0 (0.0)	BB, HB	High school	3 years	ACL (28)	NC	–
O'Kane et al. [96]	351	12–15	S	Adolescent	< 2 seasons	Any (83), knee (38)	OU	Self
O'Kane et al. [97]	351	12.8 (0.9)	S	Competitive	< 2 years	Any (134), knee (41)	TL	Self
Oshima et al. [73]	273	15.0 (–)	BB, HB	High school	3 years	ACL (24)	NC	Coach
Ostenberg and Roos [51]	123	20.7 (4.6)	S	National/competitive	1 year	Any (47)	ALL	Medical
Pickering Rodriguez et al. [52]	29	24.1 (3.2)	NB	National/competitive	1 season	Any (10)	TL, NC	Medical, self
Plisky et al. [98]	105	15.4 (1.0)[a]	BB	High school	1 season	Any (29)	TL	Coach
Ryman Aug and Ageberg [37]	89	17.0 (1.0)	S, BB, HB, FB, +	High school	< 4 years	ACL (14), knee (26)	AC	Self
Shimozaki et al. [74]	168	15.5 (0.3)	BB	High school	3 years	ACL (12)	NC	Self
Siupsinskas et al. [53]	169	23.1 (5.7)	BB	National	1 season	Any (92)	TL	Medical
Smeets et al. [75]	46	20.7 (3.2)	S, VB, HB	National	1 year	ACL (4)	NC	Medical
Smith et al. [38]	63	18.0 (1.7)	S, BB, VB, FH, L, +	College/H-school	3 years	ACL (19)	NC	Medical
Smith et al. [54]	57	14.4 (1.7)	S, BB, VB	High school	1 season	Any (15)	NC, AC	Medical
Soderman et al. [55]	146	20.6 (4.7)	S	National	1 season	Any (61)	TL, AC	Self, coach
Steffen et al. [99]	1430	15.4 (0.8)	S	Competitive	1 season	Ankle (113), knee (58), thigh (48), hip/groin (17)	TL	Medical
Steffen et al. [76]	867	20.9 (4.0)	S, HB	National	< 8 years	ACL (57)	NC	Self
Steffen et al. [39]	838	21.0 (4.0)	S, HB	National	< 8 years	ACL (55)	NC	Self
Vauhnik et al. [67]	585	18.0 (3.0)	BB, VB, HB	National	1 season	Knee (20), ACL (11)	TL	Self, coach
Verrelst et al. [56]	90	19.3 (0.9)	S, HB, VB, BB, +	Recreational	2 years	Any (35)	ALL	Self
Visnes et al. [82]	82	16.7 (0.8)	VB	National	5 years	Anterior knee pain (6)	AKP	Medical
Visnes et al. [83]	78	16.7 (0.7)	VB	High school	3 years	Anterior knee pain (4)	AKP	Self
Walbright et al. [57]	35	–	BB, VB, HB	College	1 season	Any (11)	TL	Medical
Warren et al. [58]	75	19.1 (1.1)	S, BB, VB	College	1 year	Any (52)	NC	Medical
Watson et al. [59]	54	15.7 (1.5)	S	High school	1 season	Any (23)	TL	Self
Zazulak et al. [40]	140	19.4 (1.0)	–	College	3 years	ACL (4), knee (11)	ALL	–

Table 1 (continued)

References	n	Age (SD)	Sport(s)	Level	Follow-up	Injury type (n)	Injury def	Report method
Zazulak et al. [41]	140	19.4 (1.0)	–	College	3 years	Knee (11)	ALL	Medical
Zebis et al. [42]	55	24.0 (5.0)	S, HB	National	2 seasons	ACL (5)	NC	–

Sports basketball (BB), field-hockey (FH), Gaelic Football (GB), floorball (FB), handball (HB), lacrosse (L), netball (NB), soccer (S),volleyball (VB), additional individual or non-field/court sport (+). *Injury definition* acute (AC), anterior knee pain (AKP), no restrictions (ALL), ligament injury (LIG), patellofemoral pain (PFP), non-contact (NC), overuse (OU), time loss (TL). *Report method* team coach (coach), team physiotherapist, athletic trainer, doctor or surgeon (medical), player self-report (self), other team staff (staff)

[a]Age calculated from available data. Data unavailable indicated by '–'. Standard deviation (SD)

studies (either high or low risk of bias) with consistent results in < 75% studies [19, 29]. Study bias was based on the overall rating (low or high risk) assigned using the QUIPS risk of bias assessment. Risk factors were considered 'associated' or 'not associated' based on the reported statistical significance at $p < 0.05$. Where no p value was reported, the 95% CI was used where a significant association for SMD was indicated by a 95% CI that did not contain zero, or for odds ratios when the 95% CI did not contain one. 95% CI was greater and less than one. For findings to be considered 'consistent', both the association (significant/not significant) and the direction of the risk factor (increase/decrease injury risk) were required to be the same.

3 Results

3.1 Study Characteristics

Agreement between reviewers for the independent screening of full-text articles was high ($\kappa = 0.73$, 95% CI 0.62–0.83), with 100% agreement achieved after discussion. A total of 69 articles including 2902 lower limb injuries in 14,492 athletes met the inclusion criteria, including 373 knee injuries, 436 ACL injuries, 109 cases of anterior knee pain, 340 ankle injuries, 128 thigh injuries, and 32 hip/groin injuries. Characteristics of the included studies are presented in Table 1. The median number of study participants was 123 (range = 23–1558, interquartile range = 133). The unweighted average age of participants was 18.3 years (mean age range = 12.0–24.8 years). The sports most frequently included in studies were soccer (41), basketball (34), volleyball (23), and handball (13). Fifty-five percent of studies included participants competing in high school or college leagues, 29% were elite/national league athletes, 12% were in other competitive leagues, and 4% were recreational athletes. The majority of injury follow-up periods were 1 season/year (58%), 14% were 2 seasons/years, 16% were 3 seasons/years, and 12% were 3–9 years.

3.2 Risk of Bias Assessment

Independent assessment of individual QUIPS criteria resulted in 84% agreement between reviewers ($\kappa = 0.53$, 95% CI 0.43–0.63), with 100% agreement achieved after discussion. A low risk of bias was found for 42 studies and a high risk of bias for 27 studies (Table 2). The most common source of bias was not measuring or accounting for confounding variables (62% of studies), predominantly due to grouping all lower limb injuries together. Other common sources of bias were using invalid or unreliable outcome measures (22% of studies), and low numbers of observed injuries (20% of studies). Risk of publication bias was not assessed due to low study numbers for the majority of individual risk factors. However, overall, 83% of risk factors were found to be non-significant, indicating that non-significant findings are still frequently published.

3.3 Risk Factor Synthesis

A total of 754 injury risk estimates for 80 distinct risk factors were extracted. This database can be interactively explored online at https://tcollings.shinyapps.io/risk-factor-app/. Figure 2 summarises the decision-making pathway from data extraction to synthesis (e.g. meta-analysis, best evidence synthesis). Risk factors reported by a single study are presented in Electronic Supplementary Material Appendix S3 [31–42].

3.4 Meta-analysis

A total of 69 risk factors for different lower limb injury groups had more than one study with identical data analysis and reporting methods and were included in a meta-analysis. Meta-analyses are summarised by injury group, including risk factors for any lower limb injury (Fig. 3), knee injury, ACL injury, anterior knee pain (Fig. 4), and ankle injury (Fig. 5). There were no risk factors for thigh injuries or hip/groin pain eligible for inclusion in a meta-analysis. Forest plots for individual risk factors are presented in Electronic Supplementary Material Appendix S4.

3.4.1 Any Lower Limb Injury

Five significant risk factors [43–59] and 21 non-significant factors were identified for lower limb injury (Fig. 3) [43–54, 57, 58, 60–65]. Significant risk factors included greater body mass (SMD = 0.24, 95% CI 0.18–0.29) [43, 44, 47–54, 58], greater body mass index (BMI) (SMD = 0.22, 95% CI 0.05–0.40) [43, 44, 46–48, 50, 51, 54, 56, 59], older age (SMD = 0.20, 95% CI 0.09–0.31) [43, 44, 46–48, 50–56, 58, 59], greater star excursion balance test anterior reach for the right leg (SMD = 0.18, 95% CI 0.12–0.24) [45, 57], and smaller single-leg hop distance for the left leg (SMD = − 0.09, 95% CI − 0.12 to − 0.06) (Fig. 3) [43, 44].

3.4.2 Knee Injury

The meta-analyses for knee injury indicated one significant risk factor [48, 66, 67] and six non-significant factors (Fig. 4a) [50, 60, 67, 68]. Athletes with previous knee injuries were at greater risk of a subsequent knee injury (OR = 2.41, 95% CI 1.24–4.68) [48, 66, 67]. The meta-analyses for ACL injury indicated three significant risk factors [48, 64, 67, 69–76] and 16 non-significant factors (Fig. 4b) [65, 67, 69–79]. Significant risk factors for ACL injury included previous ACL injury (OR = 3.94, 95% CI 2.07–7.50) [48, 64, 76], greater postural sway (centre of gravity movement per second) during 30 s double-leg balance with eyes open (SMD = 0.58, 95% CI 0.02–1.15) [73, 74], and greater body mass (SMD = 0.25, 95% CI 0.12–0.39) [67, 69–76]. There were no significant risk factors for anterior knee pain (Fig. 4c) [80–83].

3.4.3 Ankle Injury

The meta-analyses for ankle injury indicated three significant risk factors [43, 61, 63, 84, 85] and ten non-significant factors [43, 48, 50, 60, 61, 63, 84–88]. Significant risk factors for ankle injury included less anterior reach on a star excursion balance test (SMD = − 0.13, 95% CI − 0.14 to − 0.13) [84, 85], and single-leg hop distance between-leg asymmetry greater than 10% (OR = 3.67, 95% CI 1.42–9.45) [43, 61]. Time to complete an agility course greater than 121 s was associated with reduced risk of ankle injury (OR = 0.20, 95% CI 0.05–0.88) (Fig. 5) [61, 63].

3.5 Best Evidence Synthesis

A total of 84 factors for different lower limb injury groups were investigated by more than one study and were included in the best evidence synthesis (Fig. 6). Seventy of these

Table 2 Quality of Prognosis Studies (QUIPS) risk of bias assessment for included studies

Reference number	Participation	Attrition	Prognostic factor	Outcome measure	Confounders	Statistical analysis	Overall
[35, 38, 39, 41, 47, 68, 69, 71, 74, 76, 78, 79, 85–87, 99]	✓	✓	✓	✓	✓	✓	Low risk
[33, 34, 43, 44, 48, 51, 57, 58, 60, 62–64, 70, 80, 90–92, 96, 98]	✓	✓	✓	✓	×	✓	Low risk
[37]	✓	✓	✓	×	✓	✓	Low risk
[82, 83]	✓	×	✓	✓	✓	✓	Low risk
[40, 77, 81, 94]	×	✓	✓	✓	✓	✓	Low risk
[31, 32, 54, 56]	✓	✓	✓	✓	×	×	High risk
[73]	✓	✓	✓	×	✓	×	High risk
[52, 72, 84, 97]	✓	✓	✓	×	×	✓	High risk
[50, 53]	✓	×	✓	✓	×	✓	High risk
[67]	✓	×	✓	×	✓	✓	High risk
[75]	×	✓	✓	✓	✓	×	High risk
[45, 49, 61, 65, 88, 89]	×	✓	✓	✓	×	✓	High risk
[36, 42]	✓	✓	✓	×	×	×	High risk
[55, 66]	✓	×	✓	×	×	✓	High risk
[59]	×	✓	✓	×	×	✓	High risk
[46]	✓	×	✓	×	×	×	High risk
[93, 95]	×	✓	✓	×	×	×	High risk

✓Low risk in > 75% of questions. ×High risk in > 25% of questions

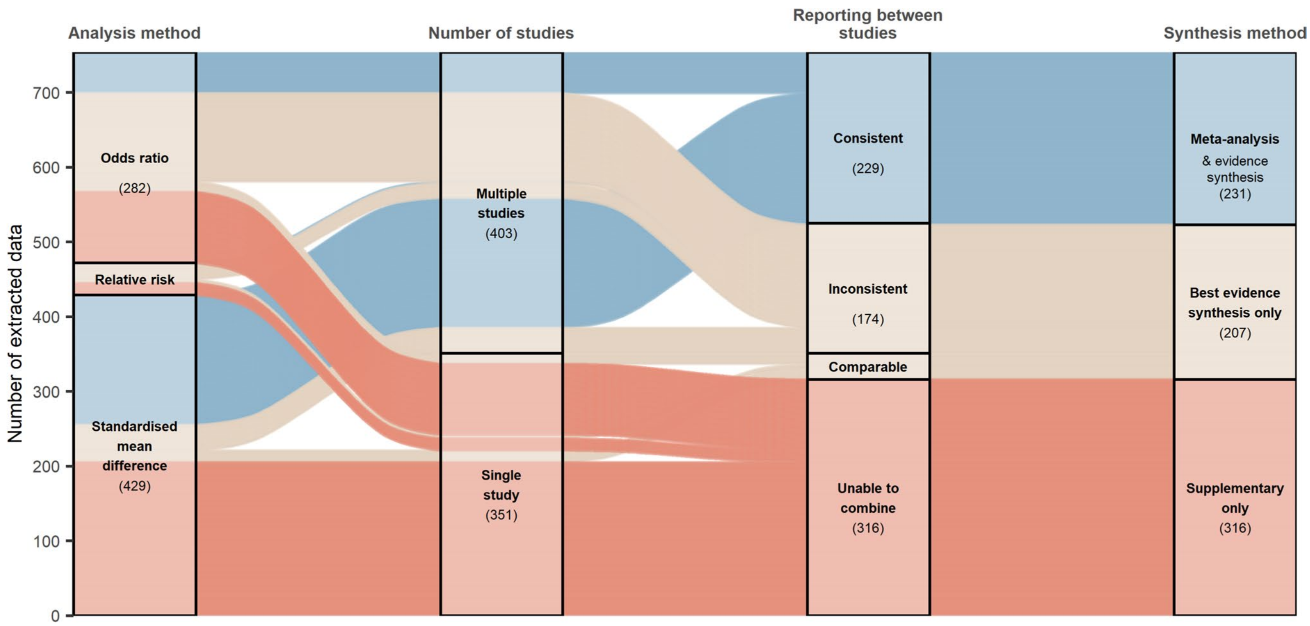

Fig. 2 Flow diagram of data from extraction to inclusion in results, highlighting the conditions required for data to be assigned to either the meta-analysis, best evidence synthesis, or included in supplementary files. Band thickness indicates the number of data in each condition and colour indicates where data were presented

factors contained additional data that were not included in a meta-analysis [89–98]. The best evidence synthesis found that prior ACL injury had strong evidence for an association with subsequent ACL injury [48, 64, 76, 94], and lower knee injury and osteoarthritis outcome score (KOOS) (e.g. worse knee related symptoms) had moderate evidence for an association with future knee injury [66, 99]. Remaining risk factors had moderate (26 factors) to strong (21 factors) evidence for no association with any of the lower limb injury categories and 35 risk factors had conflicting evidence. No risk factors for hip/groin pain and one risk factor for thigh injuries were investigated by more than one study. Risk factors with limited evidence (e.g. one study) are presented in Electronic Supplementary Material Appendix S3.

4 Discussion

This study systematically reviewed 69 prospective studies to provide a summary of the evidence for intrinsic risk factors for lower limb injury in female athletes for a range of team field and court sports. Risk factors for any lower limb injury included greater body mass, greater BMI, older age, greater star excursion balance test anterior reach distance, and smaller single-leg hop distance. Lower KOOS was a risk factor for knee injury. ACL injury risk factors included prior ACL injury, greater double-leg postural sway, and greater body mass. Risk factors for ankle injury included smaller star excursion balance test anterior reach distance, greater single-leg hop distance asymmetry, and slower agility course time. Significant risk factors indicate a statistical association with injury risk, while predictive ability was not assessed. Evidence was often conflicting between prospective studies and the majority of factors investigated to date were not associated with lower limb injury risk in female athletes. Further, significant differences between subsequently injured and uninjured players were generally small to trivial. Risk factors and tests identified in this review may warrant consideration when evaluating an athlete's risk of injury, determining training requirements, or monitoring player development over time.

4.1 Age and Anthropometric Measures

Greater body mass and BMI were risk factors for lower limb injury, though only greater body mass was associated with ACL injury. Players with greater body mass may experience greater knee joint loads during physical activity which may contribute to injury [100]. Age was a risk factor for lower limb injury [43, 46, 48, 50–52, 54–56, 58, 59], with included studies investigating participants ranging from 12 to 25 years. Players who sustained a future lower limb injury were, on average, approximately 0.4 years older than uninjured players. While we are unable to conclude why older players are at greater risk of injury from this study, there are likely a number of causes. For example, greater injury risk may arise from age-related physical changes in body size, composition, and/or hormones that coincide with

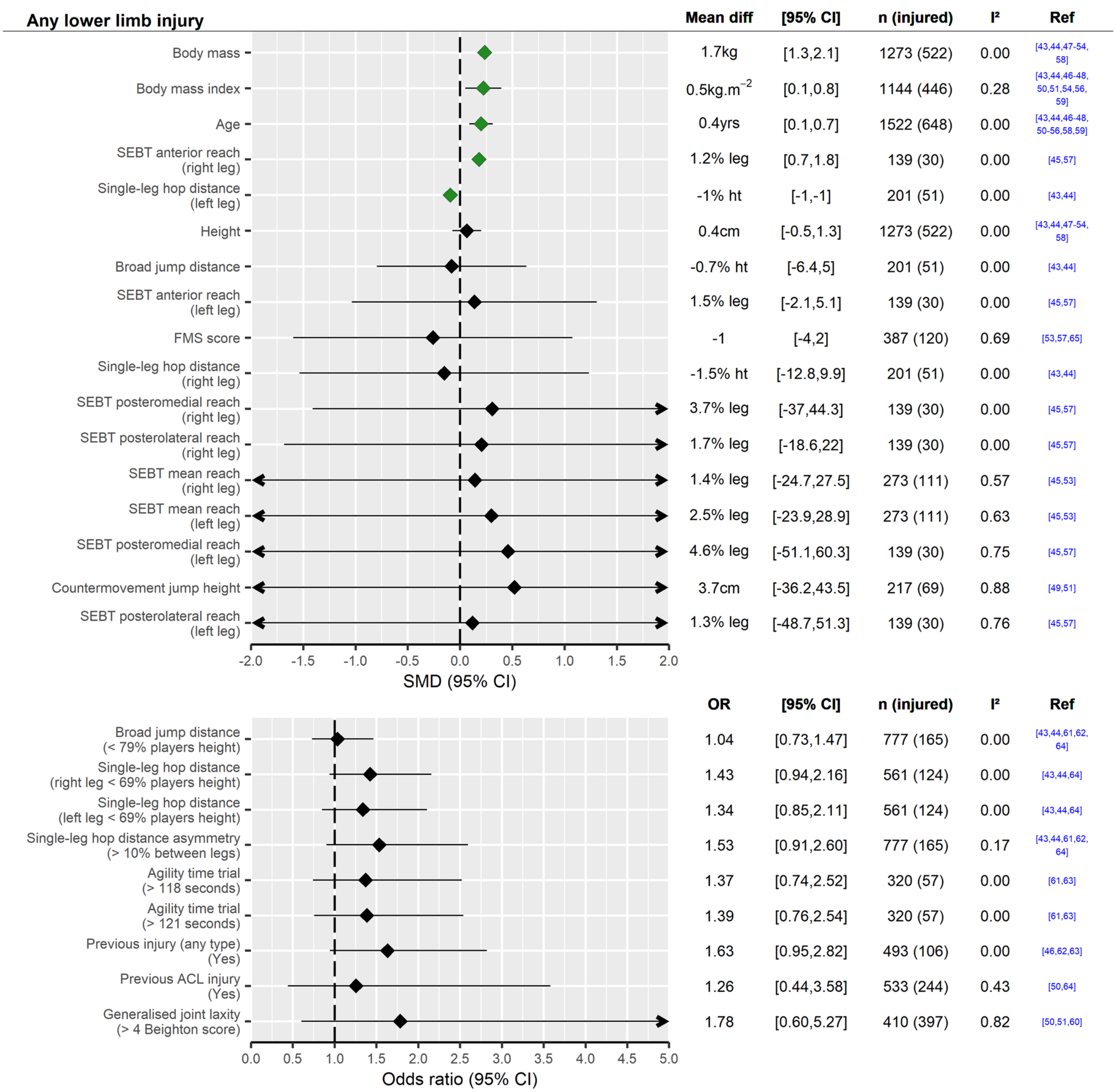

Fig. 3 Summary of results from individual random effect model meta-analyses of risk factors for any lower limb injury. Top figure shows SMD and mean difference (mean diff) with 95% CI in original units. Bottom figure shows the odds ratio. *FMS* functional movement screen, *SEBT* star excursion balance test, *leg* leg length, *yrs* years, *ht* height

the emergence of lower limb biomechanics associated with increased knee joint loads [101, 102]. Additionally, older players typically compete at higher competition levels, and are more likely to have prior injuries due to cumulative sport exposure [21]. It is important to note that although age, body mass, and BMI were statistically significant due to the increased estimate precision of a meta-analysis, the differences between injured and uninjured players at a group level are very small.

4.2 Prior Injury

Athletes with prior ACL and knee injury had 3.5 and 2.4 greater odds of experiencing a subsequent ACL or knee injury respectively. A previous review has highlighted ACL injury history as a risk factor for subsequent ACL injury in female athletes [103]. In male athletes, prior injury is the strongest independent risk factor for several prevalent lower limb injuries, including injuries to the same limb, the contralateral limb, and injury at adjacent locations (e.g. previous

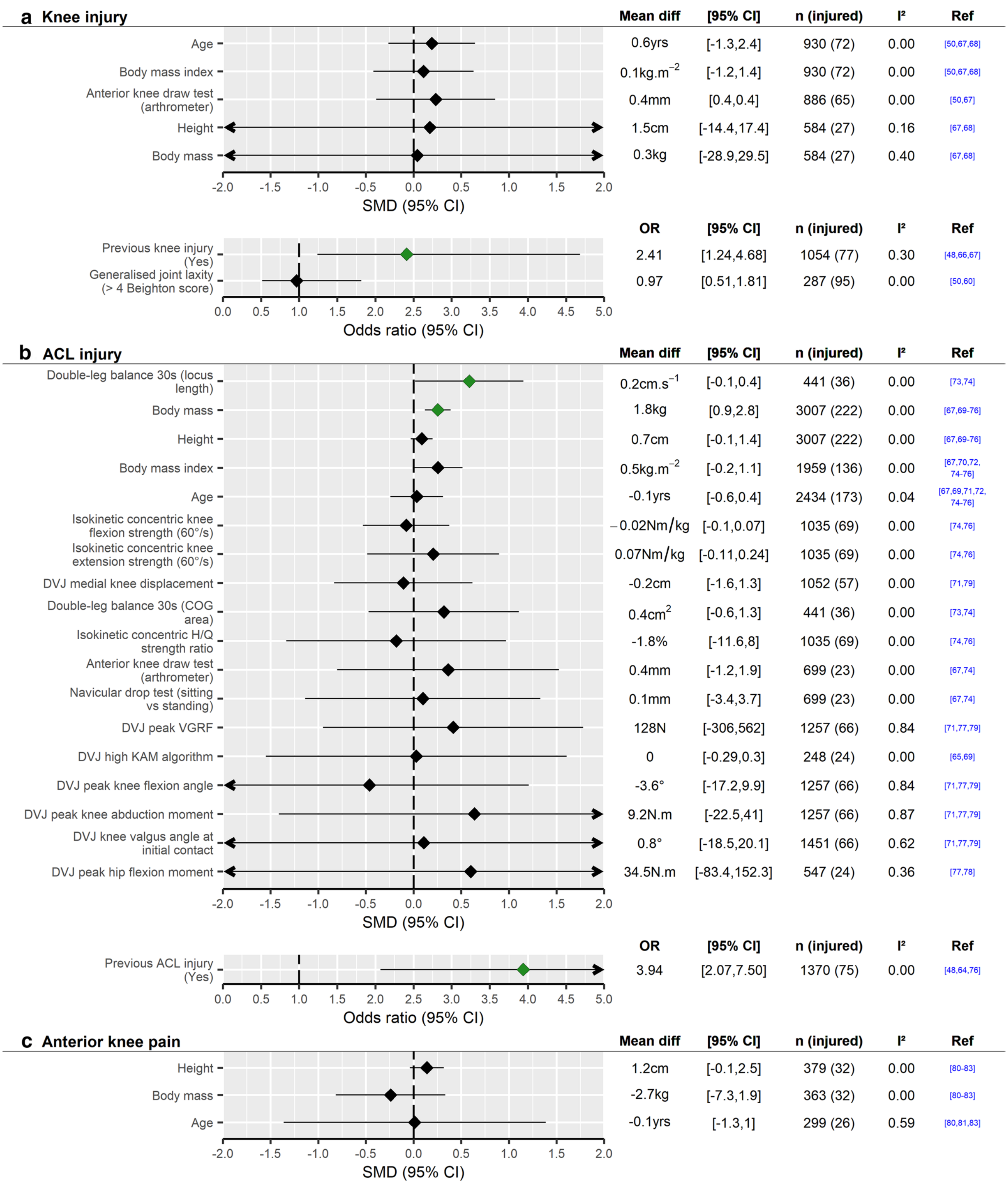

Fig. 4 Summary of results from individual random effect model meta-analyses of risk factors for knee injury (**a**), ACL injury (**b**), and anterior knee pain (**c**). Top figure shows SMD and mean difference (mean diff) with 95% CI in original units. Bottom figure shows the odds ratio. *ACL* anterior cruciate ligament, *COG* centre of gravity, *DVJ* drop vertical jump, *H/Q* hamstring to quadriceps ratio, *VGRF* vertical ground reaction force, *yrs* years

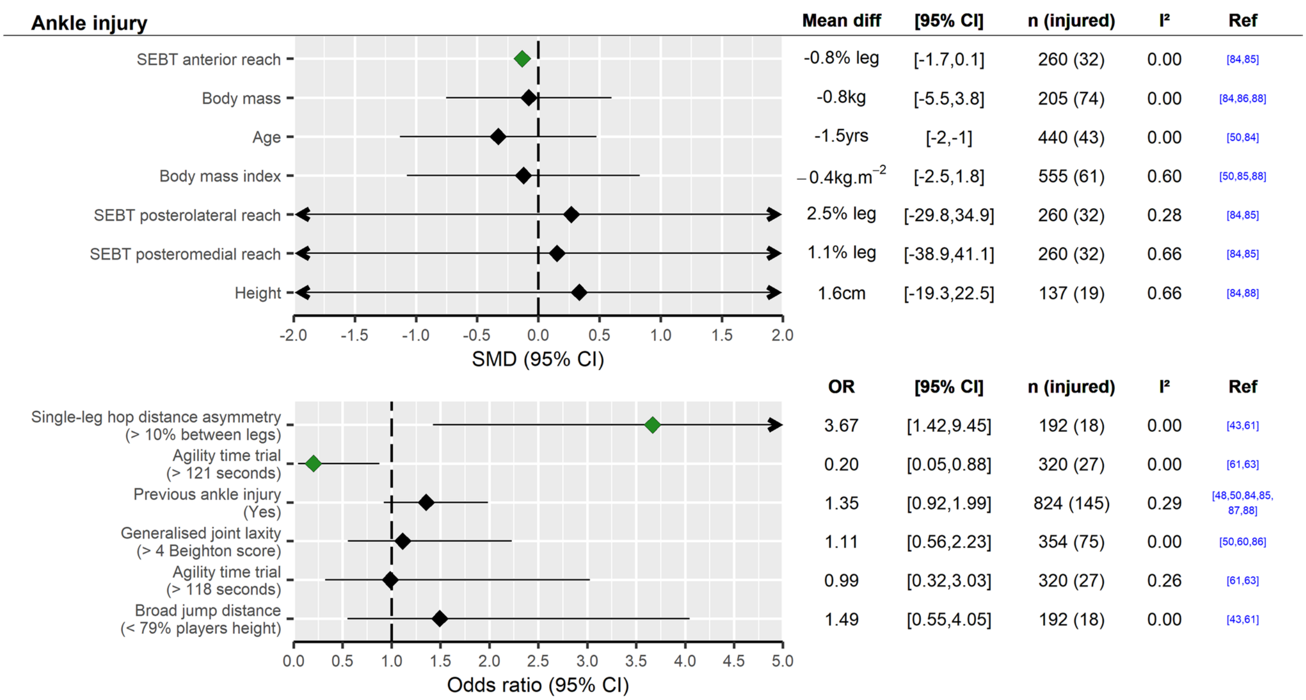

Fig. 5 Summary of results from individual random effect model meta-analyses of risk factors for ankle injury. Top figure shows SMD and mean difference (mean diff) with 95% CI in original units. Bottom figure shows the odds ratio. *SEBT* star excursion balance test, *leg* leg length, *yrs* years

ACL injury increases risk of hamstring and calf strains) [18, 21, 104, 105]. Those who have sustained a previous injury may be at greater risk due to the persistence of risk factors that contributed to the original injury. However, injury may also cause maladaptation in tissue structure and function that in turn increases risk of subsequent injury. For example, following ACL reconstruction athletes display chronic deficits in hamstring muscle activation [106], medial hamstring muscle volumes [106, 107], and knee flexor/internal rotator strength [107, 108]. Lower KOOS was also associated with an increased risk of future knee injury, which may be, in part, related to an individual's injury history [109], as well as quality of healing and restoration of function. Therefore, KOOS may be a useful tool for monitoring players after knee injury, and a modifiable target for training.

4.3 Performance Tests

Overall, evidence for risk factors relating to performance on physical tests was limited. Star excursion balance test anterior reach, and single-leg hop distance and asymmetry were associated with future lower limb injury and ankle injury. However, caution should be taken in interpreting these results, as each meta-analysis included only two studies that observed identifical effect sizes, resulting in a significant, albeit trivial overall effect (SMD < 0.2). Despite the small effect sizes, these risk factors warrant further investigation, and may prove to be clinically meaningful when combined in a multivariable injury risk model. Double-leg postural sway was associated with ACL injury. The association of other tests of strength, biomechanics, balance, mobility and joint characteristics with future lower limb injury risk were not supported by current evidence. For the star excursion balance test, greater anterior reach distance was associated with lower limb injury [45, 57], and less reach distance associated with ankle injury [84, 85]. As such, the anterior reach direction may provide useful insight into ankle dorsiflexion range of motion, which may be important for ankle function, as well as controlling knee position in the frontal plane [110]. Single-leg hop distance is commonly used as a surrogate measure of lower limb power, and asymmetries may indicate deficits in strength or coordination [111]. Be noted that the meta-analyses for single-leg hop distance, and agility time trial [43, 44, 61, 63], as well as double-leg static balance [73, 74] were based on results from studies undertaken by the same research groups, and may be influenced by unintentional systematic bias. Further, there are a number of performance tests associated with lower limb injury risk that have been reported by single studies, including the triple hop jump [56], side-step muscle activation [42], and single-leg drop vertical jump [68].

4.4 Study Limitations

Synthesis of evidence was predominantly limited by each study's chosen testing protocol, statistical analysis method, grouping of injury types, and reporting of results. Although a wide range of risk factors have been explored, there were limited studies that investigated the same risk factors. Meta-analysis was used as the preferred approach to synthesise study results; however given the broad scope of this review, meta-analyses often included a low number of studies. As a result, meta-analyses with a low number of studies should be interpreted with caution, as effects may be overestimated [112] and heterogeneity statistics (I^2) can become inaccurate [113]. To compensate for inconsistencies in methods between empirical studies, a best evidence synthesis was used to supplement the meta-analyses. Additionally, only data that were presented in the original paper or supplementary material were extracted for analysis. This review included prospective study designs only; however, for some non-modifiable risk factors, evidence from other study designs such as case–control could warrant consideration. Due to the low number of consistent studies investigating female risk factors, this review included participants across a relatively wide range of ages and sports. Potential participant heterogeneity was accounted for by limiting studies to team field and court sports with similar physical demands, and performing random effect model meta-analyses. Further, this review focussed on synthesising evidence across studies; however, there were a number of risk factors found by single studies that require further examination [32, 35, 40, 42, 56, 68, 70].

When interpreting the findings of this review, it is important to consider how study design may prevent accurate identification of injury risk factors and hinder replication of findings. First, injury risk is multifactorial [11]; however the majority of prospective studies consider single variables in isolation. As such, a limitation of this study is the analysis of risk factors as independent factors. Second, many modifiable risk factors are dynamic [114, 115], fluctuating in response to training and competition throughout a season, and consequently may be vastly different from the time of measurement [116]. However, all studies included in this review obtained data at a single time point, months to years before the injury occurred. Third, grouping a wide range of injury types together may confound results, given that injuries to different structures can greatly vary in injury mechanism. Finally, a number of prospective studies include a low number of observed injuries, either creating a bias sample due to chance, or preventing detection of small differences between groups [117].

4.5 Future Directions

This review highlights the absence of evidence for many factors and tests thought to be associated with injury risk in female athletes. Measures derived from tests such as the drop vertical jump [77], landing error score system (LESS) [38], functional movement screen [90], the majority of single- and double-leg balance tasks [39], and isometric/isokinetic strength testing [50] were not found to be associated with subsequent injury in female athletes. Conflicting evidence between studies is a major contributor to this outcome, and it is possible that non-significant findings reflect limitations of study design more so than the test itself. Further high-quality prospective studies are required to identify injury risk factors and establish valid tests, and to develop a greater understanding of any interaction between risk factors. Specifically, studies are required to investigate the most common lower limb injuries in female team field and court sports, such as quadriceps strains, hamstring strains, and hip/groin pain [1], while attempting to minimise the limitations of current prospective study design.

Given the limitations of the prospective studies included in this review, injury risk reduction strategies may benefit from targetting a combination of injury risk factors and injury mechanisms (e.g. by decreasing tissue loads or increasing tissue tolerance). Although risk factors derived from prospective studies are associated with greater risk of injury at a cohort level, this may not necessarily indicate a causative relationship, and therefore, modifying risk factors may not always generate the intended risk reduction. Randomised controlled trials are required to determine whether modifying risk factors via targeted interventions lead to a meaningful reduction in lower limb injuries.

5 Conclusion

Risk factors for lower limb injury in female team sport athletes include greater body mass, greater BMI, older age, prior injury, lower KOOS, greater star excursion balance test anterior reach distance, smaller single-leg hop distance and asymmetry, greater postural sway during double-leg balance and slower agility time trial. Overall, many tests/risk factors assessed in female athletes had no association with injury risk and conflicting evidence between studies was common. Readers should be cognisant of the limitations of existing prospective studies when interpreting findings from this review. Further high-quality prospective studies are required to establish risk factors for lower limb injury in female team and court sport athletes.

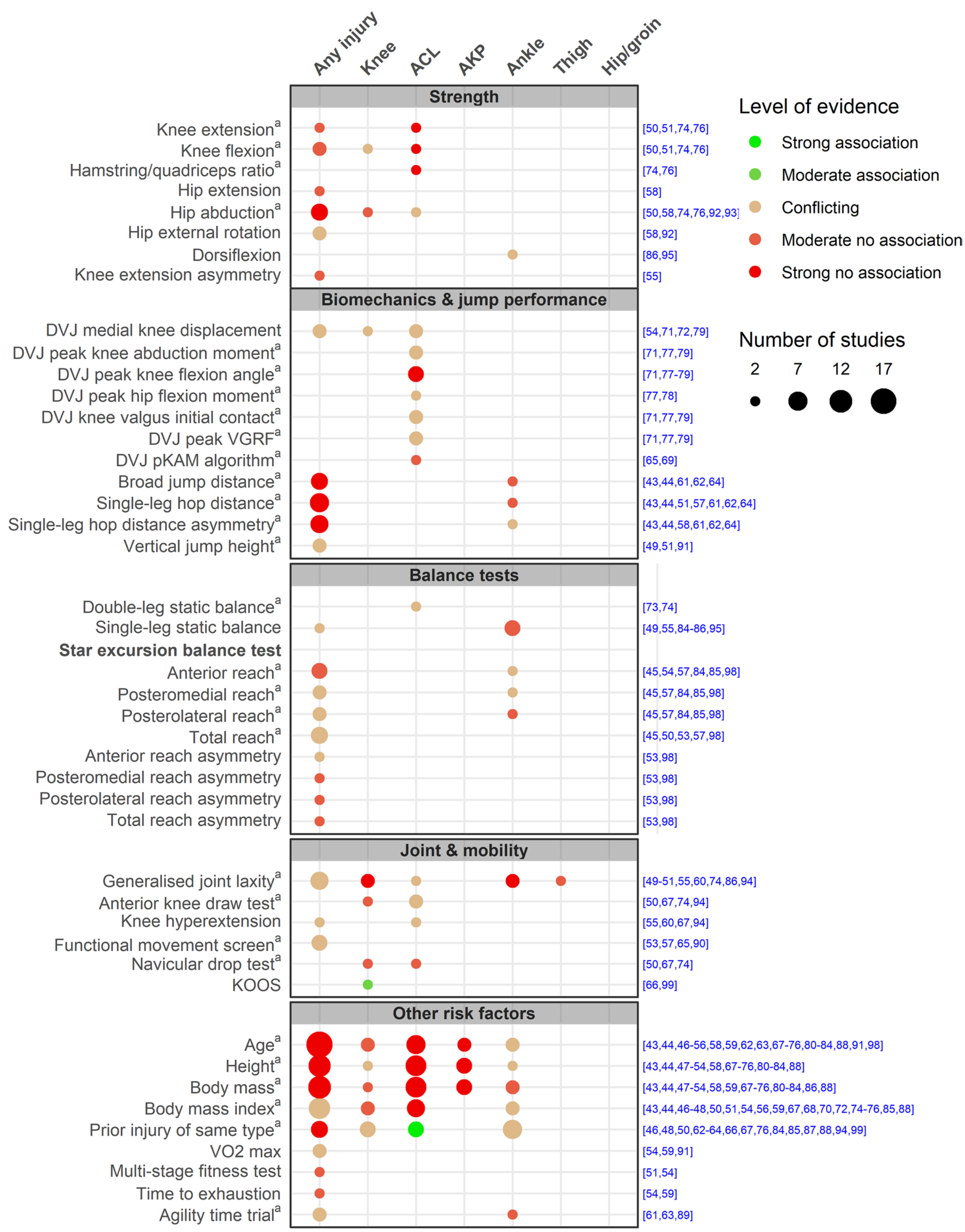

Fig. 6 Best evidence synthesis, indicating the association and strength of evidence between risk factors and lower limb injury by group. Figure includes all risk factors investigated by a minimum of two studies. [a]Risk factors that were also analysed using a meta-analysis. *1RM* one repetition maximum, *ACL* anterior cruciate ligament, *AKP* anterior knee pain, *DVJ* drop vertical jump, *KOOS* Knee Injury and Osteoarthritis Outcome Score, *pKAM* probability of high knee abduction moment, *ROM* range of motion, *VGRF* vertical ground reaction force, *VO2* maximal oxygen uptake

Compliance with Ethical Standards

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Conflicts of interest/Competing interests Tyler Collings, Matthew Bourne, Rod Barrett, William du Moulin, Jack Hickey and Laura Diamond declare that they have no conflicts of interest relevant to the content of this review.

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Consent to participate Not applicable.

Consent for publication Not applicable.

Code availability Not applicable.

Availability of data and materials Data included in this article are available online: https://tcollings.shinyapps.io/risk-factor-app/.

Author contributions TC, MB, LD and RB contributed to the review design. TC, WD and MB performed the literature screening. TC and JH performed the risk of bias assessment. All authors contributed to the writing of the manuscript.

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