Review

Risk factors for overuse injuries in short- and long-distance running: A systematic review

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Abstract

Purpose: The aim of this study was to review information about risk factors for lower extremity running injuries in both short-distance (mean running distance ≤20 km/week and ≤10 km/session) and long-distance runners (mean running distance >20 km/week and >10 km/session).
Methods: Electronic databases were searched for articles published up to February 2019. Prospective cohort studies using multivariable analysis for the assessment of individual risk factors or risk models for the occurrence of lower extremity running injuries were included. Two reviewers independently selected studies for eligibility and assessed risk of bias with the Quality in Prognostic Studies Tool. The GRADE approach was used to assess the quality of the evidence.
Results: A total of 29 studies were included: 17 studies focused on short-distance runners, 11 studies focused on long-distance runners, and 1 study focused on both types of runners. A previous running-related injury was the strongest risk factor for an injury for long-distance runners, with moderate-quality evidence. Previous injuries not attributed to running was the strongest risk factor for an injury for short-distance runners, with high-quality evidence. Higher body mass index, higher age, sex (male), having no previous running experience, and lower running volume were strong risk factors, with moderate quality evidence, for short-distance runners. Low-quality evidence was found for all risk models as predictors of running-related injuries among short- and long-distance runners.
Conclusion: Several risk factors for lower extremity injuries have been identified among short- and long-distance runners, but the quality of evidence for these risk factors for running-related injuries is limited. Running injuries seem to have a multifactorial origin both in short- and long-distance runners.

Keywords: Musculoskeletal health; Protective factors; Running-related injury

1. Introduction

Running is one of the most popular physical activities around the world to achieve or maintain better physical health.[1] In the last 10 years, the number of runners has doubled, and this number is still increasing.[2] Running is beneficial for the whole body: it improves endurance, decreases the risk of cardiovascular diseases and helps to lose weight.[3,4] Unfortunately, running is also associated with a high risk of injuries, especially in the lower extremities.[5] About 80% of running-related injuries (RRIs) are related to overload.[6,7] Tendons and ligaments mainly are at risk due to the relatively slow adaptation to training load.[7]

Because there are many different injury definitions and running types, the incidence of RRIs varies considerably.[8,9]

Runners have a high risk of getting injured, with incidence rates ranging from 7.7 to 17.8 per 1000 h of running.[6] The incidence of running injuries differs between different running distances. Short-distance runners (those who run 15 km or less) have an incidence ranging from 14.3% to 44.7% while long-distance runners (those who run half-marathons or marathons) seem to have more injuries (16.7%−79.3%).[10]

Several risk factors for RRIs have been identified.[11,12] These risk factors can be divided into personal factors (e.g., age, weight, height), training-related factors (e.g., distance, frequency, intensity, shoes), and health-related factors (e.g., medication, previous injury, use of alcohol).[10] According to recent systematic reviews (SRs), a previous injury is the most important risk factor in short- and long-distance runners.[10,12] The use of orthotic inserts in shoes and hip abductor weakness are associated with an increased injury risk as well.[10−13] Inconsistent findings were found for other risk factors, such as body mass index (BMI),[14−16] age,[15,17] and training distance.[18−20] Nonetheless, none of these risk factors have been conclusively found to be the cause of a particular RRI. Also particular injuries may not be related to a single risk factor, but instead are the result of an interaction among several risk factors.

Previous studies have indicated that risk factors vary for different populations of runners.[10,12,16] For instance, it seems that inexperienced runners are twice as likely to get injured compared to experienced runners and that men and women have different risk profiles.[9,10,21] In addition, studies conducted on short-distance runners reveal that their risk factors differ from those of marathon runners.[22,23] For example, a study showed that short-distance runners seem to be at higher risk of injury when they have a BMI of greater than 30, have an age range between 45 and 65 years, exhibit non-competitive behaviors and have experienced a previous injury.[22] However, other studies found that long-distance runners seem to be at higher risk for a RRI when their BMI is greater than 26 and when they have had a previous injury. But for these runners, older age, interval training, and running more training kilometers per week were found to be protective.[19,23,24]

Because personal, training-related, and health-related factors such as age, ratio of female/male runners, kilometers of running per week, and running experience differ between short- and long-distance runners,[22−24] we hypothesize that risk factors for short- and long-distance RRIs will also differ between these groups.

None of the previous reviews explicitly address these differences in short- and long-distance recreational runners or describe separate risk factors for short- and long-distance runners as they relate to RRIs. Moreover, none of the SRs used the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach to judge the overall quality of evidence or included both individual risk factors and risk models for short- and long-distance RRIs.

To develop injury prevention strategies for recreational runners, identifying risk factors is important.[25] If risk factors vary per distance, injury prevention strategies between short- and long-distance runners should be different. Therefore, the aim of this SR was to evaluate risk factors for lower extremity running injuries for short- and long-distance recreational runners separately.

2. Methods

2.1. Protocol and registration

This review was prospectively registered with PROSPERO (registration number CRD42019133799) and was written in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[26]

2.2. Data sources and search procedure

Electronic searches were performed by a librarian (SvdH), from inception until February 2019, in PubMed, CINAHL, Cochrane Library, SPORTDiscus, and PsychINFO, using MESH terms and free-text words. To identify relevant studies, several terms related to RRIs were used (Supplementary Table 1). Terms used to search for factors related to study design were: "cohort", "prospective", "observational", and "longitudinal". Details of the search strategy are available in Supplementary Table 1. References in the included articles were checked for relevant papers.

2.3. Study selection

Studies were included or excluded if they met the selection criteria reported in Supplementary Table 2. Two reviewers (AS and MvdW) independently screened titles and abstracts using the selection criteria. Full-text articles of all the selected studies were retrieved and independently assessed by the 2 reviewers, who applied the selection criteria (Supplementary Table 3). Disagreement was resolved by consensus. When no consensus could be reached, a third reviewer (DvP) made the final decision.

2.4. Risk of bias assessment

All risk factor studies were assessed for risk of bias (RoB) by 2 reviewers independently (MvdW and AS) using the Quality in Prognostic Studies (QUIPS) tool.[27] For risk model studies, RoB was determined using the Prediction model Risk Of Bias Assessment Tool (PROBAST).[28] Disagreement was resolved by consensus. A third reviewer (DvP) made the final decision in cases where no consensus could be reached.

2.5. Data collection and processing

The following data were extracted from the included studies: year of publication, follow-up period, population characteristics (age, BMI, or weight and height, sex), running distance, number of participants included and number of participants analyzed, the definition of an injury, number of RRIs, the type of injury and risk factors, and whether or not the studies evaluated a risk model and adjusted for confounders. The data were processed in a data extraction table. All studies were classified as short-distance (mean running distance of ≤20 km/week and ≤10 km/session) or long-distance (mean running distance of >20 km/week and >10 km/session). If kilometers per week conflicted with kilometers per session, for

instance, 40 km/week with a frequency of 5 times/week, it was classified according to kilometers per week. In case the study population consisted of only males (or females), or when the results in a mixed population were analyzed separately, the results for males and females were also described separately.

Risk factors presented in each study were extracted and categorized as personal, training-related or health-related factors, for short-distance runners and long-distance runners separately. Outcome data for risk models were extracted, including betas, odds ratios (OR), relative risk ratios, hazard ratios and explained variance, or area under the curve. The results per potential risk factor are presented in following subgroups: general (if no subgroups in sex were made), male, and female.

2.6. Outcome

The main outcome variable was a RRI, defined as "self-reported musculoskeletal complaints, in the lower extremity, caused by running activities".[23]

2.7. Data synthesis

We summarized the findings in tables, figures, and text and distinguished 3 categories for the short- and long-distance recreational runners: males, females, and the total general group. A meta-analysis could not be performed due to clinical heterogeneity with respect to population and definition of outcome(s). Cohen's K was used to determine the interobserver agreement of the RoB assessment.

The GRADE approach was used to categorize the overall quality of evidence into high, moderate, low, and very low quality. This categorization provides insight into the confidence of the estimate of the effect. In the field of prognosis, longitudinal cohort studies initially provide high-quality evidence and can be downgraded or upgraded.[29−35]

Six study characteristics downgrade the quality of evidence (phase of investigation, study limitations, inconsistency, indirectness, imprecision, and publication bias). Two study characteristics upgrade the quality of evidence: (1) large (OR > 2 or <0.5) or very large (OR > 5 or <0.2) effect size and (2) exposure−response gradient.[29−35] Concerning study limitations, the evidence was downgraded when more than 75% of the participants were in low RoB studies. Limitations regarding imprecision were determined by the width of the 95% confidence interval and sample size ($n = 2000−4000$).[32] Limitations in indirectness were reported when the outcome variable was not fully appropriate (e.g., when an outcome was not general for RRIs but was specific to patellar femoral pain syndrome) or when study populations differed.[34] Inconsistency was present if the direction of effect differed (protective vs. risk factor, or no effect) between studies or when differences in risk estimates were found.[33] Last, the evidence was upgraded when more than 75% of the participants were found to have very large effect sizes (OR > 5 or <0.2).[35] Single studies ($n < 4000$) are initially rated as low-quality evidence because of downgrading by inconsistency and imprecision.[32,34]

If most of the studies regarding a specific risk factor, including more than 50% of the participants, found no

significant association, results were described as evidence for not being a risk factor. If most of the studies, including more than 50% of the participants, found a significant association, a potential factor is described as a risk factor or a protective factor, depending on the association that was found.

3. Results

3.1. Study selection

A total of 1300 hits were identified from the electronic search of the literature, and 1 article was retrieved from the reference lists in the articles identified. A total of 53 duplicates were removed, and 1163 articles were excluded based on a review of titles and abstracts. Of the remaining 85 hits, 49 articles were excluded based on full-text screening, 7 articles were not full-text available. Finally, 29 studies with a total of 18,853 participants were included in this review; 25 studies presented risk factors (single factor studies) and 4 studies presented risk models (risk model studies) (Fig. 1).

3.2. RoB assessment

The RoB in the domains "outcome measurement" and "prognostic factor measurement" was low. The domains "study attrition" and "study confounding" showed the highest RoB, mainly due to insufficient reporting (Table 1, Fig. 2). The K for the overall interobserver agreement (using the QUIPS) between the 2 reviewers was 0.80 (95% confidence interval: 0.75−0.83).

According to the PROBAST, 3 risk model studies[23,24,36] had a low RoB and good applicability. One risk model study[19] had problems with the applicability because only male runners were included.

3.3. Study characteristics

3.3.1. Population

Seventeen studies examined risk factors (single-factor studies) in short-distance runners;[14−16,20,22,37−48] no risk model studies were found for short-distance runners. Eight studies examined risk factors (single-factor studies) for long-distance runners,[49−56] and three were risk model studies.[19,23,36] One study examined short- and long-distance runners in a risk model study.[24] Tables 2, 3, and 4 describe the characteristics of the included studies.

3.3.2. Follow-up

In studies involving short-distance runners, the follow-up period ranged from 6 weeks to 1 year. The proportion of analyzed participants ranged from 69% to 100% of the included participants at baseline. In studies involving long-distance runners, the follow-up period ranged from 4 weeks to 2 years. The proportion of analyzed participants ranged from 67% to 100% of the included participants at baseline.

3.3.3. Risk factors

A total of 38 potential risk factors were analyzed for short-distance runners, and 36 were analyzed for long-distance runners
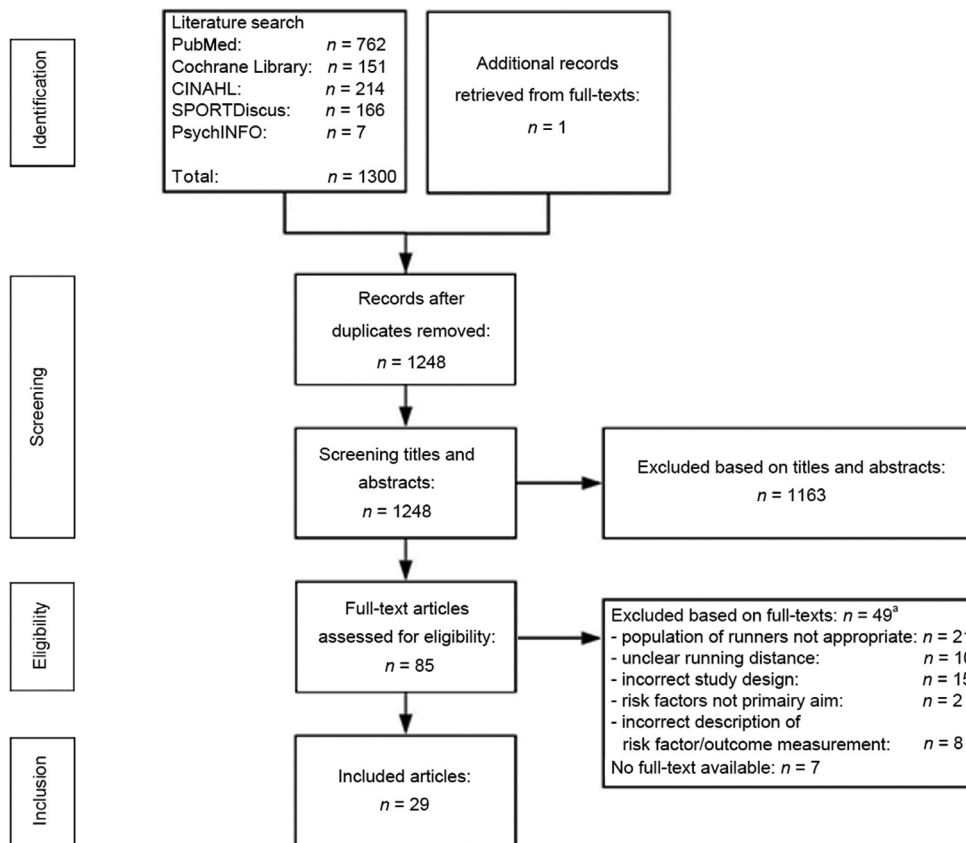
Fig. 1. Flowchart of the literature search. [a] Some articles were excluded for more than 1 reason.

Table 1
Rating for individual studies.

References	Study participation	Study attrition	Prognostic factor measurement	Outcome measurement	Study confounding	Statistical analyses and reporting
Buist et al. (2010)[14]	L	M	L	L	L	L
Kluitenberg et al. (2016)[15]	L	L	L	L	H	L
Kluitenberg et al. (2015)[16]	L	M	L	L	L	L
van der Worp et al. (2016)[20]	L	M	L	L	L	L
Nielsen et al. (2013)[22]	L	L	L	L	L	L
Bredeweg et al. (2013)[37]	M	L	L	L	L	M
Buist et al. (2010)[38]	L	M	L	L	L	L
Hesar et al. (2009)[39]	L	L	L	L	H	M
Malisoux et al. (2015)[40]	M	H	L	L	H	L
Nielsen et al. (2014)[41]	L	M	L	L	L	L
Nielsen et al. (2014)[42]	L	L	L	L	L	L
Ramskov et al. (2015)[43]	L	M	L	L	H	L
Thijs et al. (2008)[44]	L	H	L	L	H	M
Thijs et al. (2011)[45]	M	L	L	L	H	M
van Ginckel et al. (2009)[46]	L	L	L	L	H	H
Nappier et al. (2018)[47]	L	L	L	L	L	L
Taunton et al. (2003)[48]	L	L	L	L	L	H
Brund et al. (2017)[49]	L	M	L	L	L	L
Hespanhol et al. (2013)[50]	L	M	L	L	H	L
Hespanhol et al. (2016)[51]	M	L	L	L	H	L
Hirschmüller et al. (2012)[52]	L	H	L	L	H	M
Hotta et al. (2015)[53]	M	M	L	L	L	M
Kelsey et al. (2007)[54]	L	H	L	L	L	M
Reinking et al. (2007)[55]	M	M	L	M	H	L
Messier et al. (2018)[56]	M	H	L	M	H	L

Abbreviations: H = high risk of bias; L = low risk of bias; M = medium risk of bias.
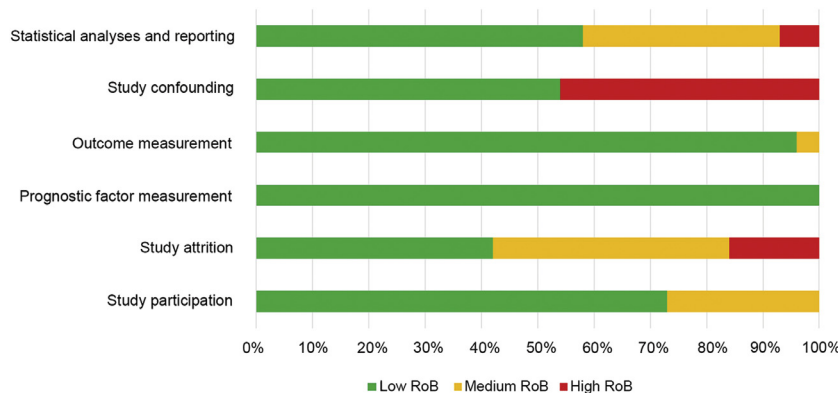
Fig. 2. Risk of bias (RoB).

(Table 5 and Supplementary Tables 4−6). The overall results (GRADE approach) for risk factors for short- and long-distance runners are summarized in Supplementary Table 7. Risk factors evaluated in more than 1 study are described in the text.

3.3.3.1. Short-distance runners
3.3.3.1.1. Personal factors
3.3.3.1.1.1. Age

Six studies evaluated age as a potential risk factor.[14,16,20,22,38,48] In a generic population, 2 studies (low RoB) found no association,[20,22] and 1 study (low RoB) found higher age to be a risk factor (hazard ratio = 1.02).[16] There is therefore moderate quality evidence (downgraded for inconsistency) for age being a risk factor for RRIs.

One study (low RoB) found older age to be a protective factor for injuries in male runners.[38] In a female population, 2 studies (low RoB) found no association.[14,38] One study (medium RoB) found older age to be a risk factor.[48] In males, there is low quality evidence (single study, downgraded for inconsistency and imprecision) that older age is a protective factor, while in females we found low quality evidence (downgraded for limitations in design and inconsistency) that age is not a risk factor.

3.3.3.1.1.2. BMI

Six studies evaluated BMI as a potential risk factor.[14,16,20,22,38,48] In a generic population, 2 studies (low RoB) found no association[20,22] and 1 study (low RoB) found higher BMI to be a risk factor.[16] We found moderate quality evidence (downgraded for inconsistency) for BMI being a risk factor. One study (low RoB) found higher BMI to be a risk factor for injuries in female runners.[38] In a male population, 1 study (low RoB) found no association,[37] 1 study (low RoB) found higher BMI to be a risk factor,[14] and another study (medium RoB) found higher BMI (>26 kg/m^2) to be a protective factor.[48] In females, we found low-quality evidence (single study, downgraded for inconsistency and imprecision) that higher BMI is a risk factor, and low quality evidence (downgraded for limitations in design and inconsistency) for BMI as a risk factor in male short-distance runners.

3.3.3.1.1.3. Running experience

Four studies evaluated previous running experience.[16,20,22,38] In a generic population, 2 studies (low RoB) found no association.[20,22] One study (low RoB) found no running experience to be a risk factor for RRIs.[16] We found moderate quality evidence (downgraded for inconsistency) that having no previous running experience is a risk factor for RRIs.

One study (low RoB) found a significantly higher risk of injury in male and female runners when they had no previous running experience.[38] We found low quality evidence (single study, downgraded for inconsistency and imprecision) that having no previous running experience is associated with an increased injury risk in male and female runners.

3.3.3.1.1.4. Previous sports activity

A type of previous sports activity was included as a risk factor in 6 studies.[14,16,20,22,38,48] In a generic population, no association was found.[16,20,22] We found high quality evidence that previous sports activity is not associated with RRIs.

One study (low RoB) found a significantly higher injury risk in males when previous sports activities without axial loading were performed,[14] 1 study (low RoB) found no association in males but a higher injury risk in females,[38] and 1 study (medium RoB) did not provide data.[47] We found low quality evidence (single study, downgraded for inconsistency and imprecision) for previous sports activity being a risk factor for RRIs in females and males.

3.3.3.1.1.5. Behavior

Competitive/hyperactive vs. relaxed/laid back behavior was included as a risk factor in 2 studies,[14,22] 1 in a generic population,[22] and 1 in males only.[14] One study (low RoB) found behavior (relaxed/laid back) to be a significant risk factor;[22] the other study (low RoB) found no association in males.[14] We found low quality evidence (single study, downgraded for inconsistency and imprecision) that behavior was a risk factor for RRIs in a generic population, and low quality evidence (single study, downgraded for inconsistency and imprecision) for behavior not being a risk factor in men.

Four studies included foot morphology (plantar arch index, navicular drop, or foot pronation) as a potential risk factor.[14,20,42,48] Two studies (low RoB) were performed in the generic population.[20,42] One study found no significant association,[20] and the other study revealed that runners with pronated feet had significantly fewer RRIs per 1000 km of running compared to runners with normal feet.[42] We found low quality evidence (downgraded for inconsistency and imprecision) for foot morphology (moderate foot pronation) not being a risk factor for RRIs.

Table 2
Description of participants, injury type, and definition and risk factors in single-factor studies involving short-distance runners.

References	Follow-up	Included/analyzed (%), injured (n)	Age (year) mean ± SD or 95%CI	Sex (M/F)	BMI (kg/m²) mean ± SD or 95%CI	Running type	Injury definition	Risk or protective factor(s)	Type of injury
Buist et al. (2010)[14]	13 weeks	603/532 (88.2) Injured: 100	M: 42.3 ± 9.9 F: 37.9 ± 9.9	226/306	M: 25.9 ± 3.3 F: 24.2 ± 3.4	Short distance: Novice runners training for a 6.7-km event	Running-related MSC of lower extremity or back; restriction of running, for at least 1 week	Demographic variables, training characteristics and kinematic variables	Overall running-related injuries
Kluitenberg et al. (2016)[15]	6 weeks	1772/1696 (95.7) Injured: 185	43.3 ± 10.0	364/1332	25.5 ± 4.0	Short distance: start-to-run program of 20 min	MSC of lower extremity or back attributed to running; hampered running ability for 3 consecutive training sessions	Sociodemographic variables	Overall running-related injuries
Kluitenberg et al. (2015)[16]	6 weeks	1772/1696 (95.7) Injured: 159	43.3 ± 10.0	364/1332	25.5 ± 4.0	Short distance: start-to-run program of 20 min	MSC in a sole body part of lower extremity or back attributed to running; restriction in running ability for at least 3 consecutive training sessions (i.e., 1 week)	Running intensity, running frequency, and running volume	Overall running-related injuries
van der Worp et al. (2016)[20]	3 months	433/417 (96.3) Injured: 93	38.7 ± 11.5	0/417	23.2 ± 2.9	Short distance: 5−10 km start-to-run	Running-related pain in lower back and/or lower extremity; restricted running for at least 1 day	Training distance and previous injury	Overall running-related injuries
Nielsen et al. (2013)[22]	1 year	933/930 (99.7) Injured: 254	37.2 ± 10.2	468/462	26.3 ± 4.4	Short distance: novice runners with a self-structured runner program	MSC of lower extremity or back caused by running; restricted the amount of running for at least 1 week	Demographic and behavioral factors	Overall running-related injuries
Bredeweg et al. (2013)[37]	9 weeks	238/210 (88.2) Injured: 34	37.2 ± 11.2	77/133	23.9 ± 3.4	Short distance: novice runners training for a 6.7-km event	Any self-reported MSC of lower extremity or back; restricted running for at least 1 week	Demographic and kinetic variables	Overall running-related injuries
Buist et al. (2010)[38]	8 weeks	875/629 (71.9) Injured: 163	43.7 ± 9.5	208/421	24.9 ± 3.3	Short distance: novice and regular runners training for a 6.7-km event	MSC of lower extremity or back; restricted running for at least 1 day	Demographic variables and training characteristics	Overall running-related injuries
Hesar et al. (2009)[39]	10 weeks	131/131 (100) Injured: 27	39.1 ± 10.3	20/111	24.9[a]	Short distance: start-to-run program of 5 km	All sports injuries that occurred during the program	Gait-related intrinsic risk factors	Overall running-related injuries
Malisoux et al. (2015)[40]	9 months	754/517 (68.6) Injured: 167	42.2 ± 9.9	336/181	Unclear	Short distance: self-structured running program, mean 22 km/week, with a frequency of 2 times/week	Any physical pain located at the lower limb or lower back region, sustained during or as a result of running practice; impeded planned running activity for at least 1 day	Running frequency and volume, BMI, and previous injury	Overall running-related injuries and traumatic non-contact injuries
Nielsen et al. (2014)[41]	1 year	933/873 (93.6) Injured: 202	37.2 ± 10.3	441/432	26.1 ± 4.2	Short distance: novice runners with a self-structured running program	MSC of lower extremity or back caused by running; restricted the amount of running for at least 1 week	Increasing weekly running distance	Overall running-related injuries
Nielsen et al. (2014)[42]	1 year	951/927 (97.5) Injured: 252	37.1 (95%CI: 36.5−37.8)	466/461	26.3 (95%CI: 26.0−26.6)	Short distance: novice runners with a self-structured running program	MSC of lower extremity or back caused by running; restricted the amount of running for at least 1 week	Foot posture	Overall running-related injuries
Ramskov et al. (2015)[43]	1 year	832/629 (75.6) Injured: 24	36.6 ± 10.1	321/308	26.1 ± 4.4	Short distance: novice runners with self-structured running program	MSC of lower extremity or back caused by running; restriction in running for at least 1 week	Eccentric hip abduction strength	Patellar femoral pain
Thijs et al. (2008)[44]	10 weeks	129/102 (79.1) Injured: 17	37.0 ± 9.5	13/89	25.0 ± 3.0	Short distance: start-to-run program of 5 km	Characteristic history and symptoms of PFPS; exhibited two of the following criteria: pain on direct compression of the patella, tenderness of the posterior surface of the medial or lateral rim of the patella	Gait-related intrinsic risk factors	Patellar femoral pain

Table 2 (Continued)

References	Follow-up	Included/analyzed (%), injured (n)	Age (year) mean ± SD or 95%CI	Sex (M/F)	BMI (kg/m²) mean ± SD or 95%CI	Running type	Injury definition	Risk or protective factor(s)	Type of injury
Thijs et al. (2011)[45]	10 weeks	77/77 (100) Injured: 16	38 ± 9	0/77	24.6 ± 2.9	Short distance: 10-week start-to-run program	Patellofemoral dysfunction with a characteristic history and symptoms of PFPS; cessation of running program on palpation, pain with isometric quadriceps muscle contraction	Hip muscle weakness	Patellar femoral dysfunction syndrome
van Ginckel et al. (2009)[46]	10 weeks	129/129 (100) Injured: 10	39[b]	10/46	Injured (n=10) 24.95 ± 4.12 Uninjured (n=53) 24.69 ± 3.89	Short distance: start-to-run program of 5 km	Musculoskeletal ailment; restriction of running speed, distance, duration or frequency for at least 1 week	Intrinsic risk factors	Achilles tendinopathy
Nappier et al. (2018)[47]	15 weeks	74/65 (87.8) Injured: 22	36.3 ± 8.4	0/74	22.7 ± 2.5	Short distance: 19 km/week	Running-related, overuse, musculoskeletal (low back and lower extremities; missed 3 training days within a 2-week window	Kinetic variables	Overall running-related injuries
Taunton et al. (2003)[48]	13 weeks	844/840 (99.5) Injured: 249	Categorical n=141, ≤30 years n=502, 31−49 years n=111, 50−55 years n=74, ≥56 years	205/635	Categorical n=29, <20 n=556, 20−26 n=190, >26	Short distance: training program of 10 km	Grade 1 injury, pain only after exercise	Sociodemographic and training-related factors	Overall running-related injuries

[a] BMI calculated because authors only described height and weight.
[b] SD not described.
Abbreviations: BMI = body mass index; CI = confidence interval; F = female; M = male; MSC = musculoskeletal complaint; PFPS = patellofemoral pain syndrome; SD = standard deviation.

One study (medium RoB) did not present data on the plantar arch as a possible risk factor.[48] One study (low RoB) found that normal navicular drop was a protective factor for RRIs compared to a high navicular drop in female runners.[14] We found low quality evidence (single study, downgraded for inconsistency and imprecision) for foot morphology (normal navicular drop *vs.* increased navicular drop) as a protective factor for RRIs in females.

3.3.3.1.2. Training-related factors

3.3.3.1.2.1. Running frequency

Three studies included running frequency as a potential risk factor.[15,40,48] In a generic population, 2 studies (medium and high RoB) found no association for running frequency and RRIs in the generic population.[15,40] We found moderate quality evidence (downgraded for study limitations) for running frequency not being a risk factor for RRIs. One study (medium RoB) found that running 1 day/week or less is associated with an increased risk for RRIs in females. We found very low quality evidence (single study, downgraded for study limitations, inconsistency and imprecision) for running frequency as a risk factor for RRIs in females.[48]

3.3.3.1.2.2. Weekly running volume

Two studies included weekly volume (min/week) as a potential risk factor.[15,40] One study (medium RoB) found a weekly volume of more than 60 min to be a protective factor,[15] and the other study (high RoB) found a weekly volume of less than 2 h to be a risk factor for injuries.[40] We found moderate quality evidence (downgraded for study limitations) that lower weekly training volume is a risk factor.

3.3.3.1.2.3. Weekly running distance

Two studies included weekly running distance as a potential risk factor.[20,41] One study (low RoB) found no association between weekly running distance and injuries,[41] while 1 study (low RoB) found a higher running distance (>30 km/week) to be a risk factor for RRIs. We found low quality evidence (downgraded for inconsistency and imprecision) for running distance as a risk factor.

3.3.3.1.2.4. Type of terrain

Two studies included type of terrain as a potential risk factor.[20,48] One study, using a generic population (low RoB), found no significant association between type of terrain and injuries in short-distance runners.[20] We found low quality evidence (single study, downgraded for inconsistency and imprecision) that type of terrain is not a risk factor. The other study reported no data on this risk factor.[48]

3.3.3.1.2.5. Running shoe age

Three studies included running shoe age as a potential risk factor.[16,20,48] Two studies found no association[16,20] in a generic population. We found high quality evidence that running shoe age is not a risk factor for RRIs. One study (medium RoB) found running shoe age (4−6 months old) (compared to 1−3 months, 7−12 months, or 1−2 years old) to be a protective factor in male runners and a risk factor in female runners.[48] There is very low quality evidence (single study, downgraded for limitations in design, inconsistency, and imprecision) that running shoe age is a protective factor in male runners and a risk factor for RRIs in female runners.

Table 3
Description of participants, injury type and definition, and risk factors in single-factor studies involving long-distance runners.

References	Follow-up	Included/analyzed (%), Injured (n)	Age (year) mean ± SD	Sex (M/F)	BMI (kg/m²) mean ± SD	Running type	Injury definition	Risk or protective factor(s)	Type of injury
Brund et al. (2017)[49]	1 year	99/79 (80) Injured: 25	39[a]	79/0	23.9	Long distance: 30 km/week	An absence of running for a minimum of 1 week due to MSC in lower extremity or back, caused by running	Medial or lateral ground pressure of the foot	Achilles tendinopathy, plantar fasciitis medial tibial stress syndrome (APM injuries)
Hespanhol et al. (2013)[50]	3 months	200/191 (96) Injured: 84	42.8 ± 10.5	141/50	24.4 ± 3.1	Long distance recreational runners, mean 28 km/week with a frequency of 3 times/week	Any pain of musculoskeletal origin, attributed to running by runners themselves and severe enough to prevent the runner from performing at least 1 training session	Previous running-related injury, speed training, and interval training	Overall running-related injuries
Hespanhol et al. (2016)[51]	3 months	89/89 (100) Injured: 24	44.2 ± 10.6	68/21	24.2 ± 3.5	Long distance: 35 km/week	If runners missed at least 1 training session due to MSC	Lower limb alignments	Overall running-related injuries
Hirschmüller et al. (2012)[52]	1 year	634/427 (67) Injured: 29	43.2 ± 11.0	285/142	23.0 ± 2.0	Long distance: 34.6 km/week	Pain 2−6 cm proximal to the insertion and at least two of the following minor criteria: palpable thickening of the tendon, tenderness on bilateral pressure of the tendon, morning stiffness of the tendon, or pain at the beginning of activity	Previous Achilles disorders and neovascularization	Achilles tendon pain
Hotta et al. (2015)[53]	6 months	101/84 (83) Injured: 15	20.0 ± 1.1	84/0	19.6 ± 4.8	Long distance: collegiate track-and-field middle- or long-distance runners	MSC that (1) occurred as a result of participating in a practice or race in track and field, or (2) was sufficient severe to prevent participation for at least 4 weeks	Functional movement screening	Overall running-related injuries
Kelsey et al. (2007)[54]	2 years	150/127 (85) Injured: 18	22.0 ± 2.6	0/127	21.2 ± 1.9	Long distance: minimum of 40 km/week	A stress-fracture confirmed by X-ray, bone scan, or magnetic resonance imaging	Previous stress fracture, bone mineral content, age, and calcium intake	Stress fractures
Reinking et al. (2007)[55]	1 season	88/67 (7) Injured: 26	19.5 (range: 18−24)	44/44	No information	Long distance: mean of 64 km/week	Unclear	Intrinsic and extrinsic risk factors	Overall running-related injuries
Messier et al. (2018)[56]	Prospective cohort, 2 years	300/252 (84) Injured: 199	36.3 ± 8.4	0/74	22.7 ± 2.5	Long distance: 20 miles/week	The injury was deemed to be running-related, overuse, musculoskeletal (low back and lower extremities), and reported to be the cause of missing 3 training days within a 2-week moving window	Kinetic variables	Overall running-related injuries

[a] SD not described.
Abbreviations: APM = Achilles tendinopathy, plantar fasciitis, medial tibial stress syndrome; BMI = body mass index; F = female; M = male; MSC = musculoskeletal complaint; SD = standard deviation.

Table 4
Description of participants, injury type and definition, and risk factors in risk model studies involving short- and long-distance runners.

References	Follow-up	Included/analyzed (%), injured (n)	Age (year) mean ± SD	Sex (M/F)	BMI (kg/m^2) mean ± SD	Running type	Injury definition	Risk or protective factor(s)	Type of injury
van Middelkoop et al. (2008)[19]	4 weeks	725/694 (96) Injured: 195	44.0 ± 9.6	694/0	23.5 ± 2.1	Long distance: marathon	MSC attributed to running, severe enough to cause a reduction in the distance, speed, duration or frequency of running	Sociodemographic and training-related factors	Overall running-related injuries
van Poppel et al. (2016)[23]	5 weeks	864/614 (71) Injured: 142	43.8 ± 11.2	414/200	23.1 ± 2.5	Long distance: (half) marathon	Self-reported MSC that has to reduce running intensity or frequency, or need medical consultation	Training characteristics and sociodemographic variables	Overall running-related injuries
van Poppel et al. (2018)[24]	5 weeks	3768/2763 (73) Injured: 811	42.8 ± 11.2	2270/1498	23.4 ± 2.5	Mixed distances	Self-reported complaints of muscles, joints, tendons or bones in the lower extremity, due to running activities by which the running intensity or frequency was reduced, or medical consultation was needed	Training characteristics and sociodemographic variables	Overall running-related injuries
Wen et al. (1998)[36]	32 weeks	355/255 (71) Injured: 90	41.8 ± 10.8	107/148	M: 25.6[a] F: 23.8[a]	Long distance: marathon training program	A running injury met the following criteria: having had "injury or pain" to an anatomic part; having had to stop training, slow pace, stop interval or otherwise having had to modify training and a "gradual" vs. "immediate" onset of injury or a self-reported diagnosis that is generally considered an overuse injury	Lower extremity alignment	Overall running-related injuries

[a] BMI calculated because authors only described height and weight.
Abbreviations: BMI = body mass index; F = female; M = male; MSC = musculoskeletal complaint; SD = standard deviation.

Table 5
Grading assessment quality of evidence (GRADE) summary table of the most important significant risk factors in 2 or more studies.

Prognostic factor	Number of studies	Number of participants	Phase	Study limitations	Inconsistency	Indirectness	Imprecision	Publication bias	Effect size	Dose effect	Overall quality
Short-distance runners											
Personal factors											
Age (generic)	3	3138	1	V	→	V	V	x	x	x	++
Age (female)	3	2322	1	→	→	V	V	x	x	x	++
BMI (generic)	3	3138	1	V	→	V	V	x	x	x	+++
BMI (male)	3	2322	1	→	→	V	V	x	x	x	+++
Sex	3	3580	1	V	→	V	V	x	x	x	+++
Running experience (generic)	3	3138	1	V	→	V	V	x	x	x	+++
Previous sports participation (male)	2	1478	1	V	→	V	→	x	x	x	++
Foot morphology (generic)	2	1384	1	V	→	V	→	x	x	x	++
Training-related factors											
Lower weekly volume (min)	2	2526	1	→	V	V	V	x	x	x	++
Distance (km)	2	1366	1	V	→	V	→	x	x	x	++
Health-related factors											
Previous RRI (generic)	3	3138	1	V	→	V	V	x	x	x	+++
Previous injury not attributed to running	2	2705	1	V	V	V	V	x	x	x	+++
Long-distance runners											
Health-related factors											
Previous RRI (generic)	3	922	1	→	V	V	→	x	↑	x	++

Notes: Generic includes both male and female runners. V means no serious limitations; ↓ means serious limitations (x = not applicable). If only 1 study was found with significant results, downgrading was done for inconsistency and imprecision. For overall quality of evidence: += very low; ++= low; +++ =moderate; ++++ =high.
Abbreviations: BMI = body mass index; RRI = running-related injury.

3.3.3.1.2.6. Hip strength

Two studies included hip abduction strength as a potential risk factor.[43,45] One study (medium RoB) in a generic population found hip abduction strength to be a risk factor for RRIs (very low quality evidence) (single study, downgraded for study limitations, inconsistency, indirectness, and imprecision).[43] The other study (high RoB) did not present data on this association.[45]

3.3.3.1.2.7. Intrinsic gait-related factors

Three studies included intrinsic gait-related factors as risk factors.[38,44,46] All 3 studies assessed different kinds of risk factors. One study (high RoB) found significantly more laterally directed force distribution underneath the forefoot at the forefoot flat and significantly decreased total displacement of the center of force (COF) to be risk factors for the development of Achilles tendinopathy.[39]

One study (medium RoB) found that force distribution was significantly more laterally directed at first metatarsal contact and at forefoot flat.[39] Furthermore, the mediolateral force ratio showed more displacement of the force from medial to lateral in the initial contact phase. During the forefoot contact phase and the foot flat phase, the COF was more laterally directed in the injured group. At heel-off, the x-component of the COF is situated significantly more laterally. During the forefoot push-off phase, the x-component of the COF is situated significantly more medially. The velocity of the mediolateral and the anteroposterior displacement of the COF at forefoot flat was significantly slower. Anteroposterior displacement of the COF at forefoot flat was significantly higher in the injured group. The absolute force time integral underneath metatarsal 5 was significantly higher in the participants who sustained an RRI.[46] One study (high RoB) found a significantly shorter time to the vertical peak force underneath the lateral heel to be a predisposing factor for patellofemoral pain syndrome, but no risk estimates were presented.[44]

In conclusion, there is very low quality evidence based on single studies (downgraded for study limitations, inconsistency, indirectness, and imprecision) that intrinsic gait-related factors are risk factors for RRIs.

3.3.3.1.2.8. Peak force

Two studies included active peak of ground reaction force as a potential risk factor.[37,47] One study (moderate RoB) published no data on this positive association,[37] and 1 study (low RoB) found no association in females.[47] We found low quality evidence (single study, downgraded for inconsistency and imprecision) that active peak is not a risk factor for RRIs in a female population.

3.3.3.1.3. Health-related factors
3.3.3.1.3.1. Previous RRIs

Four studies included previous RRIs as a potential risk factor;[14,16,20,22] three of these studies included both male and female recreational runners. Two studies (low RoB) found no association,[16,22] while 1 study (low RoB) found that a previous RRI is a risk factor for RRIs.[20] We found moderate quality evidence (downgraded for inconsistency) that previous RRIs is not a risk factor.

One study (low RoB) found that a previous RRI is associated with new RRIs in male runners (low quality evidence) (single study, downgraded for inconsistency and imprecision).[14]

3.3.3.1.3.2. Musculoskeletal injury

Two studies (low RoB) found that a previous injury (musculo-skeletal complaint) not attributed to running is a risk factor (high quality evidence) for new RRIs in short-distance runners.[16,22]

3.3.3.2. Long-distance runners
3.3.3.2.1. Personal factors
3.3.3.2.1.1. Age

Two studies included age as a potential risk factor;[52,54] one study (high RoB) in a generic population did not present data.[52] One study (medium RoB) found higher age to be a protective factor for RRIs in female runners.[54] We found very low quality evidence (single study, downgraded for study limitations, inconsistency, indirectness, and imprecision) that age is a protective factor in females.

3.3.3.2.1.2. BMI

Two studies assessed BMI as a potential risk factor but did not present data.[52,54] Three studies included weight as a potential risk factor;[52,54,56] one of these studies (high RoB) presented data and found no association.[56] We found very low quality evidence (single study, downgraded for study limitations, imprecision, and inconsistency) that weight is not a risk factor for RRIs in a generic population. Two studies included height as a potential risk factor, but did not present data.[52,54]

3.3.3.2.2. Training-related factors

Two studies included training volume as a potential risk factor.[54,55] One study (medium RoB) found no statistically significant association in female runners.[54] The other study (high RoB) presented no data.[55] We found very low quality evidence (single study, downgraded for study limitations, inconsistency, and imprecision) that training volume is not a risk factor for RRIs.

3.3.3.2.3. Health-related factors

The association between previous RRIs and new RRIs was assessed in 4 studies.[50,52,54,55] Three studies (1 medium RoB, 2 high RoB) found associations between previous RRIs and new RRIs in a generic population.[50,52,55] One of these studies (high RoB) found an association for Achilles tendinopathy specifically.[52] We found moderate quality evidence (downgraded for study limitations and indirectness, and upgraded for effect size) that a previous RRI is a risk factor for new RRIs.

One study (medium RoB) found a previous RRI to be a risk factor for stress fractures in female long-distance runners.[54] We found very low quality evidence (single study, downgraded for study limitations, indirectness, inconsistency, and imprecision) that a previous RRI is a risk factors for RRIs in female long-distance runners.

3.3.4. Risk models

We found a total of 11 risk models in 4 studies involving short- and long-distance runners (distances included 5-km, 10-km, half marathon, and marathon).[19,23,24,36] One study found a risk model for RRIs in 5-km and 10−15-km runners.[23] One study found a risk model for RRIs in half marathon runners,[24] and 4 studies found a risk model for RRIs in marathon runners.[19,23,24,36] One study found a risk model for foot and shin injuries, but no knee injury risk model was found.[36] One study also found a risk model for knee and calf injuries.[19] All models varied in terms of the relevant predictors, and all but one had an area under the curve of approximately 70% or higher. Because all models were in the derivation stage, they were graded low quality. Three studies, which developed 8 risk models, were applicable in regard to population, prediction outcome and analysis.[23,24,36] One study, which developed 3 models, had concerns about the applicability due to the fact that only male marathon runners were included.[19] There is no evidence that these models are predictive for RRIs. The results for risk models involving short- and long-distance runners are summarized in Table 6 and Supplementary Table 8.

4. Discussion

To the best of our knowledge, no previous reviews have addressed differences in risk factors between short- and long-distance recreational runners and used the GRADE approach to judge the overall quality of evidence. In this SR, several risk factors were found for both short- and long-distance runners.

We found that a previous RRI was the strongest risk factor (with moderate quality evidence) for an injury in long-distance runners. In a generic population, previous injuries that were not attributed to running was the strongest risk factor (with high quality evidence) in short-distance runners. Higher BMI, higher age, sex (male), having no previous running experience, and lower running volume (<2 h/week) were strong risk factors (with moderate quality evidence) for short-distance runners. Low quality evidence was found for risk models as predictors for RRIs in short- and long-distance runners.

Since 2000, five SRs assessing risk factors for running injuries of the lower extremities have been published.[5,10,12,16,57] None of these reviews included studies having prospective designs with multivariable analysis and none aimed at identifying differences between short- and long-distance runners.

Differences in associations between injuries and risk factors may be explained by differences in selection criteria, study designs, and the RoB tools and data synthesis methods used. Inclusion criteria differed among the SRs, which lead to differences in the studies included in the reviews. For instance, 1 review only included studies with overall lower extremity injuries and not with specific injuries.[57] The other 4 SRs included studies with several different designs, including randomized controlled trials, retrospective cohort studies and cross-sectional studies. Different methods were used for quality assessment for the articles included in the reviews. Our SR used the QUIPS tool as an assessment tool to assess RoB, but the other reviews used different tools to assess the RoB in their included studies. As a consequence, differences in the methodological quality of included studies can be found in the different SRs. For example, the study by Hirschmüller et al.[52] was classified as high quality in the SR by van der Worp et al.,[10] but in our review the same study was classified as

Table 6
Risk models.

Risk model, authors	Remained variables in model	Performance measures	Quality of the evidence
Short distance			
Running injuries *vs.* no running injuries in 5-km runners; van Poppel et al. (2016)[23]	Previous injury (yes/no): OR = 4.1 (95%CI: 2.2−7.6) Weekly distance: OR = 0.95 (95%CI: 0.90−0.99) Age: OR = 0.97 (95%CI: 0.95−0.99)	AUC = 0.71 (95%CI: 0.64−0.79)	Low quality
Running injuries *vs.* no running injuries in 10−15-km runners; van Poppel et al. (2016)[23]	Previous injury (yes/no): OR = 3.8 (95%CI: 2.7−5.3) Weekly distance: OR = 0.97 (95%CI: 0.95−0.99) BMI: OR = 1.1 (95%CI: 1.0−1.2) Weekly training frequency: OR = 1.3 (95%CI: 0.99−1.70) Age: OR = 0.98 (95%CI: 0.97−0.99)	AUC = 0.70 (95%CI: 0.66−0.73)	Low quality
Long distance			
Injuries *vs.* no injuries in marathon runners; Wen et al. (1998)[36]	High experience: OR = 1.881 (95%CI: 1.159−3.053) Previous injuries: OR = 2.018 (95%CI: 1.268−3.212)	Goodness of fit = 1.833	Low quality
Shin splints injuries *vs.* no shin splints injuries in marathon runners; Wen et al. (1998)[36]	Interval: OR = 14.886 (95%CI: 0.504−147.327) Old shin splints injuries: OR = 7.235 (95%CI: 2.399−21.815)	Goodness of fit = 0.722	Low quality
Foot injuries *vs.* no foot injuries in marathon runners; Wen et al. (1998)[36]	High experience: OR = 1.088 (95%CI: 1.027−1.152) Weight: OR = 0.941 (95%CI: 0.892−0.992)	Goodness of fit = 0.464	Low quality
Injuries *vs.* no injuries in male marathon runners; van Middelkoop et al. (2008)[19]	Race participation >7 times per year in comparison with 3−6 per year (reference): OR = 1.66 (95%CI: 1.08−2.56) Injury previous 12 months: OR = 2.62 (95%CI: 1.82−3.78) Daily smoking: OR = 0.23 (95%CI: 0.05−1.01)	AUC = 0.65	Low quality
Knee injuries *vs.* no knee injuries in male marathon runners; van Middelkoop et al. (2008)[19]	Interval training (always): OR = 0.49 (95%CI: 0.26−0.93) Injury previous 12 months: OR = 3.67 (95%CI: 1.79−7.49) Running experience: 0−4 years, OR = 1.43 (95%CI: 0.63−3.26); 15+ years, OR = 2.56 (95%CI: 1.22−5.34)	AUC = 0.69	Low quality
Calf injuries *vs.* no calf injuries in male marathon runners; van Middelkoop et al. (2008)[19]	High education level: OR = 0.60 (95%CI: 0.33−1.10) Training distance: 0−40 km, OR = 0.36 (95%CI: 0.17−0.78); 60+ km, OR = 0.57 (95%CI: 0.27−1.19) Athletics association: OR = 0.58 (95%CI: 0.31−1.09) Incident injury other location: OR = 2.57 (95%CI: 1.42−4.67)	AUC = 0.72	Low quality
Running injuries *vs.* no running injuries in marathon runners; van Poppel et al. (2016)[23]	Interval training (always *vs.* sometimes): OR = 0.67 (95%CI: 0.33−0.81) Running experience: 0−4 years, OR = 1.87 (95%CI: 1.13−3.11); 5−10 years, OR = 1.14 (95%CI: 0.64-2.01)	Nagelkerke R^2 = 0.045	Low quality
Running injuries *vs.* no running injuries in half marathon runners; van Poppel et al. (2018)[24]	Previous injury (yes/no): OR = 3.3 (95%CI: 2.3−4.8) Weekly distance: OR = 0.98 (95%CI: 0.97−1.0)	AUC = 0.67 (95%CI: 0.62−0.71)	Low quality
Running injuries *vs.* no running injuries in marathon runners; van Poppel et al. (2018)[24]	Previous injury (yes/no): OR = 4.3 (95%CI: 2.9−6.1) Weekly distance: OR = 0.98 (95%CI: 0.97−0.99)	AUC = 0.68 (95%CI: 0.64−0.72)	Low quality

Abbreviations: AUC = area under the curve; CI = confidence interval; OR = odds ratio.

having low quality (high RoB). This difference might result in different conclusions. In contrast to our study, none of the SRs used the GRADE approach to assess the quality of the evidence.

Previous reviews found a previous injury to be a risk factor.[5,10,12,16,57] In our study, a previous RRI was also found to be the strongest risk factor for injuries among long-distance runners, but the definition of a "previous injury" differed in

the included studies and ranged from missing sports practice with an unclear timeframe[54] to injuries due to running in the 12 months preceding an event.[23] It remains unclear whether a higher injury risk is related to an incomplete healing of a previous injury, changed biomechanics due to a previous injury or other reasons. Although there is no uniform definition of previous RRIs and current RRIs, many articles confirmed the association and it may be assumed that a previous injury increases the risk of a new injury. It is unclear why this association was not found in short-distance runners. In our review, 2 studies (out of four) on short-distance runners found a previous RRI to be a risk factor for a new RRI. A possible explanation for the lack of association between previous RRIs and current RRIs among short-distance runners is that most studies on short-distance runners included novice runners. Because some novice runners just started running and thus have no history of injuries, they therefore cannot have had previous RRIs. For these runners, having a previous injury not attributed to running was the strongest risk factor. A possible mechanical explanation is that individuals without previous running experience who already have musculoskeletal complaints are more likely to get injured when they do run because their biomechanical loading capacity is lower.[16]

We found moderate quality evidence showing that no previous running experience is a risk factor for running injuries among short-distance runners. Also, limited evidence showing that no running experience was risk factor for running injuries was found in 3 other SRs.[5,10,12] The risk level for injury depends on the distances that are run by those who lack running experience. A possible explanation for why short-distance runners without running experience have a higher risk of injury is that novice runners build up their training too quickly, resulting in a lack of time for their tissue to adapt to training loads. In line with these studies, we found moderate quality evidence for lower running volume as a risk factor RRIs among short-distance runners.[15,40] However, this conclusion must be interpreted carefully, since running more than 60 min/week is protective and does not necessarily mean that running less than 60 min/week is a risk factor. An association between being older and RRIs might be suggested since experienced runners are often older. Although we found inconsistent evidence for age as a risk factor in our review, older age runners may have a higher risk of osteoarthritis, which could explain why more experienced runners are at higher risk of injury than less experienced runners.[58]

We found low quality evidence for higher BMI being a risk factor for RRIs.[14,16,38] Another SR investigated this association but did not find BMI to have a significant effect on running injuries.[12] This difference in our findings and the findings in the SR could be explained by the difference in the types of injuries sustained. Many studies examined BMI as a risk factor for overall injuries but not for specific types of injuries. For instance, lower BMI is associated with lower bone mineral density, which could therefore increase the risk of stress fractures. Increased BMI was significantly associated with the development of medial tibial stress syndrome. This is possibly due to the heavier impact loads that are likely associated with increased BMI.[59−62]

Only prospective cohort studies were included in our review because this study design is considered to be best for determining risk factors.[29,63] A second strength is that our review mainly used results from multivariable analyses, and only used risk factors that were adjusted for confounders.[27] Moreover, this is the first SR of RRIs that used the GRADE approach for data synthesis.

In only a few studies[22,46,52−54] was it unclear which confounders were used. Moreover, in the studies that adjusted the analyses for confounders, the type of confounders often differed. In addition, different methods of reporting risk factors were used, including odds, hazards, or relative risk ratios, which sometimes makes it difficult to compare risk or protective factors. For instance, higher BMI was often not presented with clear cut-off points. Furthermore, SRs should define injury-specific risk factors since these factors have different influences on different injuries.[12,64] However, very few studies summarize injury-specific risk factors, and the large diversity of injury definitions, populations, and research methods in studies makes it difficult to make comparisons across studies.

Although 5 electronic databases were searched and selection bias was minimized using an adequate selection procedure and an inclusion form, it is possible that additional articles eligible for inclusion were missed. Also, unpublished studies could have been missed.[31] Differences in risk factors for short- and long-distance runners may be explained by the fact that some factors were examined in short-distance studies but not in long-distance studies, and *vice versa*.

In our study, running distance was dichotomized into short distance and long distance. However, the population of runners is quite heterogeneous in many studies, especially regarding their training patterns. The studies included in our review included participants who were either short-distance runners or long-distance runners (and the proportion was probably be balanced). Some risk factors might not apply to 1 category or the other, as stated in our study. Also, the criteria used to classify runners into short- and long-distance runners is arguable. In two of the 29 studies, running distance was around the cut-off point, so the distance was hard to classify for these 2 studies.[40,47] Finally, about two-thirds of the studies included in our review focused on short-distance runners, many of whom novice runners. Thus, the risk factors identified in our review for could be more specific to short-distance novice runners rather to short-distance runners in general. This may explain the observed differences in risk factors for short- and long-distance runners. Given these limitations, our results have to be interpreted with caution.

None of the studies included in our review directly compared the risk factors for RRIs between the 2 groups of interest, and this kind of study design should be encouraged in future research. More high-quality prognostic studies that compare the 2 groups are needed in order to improve insight into differences in risk factors between short- and long-distance runners. Study findings should be presented separately for these groups, not only in regard to distance but also in

regard to the location and type of injury. Also, a uniform definition of previous RRIs should be used, for example, the definition recommended in a Delphi approach.[65]

5. Conclusion

Evidence regarding risk factors for RRIs is limited. Running injuries seem to have multifactorial origins. There is a need for additional high-quality studies on risk factors for RRIs before strong conclusions can be drawn about the relevance of specific risk factors. Furthermore, consensus must be reached on the definition of running injuries, and large cohort studies are needed to investigate different types of risk factors (personal, training related, and health related), with an emphasis on the differences between short- and long-distance runners. In our review, we identified the following important risk factors for RRIs among short-distance runners: previous injuries not attributed to running, higher BMI, higher age, sex (male), having no previous running experience, and lower running volume. For long-distance runners, having previous RRIs was the most important risk factor.

Authors' contributions

SvdH carried out the literature search; MvdW and AS carried out the inclusion of studies and quality assessment of the studies; DvP performed the data-analysis; DvP, MvM, APV, BWK, GSP participated in its design and coordination and helped to draft the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

Supplementary materials

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