Trail running injury risk factors: a living systematic review

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► Additional supplemental material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/bjsports-2021-104858).

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Accepted 22 December 2021

Check for updates

To cite: Viljoen C, Janse van Rensburg DCC, van Mechelen W, *et al*. *Br J Sports Med* Epub ahead of print: [*please include* Day Month Year]. doi:10.1136/bjsports-2021-104858

ABSTRACT

Objective To review and frequently update the available evidence on injury risk factors and epidemiology of injury in trail running.

Design Living systematic review. Updated searches will be done every 6 months for a minimum period of 5 years.

Data sources Eight electronic databases were searched from inception to 18 March 2021.

Eligibility criteria Studies that investigated injury risk factors and/or reported the epidemiology of injury in trail running.

Results Nineteen eligible studies were included, of which 10 studies investigated injury risk factors among 2 785 participants. Significant intrinsic factors associated with injury are: more running experience, level A runner and higher total propensity to sports accident questionnaire (PAD-22) score. Previous history of cramping and postrace biomarkers of muscle damage is associated with cramping. Younger age and low skin phototypes are associated with sunburn. Significant extrinsic factors associated with injury are neglecting warm-up, no specialised running plan, training on asphalt, double training sessions per day and physical labour occupations. A slower race finishing time is associated with cramping, while more than 3 hours of training per day, shade as the primary mode of sun protection and being single are associated with sunburn. An injury incidence range 0.7–61.2 injuries/1000 hours of running and prevalence range 1.3% to 90% were reported. The lower limb was the most reported region of injury, specifically involving blisters of the foot/toe.

Conclusion Limited studies investigated injury risk factors in trail running. Our review found eight intrinsic and nine extrinsic injury risk factors. This review highlighted areas for future research that may aid in designing injury risk management strategies for safer trail running participation.

PROSPERO registration number CRD42021240832.

INTRODUCTION

Trail running is an outdoor sport requiring runners to contend with off-road terrains, substantial elevation changes and varying running distances from a few kilometres to multiday ultramarathons (>200 km).[1] An estimated 20 million runners participate in trail running, with a 15% increase in participation over the past decade.[2] The Ultra-Trail World Tour circuit includes races across all six world regions.[3] The most popular race is the Ultra-Trail du Mont Blanc in France with more than 7 000 runners participating each year in the various race distances.[1] Since 2021, the UK has been included in the Ultra-Trail World Tour by adding the Ultra-Trail Snowdonia race to the circuit.[3]

While the health benefits associated with running are well documented,[4] trail running presents with a high risk of injury.[5–9] Trail runners often participate in remote environments during training or racing, posing challenges for medical providers who need to access and/or evacuate injured runners.[10] Even though the majority of trail running injuries are minor,[7 11] in rare cases, injuries are severe and even fatal.[12] This highlights the need to identify trail runners at risk of injury before training and race participation, not only to prevent rare fatal injuries but also any injury, to ensure ongoing access to the health benefits related to running.[4]

A large body of evidence exists on running-related injury risk factors, with multiple previous systematic reviews on running as a whole.[13–15] However, little is known about risk factors specific to trail running, with no systematic reviews providing summarised evidence on this topic. Systematic reviews hold challenges for clinical practice as they are often outdated by the time they are published.[16 17] The maturing nature of the body of evidence in trail running provides an opportunity to regularly summarise available literature through a living systematic review. A living systematic review is an up-to-date summary of literature on a specific topic with frequent updates of the search, risk of bias assessment and, if applicable, the conclusions.[16] Updated findings are reported in peer-reviewed publications and on a designated webpage to avoid a delay in the availability of information due to the peer-review process.[16] This will not only inform up-to-date evidence-based medical practice but also highlight and address any gaps between trail running research and the clinical application of findings within the design of injury risk management strategies.[16 17]

The primary aim of this living systematic review is to identify, summarise and frequently update the available evidence on factors associated with injury in trail running. Our secondary aim is to report the epidemiology (incidence, prevalence and clinical characteristics) of injury in trail running.

METHODS

Protocol registration

Our protocol was registered on PROSPERO, an international prospective register of systematic reviews with no deviations from the registered protocol. The review was conducted in line with the 2020 Preferred Reporting Items for Systematic Review and Meta-Analysis guidelines.[18]

Administration, dissemination and updating the living systematic review

The living systematic review will be administered at the Department of Physiotherapy and Section Sports Medicine, University of Pretoria, South Africa. Updated searches will be done every 6 months over a minimum period of 5 years. The results will be made available on a designated webpage (http://www.slhamsterdam.com/lsr-trailrunning) and also presented in plain language to trail runners, coaches and clinicians to promote the translation of scientific evidence into clinical practice. An updated review will be submitted for publication when new findings result in changes to this review's conclusion or recommendations.

Eligibility criteria

All studies that met the criteria of trail running as defined by the International Trail Running Association[19] were eligible for inclusion, despite the various terminologies used to describe off-road running.[1] To meet the criteria for trail running, running should be performed on natural running surfaces (<20% on paved surfaces) with no limitations on the total running distance or elevation change.[1 19] For race-participation studies, the official race website was consulted when it was unclear whether an 'ultramarathon' was a trail run or not. Race distances ranging from a few kilometres to multiday ultramarathons were included in this review under the categories of (1) submarathon distance (<42.2 km), (2) marathon distance (42.2 km) and 3() ultramarathon distance (>42.2 km). In non-race studies, the authors had to clearly state that the participants under investigation were trail runners. To ensure a comprehensive summary of injury risk factors and epidemiology of injury in trail running, we included clinical assessment, self-reported and medical attention injuries. Even though the primary mode of injury involves transfer of kinetic energy with resulting tissue damage, we also included injuries with different aetiologies (eg, sunburn) in line with the 2020 International Olympic Committee (IOC) consensus statement.[20] Injury risk factors from univariate and multivariate analyses were included. We excluded studies that investigated biomarkers of potential injury, reviews, conference proceedings, case studies, case series, commentaries and editorials.

Main outcome measures

Statistically significant (significance level as set out by each study: $p<0.05$ or $p<0.01$) injury risk/protective factors determined through either a univariate or multivariate analysis were reported (OR/risk ratio, Pearson's correlation coefficient). For the injury epidemiology, we reported the injury incidence (injuries/1000 hours or injuries/1000 runners) and the prevalence (%). The frequencies (n, %) related to the clinical characteristics of injury were reported in accordance with the 2020 IOC consensus statement.[20]

Literature search strategy and information source

The lead author (CTV) developed the search strategy under the guidance of a medical librarian (SS) (online supplemental appendix 1). Relevant electronic databases (MEDLINE OVID, PubMed, Scopus, SPORTDiscus, MEDLINE EBSCO, CINAHL, Health Source: Nursing/Academic via EBSCO and Cochrane Library) were searched from inception to 18 March 2021. The search process was completed prior to registration of our protocol on PROSPERO.

To identify studies relevant to the scope in line with our research question, we used two sets of keywords during our search. Set 1 included various terminologies for trail running, while set 2 included terminologies used for injury risk factors and the epidemiology of injury (online supplemental appendix 1). The final study selection was limited to humans, academic publications and language (English, French, Spanish and Portuguese). The selected studies were imported into EndNote V.20.1 where one researcher (CTV) screened for duplicates.

Study selection

Two researchers (CTV and BS) independently screened the identified study titles and abstracts and thereafter reviewed the full text of the identified studies for eligibility. A third researcher (EV) was appointed to resolve any discrepancies if consensus could not be reached between CTV and BS. However, discrepancies between CTV and BS were unanimously resolved following online consensus meetings for both the title/abstract screening and full-text review. CTV then reviewed the references of all included studies to ensure no relevant study was overlooked. For all updates, a similar process will be followed. But if needed, the data sources and search strategy will be updated and clearly described in follow-up peer-reviewed publications to remain relevant over the full study period of this living systematic review.

Data extraction

Four researchers (EV, VS, WvM and AJvR) each received a random sample from only the included English-written studies[6–9 11 21–33] to extract data from. One researcher (CTV) extracted data from all the English-written studies for quality control. Data from the only Spanish study[34] were extracted by MB, and quality control was done by BS. All researchers used a standardised form for data extraction (online supplemental appendix 2), consisting of:

- *Publication and study detail*: authors, year of publication, study design, data collection procedure, study setting (country, race distance, elevation changes, min/max temperatures, altitude), number of participants (n), follow-up period and injury definition.
- *Participant demographics:* age (years), sex (male/female) and body mass index (BMI, kg/m^2).
- *Injury risk factors:* risk factors and/or protective factors, univariate/multivariate analyses used.
- *Epidemiology of injury:* incidence of injury (injuries/1000 hours or injuries/1000 runners), prevalence (% of injured participants) and clinical characteristics of injury (frequency of injured anatomical region, body area, tissue type, pathology type and injury severity).

Quality and level of evidence assessment

A modified Downs and Black assessment tool[35] was used to assess the quality of each included study (online supplemental appendix 3). The modification involved the removal of irrelevant aspects from the original tool that related to intervention. The maximum attainable score was 15 (a higher score indicating a higher quality study). Two researchers (MS and MB) independently assessed the quality of evidence of the studies published in English.[6–9 11 21–33] The Spanish study[34] was independently assessed by MB and RG-B, who are both proficient in Spanish. Any discrepancies that could not be resolved through consensus were reviewed by a third researcher (WvM) to decide on the final scoring.

For each of the included studies, the level of evidence (LoE) was determined using the Oxford Centre of Evidence-Based Medicine (OCEBM) model.[36] Prospective cohort studies with good follow-ups (>80%) were rated as level 1b and poor follow-up as level 2b. Poor-quality prognostic cohort studies or case-series were rated as level 4 evidence. Two researchers proficient in English and Spanish (RG-B and SM) independently assessed the LoE for all included studies, and any discrepancies between their scores were resolved through consensus between the two authors.

Data analysis

The data analysis was done by reporting on associated injury risk factors and the epidemiology of injury. Data were reported under the larger themes of *race-related* and *training/race-related* studies (training focused, but participants might still have participated in races during the study period). Performing a meta-analysis was not appropriate due to the heterogeneous nature of the included studies in study design, data collection procedure, injury definition, statistical analysis and running exposure.

RESULTS

Our search produced 2 755 records (figure 1), of which 1 124 duplicates were removed, resulting in 1631 records to be screened. A total of 1 442 ineligible studies were excluded during the screening process, and an additional 108 duplicates were identified and excluded. The remaining 81 studies were screened, and 19 studies met the inclusion criteria for this review.

Characteristics of included studies

The 19 included studies had a publication date range of 2011–2021. Thirteen studies focused on injury outcomes related to race participation[6 7 11 22–25 27 29–32 34] (table 1). The majority of studies included ultramarathons,[6 7 23–25 27 29–32 34] followed by marathons,[11 22] and submarathon distances.[11] Injury outcomes related to 56 different races (submarathon distance: n=34, ultramarathons: n=19 and marathons: n=3) across all six world regions (Europe,[11 23 30–32 34] North America,[25 27 29] Asia,[7 22 24]

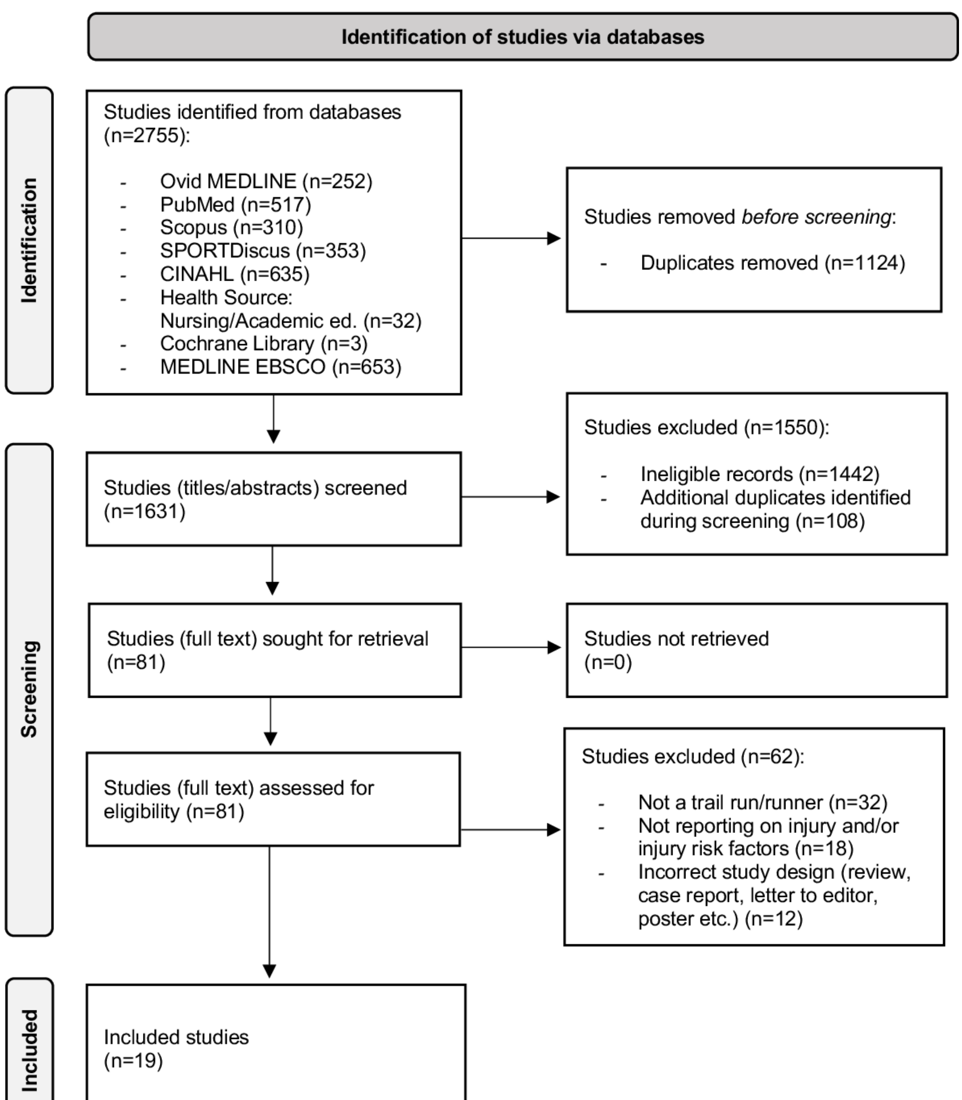

Figure 1 Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 flow diagram.

Table 1 Characteristics of the 13 studies that included only race-related injury outcomes

Author(s) and publication year	Study design	Data collection	Setting	Number of participants (n)	Age (years)	Sex	BMI (kg/m^2)	Quality and LoE
Buckler and Higgins (2000)[22]	Observational race report	Medical encounters prospectively recorded at baseline and during the race.	Tibet: 1999 Everest Marathon Altitude range: 5184–3446 m Temperature: −10°C and below	70	Not reported	Not reported	Not reported	Quality 5/15 LoE 4
Costa *et al* (2016)[23]	Event 1: MSUM Prospective Event 2: Cross-sectional	Event 1: MSUM prospective data collected over 4 days Event 2: continuous marathon (24 hours) Cross-sectional data collected at the end of the 24 hours race	Event 1 (Spain) MSUM: Al Andalus Ultimate Trail (2010 and 2011) Event 2 (Scotland) 24 hours continuous ultramarathon: Glenmore24 Trail Race (2011 and 2012)	Event 1: MSUM 54 Event 2: Continuous marathon (24 hours) 22	Event 1: MSUM 40 (±8) Event 2: Continuous marathon (24 hours) 40 (±7)	Event 1: MSUM men: n=33 (61%); women: n=21 (39%) Event 2: continuous marathon (24 hours): men: n=16 (73%); women: n=6 (27%)	Not reported	Quality 11/15 LoE 2b
Dawadi *et al* (2020)[24]	Retrospective descriptive	Medical encounters	Nepal: Manaslu trail race: 7 day stage race: 212 km High altitude	100 2014: 34 2015: 26 2016: 40	Not reported	Men: n=60 (60%) women: n=40 (40%)	Not reported	Quality 12/15 LoE 4
Garcia-Malinis *et al* (2020)[34]	Cross-sectional	Self-reported questionnaires	Spain: Ultra-trail race (GranTrail Aneto-Posets) 105 km	657	39.7±7.9	Men: n=474 (72.1%) women: n=183 (27.9%)	Not reported	Quality 10/15 LoE 2b
Gonzales-Lazaro *et al* (2021)[11]	Retrospective cohort study	Self-reported participant form recording injuries sustained during the race.	Spain: mountain races (n=36) Mean distance: 28±6 km (95% CI, 26 to 30). Mean accumulative elevation change: 3497±717 m (3254–3740). Minimum temperature: 7°C±5°C (5–9). Maximum temperature: 23°C±7°C (20–25)	4831	40±7 (18–72)	Men: 91% women: 9%	Not reported	Quality 9/15 LoE 4
Graham *et al* (2012)[6]	Observational	Injuries clinically diagnosed (daily recorded via a standardised injury reporting form).	New Zealand: 2009 Gobi Challenge, 7 stage desert race ultramarathon with a total of 150 miles (240 km).	11 one below knee amputee	33±11 Amputee age: 43	Men: n=11 (100%) women: n=0 (0%)	24±1.8 Amputee: 25	Quality 8/15 LoE 2b
Graham *et al* (2021)[25]	Prospective cohort	Medical encounters recorded over 3 days during the race.	Yukon, Canada: 6633 Ultra: 120 miles (192 km) ran over 3 days; Minimum temperature: −20°C	12	42±5.4 years.	Men: n=9 (75%) women: n=3 (25%)	Not reported	Quality 11/15 LoE 2b
Hoffman and Stuempfle (2015)[27]	Observational	Self-reported symptoms of muscle cramping recorded with online questionnaire post-race.	USA, California: 2014 Western States Endurance Run 161 km (100 miles)	280	Not reported	Not reported	Not reported	Quality 13/15 LoE 2b
Krabak *et al* (2011)[7]	Observational	Medical encounters: data recorded daily over a 7 day period, during each race at a medical checkpoint (every 10 km and finish line)	4 Ultramarathons (240 km) (7 day stage race) Gobi Desert, China: 2005 and 2006 Sahara Desert, Egypt: 2005 Atacama Desert, Chile: 2006	396	40 (±10.6) (18-64)	Men: n=314 (79.2%) women: n=82 (20.8%)	23.9±3.5	Quality 12/15 LoE 2b
McGowan and Hoffman (2015)[29]	Observational	Race-day medical encounters. Data collected at the 2010–2013 races. 2010–2011: data collected only at the race finish line. Medical encounters: 2012–2013: data collected at all the race medical stations.	USA, California: Western States Endurance Run 161 km (100 miles) 5500 m ascent, 7000 m descent Maximum altitude: 2667 m; temperatures (min–max): 2010: 3°C–33°C; 2011: 0°C–28°C; 2012: 9°C–22°C; 2013: 5°C–39°C 30 hours cut of time, 24 aid stations	1563	2010: 43±10 (18-75); 2011: 43±10 (22-74); 2012: 42±10 (23-77); 2013: 42±10 (22-70)	2010— men: n=337 (79.7%) 2011— men: n=305 (81.3%) 2012 Males: n=313 (81.9%) 2013— men: n=306 (79.9%)	Not reported	Quality 8/15 LoE 2b
Scheer and Murray (2011)[30]	Prospective observational	Clinical encounters; data were recorded on a standard form	Spain: 2010 Al Andalus Ultra Trail Ultramarathon 5 day stage race (219 km)	69	Males: 46 (27-63) Females: 40 (25–50)	Men: n=48 (70%); women: n=21 (30%)	Not reported	Quality 10/15 LoE 4
Scheer *et al* (2014)[31]	Prospective observational	Data collected after each stage race through a direct interview technique using a standardised questionnaire on blisters	Spain: 2010 & 2011: Al Andalus Ultra Trail Ultramarathon 5 day stage race (219 km) Temperature: 32°C–40°C Humidity:32%–40%.	50	Men: 40.4±8.3 Women: 40.4±7.5	Men: n=30 (60%) women: n=20 (40%)	Males: 24.5±1.9; Females: 21.3±2.2	Quality 12/15 LoE 2b
Vernillo *et al* (2016)[32]	Cross-sectional	Medical encounter: data recorded at the end of the race.	Trento, Italy: Vigolana Trail Run (65 km)	77	43.6 (±10.9)	Men: n=64 (83%); women: n=13 (17%)	Not reported	Quality 11/15 LoE 4

LoE, level of evidence; MSUM, multistage ultramarathon.

Table 2 Characteristics of the six studies that included training/race-related injury outcomes

Author(s) and publication year	Study design	Data collection	Setting	Number of participants (n)	Age (years)	Sex	BMI (kg/m²)	Quality and LoE
Babi *et al* (2018)[21]	Retrospective cross-sectional	Questionnaire examining five psychological dimensions. Data collected at a race. Retrospectively inquired on an injury during the past 3 years	Spain: Cros de Muntanya Can Caralleu (7.5 km and 15 km); Borredà-Xtrail (11 km, 28 km and 44 km); Zurich Marató de Barcelona (42 km)	237 (Includes 45 from a non-trail race)	38.4±8.4 (17–60)	Men: n=183 (77.2%) Women: n=54 (22.8%)	N/A	Quality 8/15 LoE 2b
Malliaropoulos *et al* (2015)[8]	Cross-sectional	Self-reported injury questionnaire completed with the help of a physiotherapist	Greece: training/racing	40	38.4±8.7	Men: n=36 (90.0%) Women: n=4 (10.0%)	23.4±2.0	Quality 10/15 LoE 2b
Hespanhol Junior *et al* (2017)[26]	Prospective cohort	The Dutch version of the OSTRC Questionnaire on Health Problems was used to collect self-reported injury and illness data biweekly over 6 months	Netherlands: training/racing	228	All participants: 43.4 (95% CI: 42.2 to44.6) Men: 43.8 (42.4–45.2) Women: 42.4 (39.9 to 44.8)	Men: n=171 (75%) Women: n=57 (25%)	All: 22.6 (95% CI[b]: 22.3 to 22.8) Men: 23.0 (22.7 to 23.3) Women: 21.3 (20.9–21.8)	Quality 9/15 LoE 2b
Matos *et al* (2020) A[9]	Retrospective cross-sectional	Self-reported injury: data collected via an online questionnaire during the previous 12 months (related to the year 2017)	Portugal: training/racing recreational runners	719	38.0±7.8	Men: n=529 (74%) Women: n=190 (26%)	Not reported	Quality 9/15 LoE 2b
Matos *et al* (2020) B[28]	Prospective cohort	Self-reported injury questionnaire. Workload-related data collected daily via GPS	Portugal: training towards 2018/2019 Portuguese trail running championships	25	36.23±8.30	Men: n=25 (100%) Women: n=0 (0%)	Not reported	Quality 12/15 LoE 1b
Viljoen *et al* (2021)[33]	Retrospective cross-sectional	Self-reported injury questionnaire completed 2 weeks prior to race participation. Injury recorded retrospectively.	South Africa: Training toward SkyRun races (38 km, 65 km, 100 km)	305	All: 38.3 (95% CI: 37.4 to 39.2) Men: 38.7 (37.6 to 39.8) Women: 37.3 (35.7 to 38.8)	Men: n=213 (69.8%) Women: n=92 (30.2%)	All: 23.9 (95% CI: 23.6 to 24.2) Men: 22.2 (21.7 to 22.6) Women: 24.6 (24.3 to 25.0)	Quality 12/15 LoE 2b

GPS, global positioning system; LoE, level of evidence; OSTRC, Oslo Sports Trauma Research Centre.

Africa,[7] South America[7] and Oceania[6] were included). Six studies included training-related injury outcomes[8 9 21 26 28 33] (table 2).

The majority (n=10) of race participation studies used injury definitions related to medical encounters (injuries requiring medical attention during a race)[7 22–25 29 30 32] or clinical assessments (routine assessment of all participants during the study).[6 31] All studies that included training exposure used self-reported injury data.[8 9 21 26 28 33] Injury risk factors were investigated among 2 785 participants in a total of 10 studies,[7–9 21 23 27 28 31 33 34] of which five focused on *race participation*[7 23 27 31 34] and five on training/race participation.[8 9 21 28 33]

Five studies collected data cross-sectionally[11 23 29 32 34] in race participation, and 10 studies recorded data prospectively with short follow-up periods (duration of the race).[6 7 22–25 27 29–31] Two studies collected data both prospectively and cross-sectionally at the different races under investigation.[23 29] Studies that included training exposure mainly collected data cross-sectionally[8 9 21] with only two studies following prospective study designs with long-term follow-up periods.[26 28]

This review included 9 763 participants, of which 80.6% (n=7871) were men and 15.8% (n=1542) were women. No sex classification was reported for 3.6% (n=350) of participants. Participants' mean age ranged between 33 and 46 years (age range 17–72 years), and mean BMI ranged between 21.3 kg/m^2 and 24.5 kg/m^2.

Quality assessment and LoE

The mean score following the quality assessment of all studies was 10/15 (range 5–12) (tables 1 and 2). Prior to consensus, the observed agreement for interrater reliability was 82.5% (Cohen's kappa=0.60). Items 11 and 12 that relate to the studies' external validity, and item 27 that assessed the power of each study, most frequently scored 0 ('no' or 'unable to determine'). The individual item scores for each study are presented in online supplemental appendix 3. The OCEBM LoE[36] was rated as 2b in 13 studies,[6–8 21 23 25–29 31 33 34] 4 in 5 studies,[11 22 24 30 32] and 1b in 1 study (tables 1 and 2).[28] Prior to consensus, the observed agreement for inter-rater reliability was 89.5% (Cohen's kappa=0.75).

Trail running injury risk factors

A summary of significant and non-significant factors associated with either a higher or lower risk for injury among trail runners is presented in table 3. Among the 10 studies that investigated injury risk factors,[7–9 21 23 27 28 31 33 34] five studies used cross-sectional data[8 9 21 33 34] and three studies collected data prospectively with short follow-up periods (duration of the race).[7 27 31] Only one study used data collected in a prospective cohort study with a long follow-up period (52 weeks).[28] Four *race participation* studies[23 27 31 34] focused on injury risk factors related to specific pathologies types only, namely muscle cramps[27] and dermatological injuries.[23 31 34] The most common injury risk factors investigated were age,[7 27 33 34] running experience (all running,[8 33] trail running[33] and ultramarathon),[27 31] sex,[7 27 33] total weekly running distance,[8 27 33] BMI,[8 33] and running frequency (all running: days per week[8 33] and sessions per day[8]; trail running: days per week).[33]

There is level 2 evidence showing that neglecting a warm-up before running ($r=3.37$ $p<0.001$)[9] not using a specialised running plan ($p=0.0995$),[8] regular training on asphalt ($p=0.0004$),[8] double training sessions per day ($p=0.06$, hip joint specific),[8] higher running experience (>6 years) ($p=0.001$),[8] level A runner ($p=0.067$),[8] higher total propensity to sports accident questionnaire (PAD-22) score (sensation seeking, assumption of risk, perceived competence, perception of risk and competitiveness) ($p<0.01$)[21] and physical labour occupations ($p=0.058$)[8] are associated with significantly higher injury risk.

Specifically for sunburn, more than 3 hours of training per day (OR: 1.01, 95% CI 1.00 to 1.01, $p=0.048$), using shade as primary mode of sun protection (OR: 1.42, 95% CI 1.00 to 2.01, $p=0.048$), younger age (OR: 0.98: 95% CI: 0.97 to 0.99,

Table 3 Summary of significant and non-significant factors associated with injury risk by the number of studies, quality and level of evidence

Level of evidence		2b				2b	1b	
		Higher injury risk (n; quality of evidence rating)		Lower injury risk (n; quality of evidence rating)		Non-significant: direction of the association is unknown (n; quality of evidence rating)		Total studies (n)
	Injury risk factors	SIG*	Non-SIG†	SIG*	Non-SIG†			
Intrinsic	Age (younger)‡	1 (10)[34]						1
	Prior history cramping in a race§	1 (13)[27]						1
	Higher post-race blood creatine kinase (UI/L)§	1 (13)[27]						1
	Higher post-race blood urea nitrogen (mg/dL)§	1 (13)[27]						1
	Higher total PAD-22 score¶	1 (8)[21]						1
	Low phototypes (I and II)‡	1 (10)[34]						1
	Level A runner**	1 (10)[8]						1
	Higher experienced runner††	1 (10)[8]				1 (12)[33]		2
	Higher post-race blood creatinine (mg/dL)§		1 (13)[27]					1
	Lower post-race serum sodium (mmol/L)§		1 (13)[27]					1
	Less ultramarathon running experience§		1 (13)[27]					1
	Higher weight loss during a race§		1 (13)[27]					1
	Age§		1 (13)[27]			1 (12)[33]		3
	Age (older)			1 (12)[7]				
	More ultramarathon running experience‡‡			1 (12)[31]				1
	Trail running experience					1 (12)[33]		1
	Sex					3 (12–13)[7 27 33]		3
	BMI§§					2 (10–12)[8 33]		2
	Knowledge on photoprotection‡					1 (10)[34]		1
	Previous history of sunburn‡					1 (10)[34]		1
Extrinsic	No warm-up before running	1 (9)[9]						1
	Not using a specialised running plan	1 (10)[8]						1
	Training on asphalt¶¶	1 (10)[8]						1
	≥2 training sessions per day	1 (10)[8]						1
	≥3 hour training per day‡	1 (10)[34]						1
	Use of shade as sun protector‡	1 (10)[34]						1
	Slower race finishing time§	1 (13)[27]						1
	Marital status: single‡	1 (10)[34]						1
	Physical labour occupations	1 (10)[8]						1
	Less weekly running distance§		1 (13)[27]					1
	Fewer prior 161 km race finish§		1 (13)[27]					1
	Slower sodium intake rate (mg/h) during a race§		1 (13)[27]					1
	Use of sunscreen (SPF>15)‡			1 (10)[34]				1
	Finding shade at noon‡			1 (10)[34]				1
	Higher running exposure (time)			1 (9)[9]				1
	Type of stretching routine before running					1 (10)[8]		1
	Total weekly running distance					2 (10–12)[8 33]		2
	Running frequency per week					2 (10–12)[8 33]		2
	Trail running frequency per week					1 (12)[33]		1
	Running speed					1 (10)[8]		1
	Total weekly vertical gain during training					1 (12)[33]		1
	Type of running shoe					1 (10)[8]		1
	Prophylactic measures for blisters‡‡***					1 (12)[31]		1
	Alcohol use					1 (10)[8]		1
	Smoking					1 (10)[8]		1
	Previous highest running distance per week§					1 (13)[27]		1
	Previous longest furthest single run§					1 (13)[27]		1
	Prior unsuccessful 161 km race attempts§					1 (13)[27]		1
	Variations in training workload indices						1 (12)[28]	1

*Statistically significant.
†Not statistically significant.
‡Related to sunburn only.
§Related to muscle cramping only.
¶Focus on five psychological factors, namely: sensation seeking, assumption of risk, perceived competence, perception of risk and competitiveness.
**Mathematical algorithm to classify runners based on the difficulty level of previous races, performance, sex and age.
††Significant injury risk shown for>6 years.
‡‡Related to blisters only.
§§Body mass index.
¶¶Versus tartan or mountain surfaces.
***Type/fabric of socks, antiperspirants, talcum powder, lubricant to feet and prophylactic taping.
SIG, Significant; SPF, Sun protection factor.

p<0.001), low skin phototypes (I and II) (OR: 2.06, 95% CI 1.35 to 3.14, p=0.001) and single relationship status (OR: 1.66, 95% CI 1.45 to 2.41, p=0.007) are associated with a significant higher sunburn risk.[34]

A prior history of cramping (p<0.0001), higher levels for both postrace blood urea nitrogen (mg/dL) (p<0.05) and creatine kinase (IU/L) (p<0.001) and a slower race finishing time (p=0.048) were associated with a significantly higher risk for muscle cramping during a race.[27]

Level 2 evidence showed that a significant lower risk for injury was associated with higher running exposure time (r=−0.344, p<0.001),[9] a 10-year increase in age (adjusted for sex and race hours) is associated with: 0.2 fewer (95% CI −0.3 to −0.1) musculoskeletal (MSK) injuries and 0.4 fewer (95% CI: −0.6 to −0.1) skin disorders.[7] Sunscreen use (sun protection factor (SPF) >15) (OR: 1.59, 95% CI 1.05 to 2.41, p=0.027) and being in shade at noon (OR 1.83, 95% CI 1.14 to 2.96, p=0.013) were associated with a lower risk for sunburn.[34] Previous ultramarathon experience (r=−0.44, p<0.05) was associated with a lower risk for blisters.[31]

There is consistent evidence that suggests that running distance,[8 27 33] running frequency per week,[8 33] age,[7 27 33] sex[7 27 33] and BMI[8 33] are not associated with injury risk in trail running.

Epidemiology of injury

Among the 19 included studies, eight (42.1%) reported the incidence of injury,[7 9 11 24 26 30 32 33] 11 (57.9%) reported on the prevalence of injury,[8 9 23–28 31 33 34] while 18 (94.7%)[6–9 11 22–34] reported on the clinical characteristics of injury (online supplemental appendix 4).

Incidence and prevalence of injury

The overall reported incidence ranges were; 0.7–61.2 injuries/1000 hours of running,[7 33] 5.9–2762.1 injuries/1000 runners,[7 11] and only one reported the incidence/1000 km ran as 1.2[24] (online supplemental appendix 4). The overall injury prevalence range was 1.3%–90% (online supplemental appendix 4).[8 33]

Anatomical region and body area

Across all 18 studies that reported on the clinical characteristics of injury,[6–9 11 22–34] injuries of the lower limb were reported by 15 (83.3%) studies,[6–9 11 22–27 30–33] trunk injuries by 8 (44.4%)[7–9 11 25–27 33] and upper limb injuries by 6 (33.3%)[7 11 22 26 27 33] (table 4). The body regions most commonly reported on in all 18 studies[6–9 11 22–34] included the foot/toe (n=10, 55.6%),[6 8 9 11 22 23 26 31–33] ankle (n=9, 50.0%)[7 9 11 22 24–26 32 33] and hip/groin (n=9, 50.0%)[7–9 22 25–27 30 33] (table 4).

Tissue type and pathology type

Among the 18 studies that reported on clinical characteristics of injury,[6–9 11 22–34] superficial tissue/skin injuries were noted in 13 (72.2%) studies,[1 6 9 22–26 28 31–34] muscle/tendon injuries in 8 (44.4%) studies[8 9 22 26 27 29 32 33] and ligament/joint capsule injuries in 7 (38.9%) studies.[9 22 24 26 29 32 33] The specific injuries mostly included blisters (50.0%),[6 22–26 30–32] joint sprains (44.4%)[8 9 22 24 26 29 32 33] and tendinopathies (38.9%)[8 9 22 26 29 32 33] (table 5). Severe injuries in trail running include bone fractures[9 33] and concussions reported in two (11.1%) studies each.[29 33] Also, a dislocated metacarpophalangeal joint,[22] frost injury,[25] joint subluxation[9] and tendon rupture[33] were reported in one (5.6%) study each.

DISCUSSION

In this living systematic review, we identified intrinsic factors including higher running experience,[8] being a level A runner,[8] having a higher total PAD-22 questionnaire score[21] and extrinsic factors including neglecting a warm-up,[9] not using a specialised running plan,[8] regular training on asphalt,[8] double training sessions per day[8] and physical labour occupations[8] that are associated with significantly higher injury risk in trail running. A

Table 4 Summary of the number of studies (n) reporting injury variables regarding anatomical region and body area

				Race-related studies (n=13)		
Anatomical region	**Body area**	**All studies (n=19)**	**Training-related studies (n=6)**	**Sub-marathon* (n=1)**	**Marathon† (n=2)**	**Ultramarathon‡ (n=11)**
Head and neck		5[7 9 22 32 33]	2[9 33]	–	1[22]	2[7 32]
	Head	3[9 22 33]	2[9 33]	–	1[22]	–
	Neck	2[9 32]	1[9]	–	–	1[32]
Upper Limb		6[7 11 22 26 27 33]	2[26 33]	1[11]	2[11 22]	2[7 27]
	Shoulder	1[33]	1[33]	–	–	–
	Upper arm	1[27]	–	–	–	1[27]
	Forearm	1[27]	–	–	–	1[27]
	Wrist	2[26 33]	1[26]	–	–	–
	Hand	3[22 27 33]	1[33]	–	1[22]	1[27]
Trunk		8[7–9 11 25–27 33]	4[8 9 26 33]	1[11]	1[11]	3[7 25 27]
	Chest	3[9 26 33]	3[9 26 33]	–	–	–
	Thoracic spine	1[7]	–	–	–	1[7]
	Lumbosacral	4[8 9 26 33]	4[8 9 26 33]	–	–	–
Lower limb		15[6–9 11 22–27 30–33]	4[8 9 26 33]	1[11]	2[11 22]	9[6 7 23–25 27 30–32]
	Hip/groin	9[7–9 22 25–27 30 33]	4[8 9 26 33]	–	1[22]	4[7 25 27 30]
	Thigh	6[8 9 26 27 32 33]	4[8 9 26 33]	–	–	2[27 32]
	Knee	7[8 9 11 25 26 32 33]	4[8 9 26 33]	–	–	2[25 32]
	Lower leg	8[6 8 9 25–27 30 33]	4[8 9 26 33]	–	–	4[6 25 27 30]
	Ankle	9[7 9 11 22 24–26 32 33]	3[9 26 33]	–	1[22]	4[23 25 30 32]
	Foot/toe	10[6 8 9 11 22 23 26 31–33]	4[8 9 26 33]	–	1[22]	4[6 23 31 32]

*< 42.2 km.
†42.2 km.
‡>42.2 km.

Table 5 Summary of the number of studies (n) reporting injury variables regarding tissue and pathology type

				Race-related studies (n=13)		
Tissue type	Pathology type	All studies (n=19)	Training-related studies (n=6)	Sub-marathon* (n=1)	Marathon† (n=2)	Ultramarathon‡ (n=11)
Muscle/tendon		8[8 9 22 26 27 29 32 33]	4[8 9 26 33]	–	1[22]	3[27 29 32]
	Muscle injury	5[8 9 26 29 33]	4[8 9 26 33]	–	–	1[29]
	Muscle cramping	3[27 29 32]	–	–	–	3[27 29 32]
	Tendinopathy	7[8 9 22 26 29 32 33]	4[8 9 26 33]	–	1[22]	2[29 32]
	Tendon rupture	1[33]	1[33]	–	–	–
Nervous		4[8 26 29 33]	3[8 26 33]	–	–	1[29]
	Brain/concussion or spinal cord injury	2[29 33]	1[33]	–	–	1[29]
	Peripheral nerve injury	2[8 33]	2[8 33]	–	–	–
Bone		4[8 9 26 33]	4[8 9 26 33]	–	–	–
	Fracture	2[9 33]	2[9 33]	–	–	–
	Bone stress injury	3[8 9 33]	3[8 9 33]	–	–	–
Cartilage/synovium/bursa		4[8 22 26 33]	3[8 26 33]	–	1[22]	–
	Cartilage injury	2[8 33]	2[8 33]	–	–	–
	Synovitis/capsulitis	1[33]	1[33]	–	–	–
	Bursitis	2[22 33]	1[33]	–	1[22]	–
Ligament/joint capsule		7[9 22 24 26 29 32 33]	3[9 26 33]	–	1[22]	3[24 29 32]
	Joint sprain (ligament tear/acute instability episode)	8[8 9 22 24 26 29 32 33]	4[8 9 26 33]	–	1[22]	3[24 29 32]
	Chronic instability	1[9]	1[9]	–	–	–
Superficial tissues/skin		13[6 9 22–26 28 30–34]	4[9 26 28 33]	–	1[22]	8[6 23–25 30–32 34]
	Laceration	4[22 24 32 33]	1[33]	–	1[22]	2[24 32]
	Abrasion	6[6 9 23–25 29]	1[9]	–	–	5[6 23–25 29]
	Blisters	9[6 22–26 30–32]	1[26]	–	1[22]	7[6 23–25 30–32]
	Contusion (superficial)	2[9 29]	1[9]	–	–	1[29]
	Haematoma	2[23 32]	–	–	–	2[23 32]
	Frost injury	1[25]	–	–	–	1[25]
	Chafing	4[9 23 30 32]	1[9]	–	–	3[23 30 32]
	Sunburn	3[23 24 34]	–	–	–	3[23 24 34]

*<42.2 km.
†42.2 km.
‡>42.2 km.

significantly higher risk of sunburn was associated with intrinsic factors of younger age and low skin phototypes, and external factors of more than 3 hours of training per day, using shade as the primary mode of sun protection and single relationship status.[34] In addition, prior history of cramping, and higher levels of postrace blood urea nitrogen and creatine kinase were intrinsic factors associated with a significantly higher risk for muscle cramping during a race.[27] A slower race finishing time was reported as an intrinsic risk factor associated with a significantly higher risk for muscle cramping.[27]

The injury incidence ranges from 0.7 injuries/1000 hours to 61.2 injuries/1000 hours of running and 5.9 injuries/1000 hours to 2762.1 injuries/1000 runners, while prevalence of injury ranges between 1.3% and 90%. The clinical characteristics most commonly reported include: anatomical region (lower limb, trunk, upper limb), body area (foot/toe, ankle, hip/groin), tissue type (superficial tissue/skin, muscle/tendon, ligament/joint capsule) and pathology type (blisters, joint sprains, tendinopathies).

The higher number of injury-related studies included in this living systematic review (n=19), compared with a previous systematic review (n=11)[5] testifies of an emerging body of evidence pertaining to trail running injuries.

Significant injury risk factors in trail running

Having no previous running experience has moderate-quality evidence for being an associated injury risk factor in non-specific running-related injuries.[14] However, increased running experience was reported as a significant intrinsic injury risk factor in trail running.[8] In contrast, Scheer *et al* reported that increased ultramarathon running experience had a significantly lower risk for dermatological injuries among trail runners,[31] while running experience (road and trail) was not associated with injury among South African trail runners.[33] The inconsistent evidence in trail running literature could be attributed to the variance in data collection methods (retrospective cross-sectional,[8 33] prospective with short follow-up period)[31] injury definitions (self-reported,[8 33] clinical assessment of blisters)[31] and pure race[31] versus race/training participation.[8 33] Extrinsic factors, such as not using a specialised running plan, regular training on asphalt, double training sessions per day, physical labour occupations and an intrinsic factor of being a level A runner, were reported as significantly associated with injury risk among Greek trail runners.[8] No other studies have investigated these factors' association with injury in trail running. Considering the small sample size (n=40), self-reported injury data, potential recall bias and retrospective cross-sectional study design, further investigation of these factors' association with injury is needed before generalisations to the global trail running community are made.

In agreement with various sports where the efficacy of neuromuscular warm-up strategies in lower limb injury prevention is seen,[37] neglecting warm-up before running was an extrinsic factor associated with a significantly higher injury risk among Portuguese runners.[9] However, for effective translation of these findings into clinical practice, clear details of these warm-up strategies should be disclosed.

One study analysed psychological dimensions' association with injury using the PAD-22 questionnaire.[21] None of the individual psychological dimensions were significantly associated with injury; however, a higher total PAD-22 questionnaire score (sensation seeking, assumption of risk, perceived competence, perception of risk and competitiveness) was significantly associated with injury.[21] This finding should be extrapolated with caution considering the retrospective cross-sectional study design, predominantly male sample, specific Spanish population and low quality of the study's evidence.[21] Nevertheless, these psychological dimensions have previously been shown to be associated with injury in other sports[38–40] and warrant further investigation into higher risk-taking behaviours among trail runners.

Hoffman and Steumplfe reported that intrinsic factors of a prior history of cramping, postrace muscle damage (higher blood urea nitrogen and creatine kinase) and an extrinsic factor of slower race finishing time were significantly associated with muscle cramping in a 161 km trail running event.[27] Similar results with regards to the previous history of muscle cramping and elevated biomarkers of muscle damage were reported among ultramarathon road runners.[27,41] However, a faster running time in road running (56 km)[41] was a significant injury risk factor for muscle cramping, compared with a slower time in trail running (161 km).[27] Progressive muscle fatigue heightens the risk for muscle cramping;[42] therefore, the contrasting finding could possibly be attributed to increased muscle fatigue, resulting from different running surfaces (road vs trail), vertical gain/loss differences, longer race distances (161 km vs 56 km) and duration of the Western States Endurance Run[27] versus the Two Oceans Marathon.[41] Muscle cramping is multifactorial in nature[43] and needs to be investigated in trail running-specific settings as the current findings cannot be generalised to specific race participation within the global trail running population.

Two studies analysed risk factors specifically related to dermatological injuries.[31,34] Only one study reported significant associations for factors related to sunburn specifically.[34] Trail running is an outdoor sport[1] where the duration of sun exposure could vary substantially, depending on the race distance and time of day. Garcia-Malinis *et al* reported multiple sunburn risk factors in trail running and highlighted how extrinsic factors such as sunscreen use and avoiding sun exposure at noon are associated with a significantly lower sunburn risk.[34] The acute skin effects of sunburn[44] can result in pain and discomfort during trail running participation, but of larger concern is the risk of developing skin cancer due to long-term and severe sun exposure.[45]

Since most of the reported associated injury risk factors were determined using univariate analyses in cross-sectional study designs, we are cautious of elaborating on the clinical implications of these factors in the design of risk management strategies. As higher quality studies investigating risk factors over longer periods become available, future review updates will address the implication of modifiable and non-modifiable factors on risk management strategies.

Epidemiology of injury

The findings of this review, regarding the injury incidence/prevalence and clinical characteristics of injury, need to be considered in the context of the various injury definitions used. Race participation studies mainly reported on medical encounters.[7,22–25,29,30,32] This could result in underestimating injury as not all race participants will report their injuries to event medical staff.[46] In contrast, all training exposure studies used self-reported injury data.[8,9,21,26,28,33] Even though self-reported injury allows for a broader range of injuries to be included,[20] the accuracy of data could be affected by recall bias and participant's limited understanding of pathology during self-diagnosis.

Incidence and prevalence

Studies included in this review showed a wide injury incidence range, especially a high upper limit (0.7 to 61.2 injuries/1000 hours running) compared with other running literature (weighted injury incidence: 7.7 injuries/1000 hours to 17.8 injuries/1000 hours running).[47] A similar wide injury prevalence range was reported of 1.3%–90%. A high incidence and lowest prevalence of injury were reported among South African trail runners during a medical screening process 2 weeks before a high altitude mountain ultramarathon.[33] The high incidence of injury could be due to the high training loads involved in preparation for the race. These results need to be interpreted in context of the retrospective cross-sectional study design used to collect data dating back 12 months before the race and potential recall bias involved in self-reported injury data.[33] Runners' fears for being medically disqualified before the race[33] may also have contributed to the lower reported injury prevalence. Only two trail running studies used prospective study designs to collect data over longer periods and reported injury incidence (10.7 injuries/1000 hours running)[26] and prevalence values (22.4%–52%)[26,28] concurring with other running literature.[13,47]

Clinical characteristics

The lower limb is still the most commonly reported anatomical region of injury in trail running literature (83.3% of studies) and is in agreement with a previous review.[5] Notably, a growing number of studies indicated that the trunk,[7–9,11,25–27,33] upper limb[7,11,22,26,27,33] and head/neck[7,9,22,32,33] are injured anatomical regions. Although less frequent, clinicians need to consider injuries such as finger joint dislocations,[22] upper limb/hand lacerations,[22] lumbar/cervical spine strains[7–9,26] and concussions[29,33] during planning for optimal medical provision.

The foot/toe was previously and is currently still reported as the most common body region of injury across all trail running studies.[5] This finding may be supported by the fact that the most common injured tissue type reported was skin, specifically blistering resulting from footwear due to cyclic shearing forces typically experienced during ultramarathons.[48] Our review also included a high number of studies investigating race-related injury outcomes related to ultramarathon distances[6,7,23–25,27,29–32,34] and one study investigated foot blisters specifically.[31]

In this review, the ankle is more commonly reported across trail running injury studies as opposed to the knee.[5] The commonly occurring acute ankle sprains[26,32] due to variation of uneven running surfaces synonymous with trail running could explain this discrepancy/change in finding. This finding is further supported by ligament/joint capsule and joint sprains being among the top three most commonly reported tissue and pathology types reported among all included studies.

Clinical implications

The clinical implications of this review are restricted by the limited research and poor quality of available evidence in the field. In the absence of quality research evidence, a proposed solution is to make use of clinical practice guidelines or expert opinion to guide clinical decision-making.[49] The only clinical practice guidelines on reducing the risk for health problems in trail running focused on medical support at ultra-endurance races in remote regions.[10] The authors mainly addressed guidelines for primary medical care at races but also highlighted the importance of risk reduction strategies such as prerace runner education, prerace medical screening and considerations for cancelling races in the presence of extreme environmental conditions (floods, fire, heavy snow or rainfall).[10] Clear guidance on what runners should be educated on, or the specific factors to consider during prerace medical screening are unclear. As this living systematic review matures, we expect to provide the clinician with evidence-based guidance on injury risk factors to consider during runner education and medical screening either prerace or during training.

Limitations

Studies included in this review had a relatively low mean quality score (66.7%). This is attributed to the lack of sample size calculations, which negatively affected the power of included studies. In the majority of studies, the external validity was threatened due to uncertainty regarding whether participants were recruited from a representative population.

Significant injury risk factors are mainly reported in individual studies and not replicated across various settings. The majority of studies used univariate analyses to investigate risk factors' association with injury. It is unlikely that the injury risk in trail running can only be assigned to a single factor, which further ignores the complex interaction between different factors involved in sports injuries.[50] Not all injury risk areas have yet been studied. Multiple studies did not state the direction of the association for non-significant injury risk factors.[7 8 27 28 31 33 34] Some factors might still have clinical relevance despite not meeting the required alpha-level for statistical significance. The majority (80.8%) of participants were men, and risk factors associated with specific injuries among [51]women have not been investigated.

Mainly *race participation studies*[6 7 11 22–25 27 29–32 34] were included in this review, which largely focused on ultramarathons.[6 7 23–25 27 29–32 34] This may have skewed the findings of the foot as the most commonly injured body region and superficial skin as the most commonly reported injured tissue type most likely stemmed from shoe blister formation. Furthermore, one study only reported on injury outcomes related to blisters of the feet.[31] All *training/race participation* studies used self-reported injury data,[8 9 21 26 28 33] subjected to recall bias. Not all studies gave clear indications of the frequencies of injuries under the categories within clinical characteristics.

Recommendations

Higher quality studies are required to further investigate the significance of the current injury risk factors available in the literature. More risk factors also need to be investigated as pointed out in a recent position statement.[1] These include race setting, distance, elevation changes, min/max temperatures, humidity and running surfaces.[1] To address current insufficient power among trail running studies, researchers are encouraged to report sample size calculations where appropriate. Prospective cohort studies with longer follow-up periods are needed to investigate the temporality of risk factors associated with injury. The casual nature of these factors should be investigated in randomised controlled trials. Multivariate risk factor analyses should be used where applicable to account for the interaction of different factors in sports-related injuries. Attempts to account for the complexity of trail running injury require moving away from discrete risk factor identification and towards risk pattern recognition.[50] Investigation into the current known significant injury risk factors is needed to evaluate whether these results can be reproduced and are applicable among different trail running populations. Risk factors among shorter distance trail races and female runners should also be investigated.

CONCLUSION

There is a dearth of studies investigating injury risk factors in trail running. These studies predominantly focus on the reductionist paradigm, identifying linear relationships of isolated factors associated with injury using univariate analyses. Our review found eight intrinsic and nine extrinsic risk factors associated with injury in trail running. The lower limb is the most commonly injured anatomical region, specifically the foot/toe, ankle and hip/groin. Advances in trail running injury research focused on injury risk factors associated with specific injury profiles will assist in the design and implementation of future injury risk management strategies for safer trail running participation.

What is already known?

- The lower limb is the most commonly injured anatomical region in trail running.
- The foot is the most commonly injured body area.
- There is a lack of literature on the epidemiology of injury among submarathon distance trail runners.

What are the new findings?

- The foot/toe, followed by the ankle, and hip/groin are the most commonly injured body areas.
- Blisters, followed by joint sprains, and tendinopathies are the most common pathology types reported in trail running.
- Mainly univariate analyses were used to identify 17 statistically significant injury risk factors in trail running literature.
- There is a lack of literature on risk factors among female participants.

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Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval This study does not involve human participants.

Provenance and peer review Not commissioned; externally peer reviewed.

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