Epidemiology of injury and illness among trail runners: A systematic review

Short title: Injury and illness among trail runners

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Abstract

Title: Epidemiology of injury and illness among trail runners: A systematic review

Background: Trail running is characterised by large elevation gains/losses and uneven varying running surfaces. Limited information is available on injury and illness among trail runners to help guide injury and illness prevention strategies.

Objective: The primary aim of this review was to describe the epidemiology of injury and illness among trail runners.

Methods: Eight electronic databases were systematically searched (MEDLINE Ovid, PubMed, Scopus, SportsDiscus, CINAHL, Health Source: Nursing/Academic, Health Source: Consumer Ed., and Cochrane) from inception to November 2020. The search was conducted according to the PRISMA statement and the study was registered on PROSPERO international prospective register of systematic reviews (CRD42019135933). Full text English and French studies that investigated injury and/or illness among trail runners participating in training/racing were included. The main outcome measurements included: trail running injury (incidence, prevalence, anatomical site, tissue type, pathology type/specific diagnosis, severity), and illness (incidence, prevalence, symptoms, specific diagnosis, organ system, severity). The methodological quality of the included studies was assessed using an adapted Downs and Black assessment tool.

Results: Sixteen studies with 8644 participants were included. Thirteen studies investigated race-related injury and/or illness and three studies included training-related injuries. The overall incidence range was 1.6-4285.0 injuries per 1000 hours of running and 65.0-6676.6 illnesses per 1000 hours of running. The foot was the most common anatomical site of trail running injury followed by the knee, lower leg, thigh, and ankle. Skin lacerations/abrasions were the most common injury diagnoses followed by skin blisters, muscle strains, muscle cramping, and ligament sprains. The most common trail running illnesses reported were the gastro-intestinal tract (GIT), followed by the metabolic, and cardiovascular systems. Symptoms of nausea and vomiting related to GIT distress and dehydration were commonly reported.

Conclusion: Current trail running literature consists mainly of injury and illness outcomes specifically in relation to single-day race participation events. Limited evidence is available on training-related injury and illness in trail running. Our review showed that injury and illness are common among trail runners, but certain studies included in this review only focused on dermatological injuries (e.g. large number of feet blisters) and GIT symptoms. Specific areas for future research were identified that can improve the management of trail running injury and illness.

Key Points:

- Both overuse and acute running related injuries (RRIs) are common in trail running
- The foot is the most common site of injury among trail runners
- Lacerations/abrasions are the most common diagnoses in trail running
- Illness related to the gastrointestinal tract (GIT) system is most commonly reported among trail runners
- Limited research is available on training-related injury and illness among trail runners and shorter distance trail running events

1. Introduction

Physical activity has established health and well-being benefits.[1, 2] Participation in regular physical activity decreases the risk for premature all-cause mortality, development of chronic disease and is effective in management of a current chronic disease.[1-3] Running is a popular mode of physical activity due to its easily accessible nature, with no need for specialised equipment or requirement of specific facilities.[4, 5] Some evidence suggests that physical activity in outdoor environments have a higher positive impact on mental well-being compared to indoor activity.[6] Trail running involves running outdoors on off-road terrains, often in remote geographical regions and has shown exponential growth in popularity.[7-9] Although running participation has proven health benefits[2] a high risk for injury remains.[10]

The International Trail Running Association (ITRA) defines a trail run as a race run on foot on a clearly marked route, that is usually set in a natural environment and on varying natural terrains such as mountains, deserts, forests or plains, with a maximum of 20% of the total route run on paved road [https://itra.run/content/definition-trail]. Participants preferably had to have completed the route with self-sufficiency or semi self-sufficiency with regards to clothing, communication, and nutrition [https://itra.run/content/definition-trail]. In these settings, trail runners are exposed to environmental hazards, which include: water crossings, extreme weather, insect-borne infections, and wildlife.[11] Due to the logistical challenges of providing medical care in remote regions, distressed runners, who sustain an injury or who suffer from illness, will often receive delayed medical care in comparison to road running events.[11, 12] Inexperienced runners are often unaware of the physical demands and risks involved in trail running, which has resulted in serious injury, illness, and even death.[13]

Previous studies, including systematic reviews, have largely focused on the epidemiology of road running related injury (RRI) outcomes.[5, 10, 14-18] The application of these results to trail running seems problematic due to the nature of trail running that requires a specific endurance effort affected by large elevation gains/losses, environmental conditions, altitude, distance covered, and uneven surfaces.[19] Increased effort is required to constantly adapt to the changing running surface, resulting in the body being exposed to increased physiological and biomechanical stress.[19, 20] The uneven running surfaces and related risk for ankle sprains,[21] increase the risk for falling and sustaining acute injuries, such as concussions, contusion,[22] and lacerations.[21] The larger volume of eccentric muscle work, especially in downhill running, has further shown to decrease muscle performance and increase muscle damage, compared to running on level surfaces.[23] Therefore, the injury profile and injury risk factors in trail running may differ from road running, justifying special considerations regarding injury and illness among this population.

Considering the environmental factors and large endurance requirements, illness is another risk that trail runners face. Krabak et al. (2011) reported an incidence rate of 2.0 major medical illnesses per

1000 hours of running and 4.5 minor medical illnesses per 1000 hours of running during an off-road multistage ultramarathon.[24] In training for trail running races, training loads will often increase in preparation for the extreme conditions trail runners will face, which subsequently may increase the trail runner's susceptibility to illness.[25] Among road runners, an existing pre-race acute systemic illness was associated with unsuccessful attempts to finish a race.[26] Distressed road runners that cannot further continue with running, can easily be reached by medical staff compared to trail runners participating in remote regions. This justifies the need for clear information specifically on illness among trail runners.

The increasing insight into demand and potential hazards of outdoor sports have highlighted the need to understand how injury and illness present among trail runners. This systematic review aimed to describe the epidemiology of injury and illness in trail runners. Insight to these issues at hand will guide future research by building baseline data and will inform the development of interventions regarding the management of injury and illness risk among this specific mode of running.

2. Methods

2.1. Data sources and search

In this systematic review, we identified eight electronic databases relevant to our research topic and performed a search from inception to November 2020. The databases searched included MEDLINE Ovid, PubMed, Scopus, SportsDiscus, CINAHL (Cumulative Index to Nursing and Allied Health Literature), Health Source: Nursing/Academic, Health Source: Consumer Ed., and Cochrane. The search was done according to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) statement[27] and the study was registered on PROSPERO International prospective register of systematic reviews (CRD42019135933).

Two groups of keywords were used. The first group included all the different terminologies and variations of the trail running activity, while the second group included all the different words for epidemiology, injury, and illness. After using the OR operator in each group to retrieve as many articles as possible, the two groups were combined with the AND operator in order to narrow down to the topic, as shown in the online supplementary material (S1). The only limiters used in some of the database searches were restricted to language (English or French), and humans.

After retrieving the articles, duplicates were removed. The remaining records' titles and abstracts were independently reviewed by (CTV) and (EV) to identify relevant studies. Full text of the relevant articles was retrieved and further reviewed for eligibility by (CTV) and (CJVR) to determine the final selection of studies. The references of the selected studies were reviewed to ensure no relevant articles were missed.

2.2. Study selection

Studies were included if they aimed to investigate injury or illness among trail runners, while participating in races or training. Both self-reported injury/illness data and data on medical encounters (ME's) were included in this review as defined by Schwellnus et al.[28] Including self-reported injury/illness data allows reporting on a broader scope of injuries/illnesses as not all runners will report their injury/illness to a medical professional.[29] Subsequently studies investigating biomarkers relating to possible injury or illness in the absence of participants reporting injury or illness were excluded. Participants were recognised as trail runners if they had participated in a race or training that was defined as a trail run according to the definition of the ITRA.[30] Studies were excluded if the running surface did not meet the definition of a trail run according to the ITRA. In cases of uncertainty the race's websites were accessed to determine if a specific study was investigating a trail run. Certain "ultramarathon" studies were excluded if no clear evidence of it being a trail run was available. For training-related studies, the authors had to specify that a sample of trail runners was investigated. No limit was placed on the geographical region of participation, age and the sex of participants or publication date. Case reports, case-series, conference proceedings, editorials, commentaries, opinion-based papers, and reviews were excluded. An Excel spreadsheet was used to keep detailed tracking of the study selection process. No specific systematic review software tools were used during the study selection process.

2.3. Data extraction

Extracted data from the final selection of studies consisted of: study design, year of study, population (sample size, age, sex), race/training distance, study location, aim of the study, injury/illness definition duration/follow-up, injury outcomes (incidence, prevalence, anatomical site, tissue type, specific diagnosis, severity), and illness outcomes (incidence, prevalence, symptoms, specific diagnosis, organ system, severity). Data were extracted by five reviewers: (CTV), (CJVR), (EV), (RT), and (MS). Each reviewer received a random sample of articles from which to extract data. One reviewer (CTV) independently extracted data from all the articles for quality control, while another reviewer (CJVR) did quality control of the sample of studies (CTV) extracted data from.

2.4. Quality evaluation

The level of evidence of all the articles was determined using the Oxford Centre of Evidence Based Medicine (OCEBM) model.[31] The modified Downs and Black Quality Assessment Tool was used to rate the quality of evidence under the categories of reporting, external validity, internal validity –bias, internal validity – confounding (selection bias) and power.[32] The Downs and Black quality assessment tool was modified by removing questions related to interventions done as studies included in this review used observational study designs. The modified Downs and Black quality assessment tool consisted of four sections which assessed the quality of reporting of the results (items 1, 2, 3, 6, 7, 9 and 10), external validity (items 11 and 12), internal validity (16, 17, 18, 20, and 26) and power (item 27). The maximum total score on the tool was 25, with a higher total score indicating a higher quality of evidence for the specific study. The quality and level of evidence were assessed independently by two authors [quality assessment done by (CTV) and (EK), and level of evidence done by (CTV) and (MS)] and the extracted data were summarised for the final selection of articles (online supplementary material S2). Any discrepancies between the two authors were resolved through consensus by all authors.

2.5. Data analysis

Data analysis was in the form of reporting on variables extracted from the included studies. The incidence of injury/illness was reported per 1000 hours of running or per 1000 runners with confidence intervals (90% or 95% CI), while the prevalence or mean prevalence of injury/illness were reported as % of injured/ill runners. The frequency of injury (n, %) was reported for the categories of anatomical site, tissue type, and pathology type/specific diagnosis. The frequency of illness (n, %) was reported for the categories of illness symptoms, organ system involved, and specific diagnosis. For injury/illness severity the frequency (n, %) and mean severity scores were reported. Attempts were made to combine comparable data, however, not all studies reported on all the variables of injury or illness among trail runners. The injury and illness outcomes were grouped by study design and training vs. race participation. Due to the heterogeneous nature of the studies included, a meta-analysis could not be performed.

3. Results

3.1. Identification of studies

The search produced 4830 records, as shown in our PRISMA flow diagram (Figure 1). After all duplicates were removed, 2887 records remained. The titles and abstracts of these records were evaluated according to the eligibility criteria and 2722 records were excluded. The remaining 165 full-text articles were then reviewed, and 16 studies met the inclusion criteria.

INSERT FIGURE 1 HERE

3.2. Study characteristics

The 16 included studies had a publication date range from 1990 – 2020 and are summarised in Table 1. Injury/illness related to race participation were studied in 13 studies[8, 21, 22, 24, 33-41] and four of these studies[22, 24, 35, 41] included data of multiple races. Only three studies[9, 42, 43] included training-related injury outcomes. Studies reported either on *injury and/or illness related outcomes* using different *injury/illness definitions* and *study designs*.

Eleven studies[8, 9, 21, 22, 24, 35-37, 41-43] investigated injury related outcomes and similarly, 11 studies [8, 21, 22, 24, 33-36, 38-40] investigated illness related outcomes. Five of the 16 included studies reported on both injury and illness related outcomes. [21, 22, 24, 35, 36]

Injury/illness definitions mainly consisted of ME's or self-reported injuries. With regards to race participation, five studies investigated ME's [21, 22, 24, 36, 41] and eight studies used questionnaires to collect data on self-reported injuries.[8, 33-35, 37-40] Among the three included training related studies studies[9, 42, 43], both ME's and self-reported injuries were reported on.

Data was mainly collected using cross-sectionally [8, 22, 37, 38, 41, 42] or prospectively with short follow-up periods[21, 24, 33, 34, 36, 39, 40] among race participation studies. One study reported on two different races and collected data both cross-sectionally and prospectively with a short follow-up period.[35] Among the three studies[9, 42, 43] that included training-related injury outcomes, two studies used cross-sectional designs[42, 43] and one study used a prospective cohort study design over a 6-month period[9]). The difference in injury and illness definition and study designs limited our ability to group and compare results.

A total of 8644 participants was studied with an age range of 18-75 years (mean age range of 33-49.9 years). Data on sex was available for 3533 participants. The review included predominantly males (n=2771; 78.4%; versus 762 females; 21.6%).

3.3. Quality assessment and level of evidence

The mean score of the quality assessment was 8/15 (range 5-10). The quality assessment for each study is presented in the online supplementary material (S2). The interrater reliability had an observed agreement of 80%, with a Cohen's kappa value of 0.59. During the quality assessment, item 3 and 9 were most commonly scored as "no", while items 26 and 27 were rated most commonly as "unable to determine". The level of evidence of the 14 included articles were rated as level 2b, using the OCEBM model.[31] The level of evidence rating of each article is presented in Table 1.

Table 1: Characteristics of the 16 included studies

Author and publication date	Investigated Injury/illness	Data collection	Setting	No. of participants	Mean age	Gender	BMI	Level of evidence	Quality assessment
Graham et al. (2012)[36]	Injury and Illness	Prospective: recorded injury and illness data, twice per day over a 7-day period. Only recorded data of participants that required medical attention	Ultramarathon (7-day stage race) in the Gobi desert, China. Total distance of 150 miles (241 km)	11	33 (± 11)	Males: 100% (n=11) Female: 0% (n=0)	24 (± 1.79)	2b	8/15
Krabak et al. (2011)[24]	Injury and Illness	Prospective: Data recorded daily over a 7-day period, during each race. No post-race follow-up	4 Ultramarathons (7-day stage race) in the Gobi Desert, China (2005 & 2006), Sahara Desert, Egypt (2005) and Atacama Desert, Chile (2006). (240 km)	396	40 (±. 10.6) (18-64)	Males: 79.2% (n=314) Female: 20.8% (n=82)	Not reported	2b	10/15
Scheer and Murray (2011)[21]	Injury and Illness	Prospective: Data recorded daily at medical tents during a 5-day ultramarathon stage race. No post-race follow-up	Ultramarathon (5-day stage race) in Spain. Al Andalus Ultratrail	69	Males: 46 (27-63) Females: 40 (25-50)	Males: 70% (n=48) Females 30% (n=21)	Not reported	2b	8/15
McGowan et al. (2015)[22]	Injury and Illness	Race-day medical encounter data recorded by medical staff at aid stations during a 161km race (2010-2013). Observational	Western States Endurance Run, California, United States of America. (161km)	1563	2010: 43 ±10 (18–75), 2011: 43 ±10 (22–74), 2012: 42 ±10 (23–77), 2013: 42 ±10 (22–70)	2010 (total n=423): Males: 79.7% (n=337) 2011 (total n=375): Males 81.3% (n=305) 2012. (total n=382): Males 81.9% (n=313) 2013 (total n=383): Males 79.9% (n=306)	Not reported	2b	9/15
Vernillo et al. (2016)[8]	Injury and Illness	Cross-sectional: Data recorded via a questionnaire at the end of the race. No follow-up	Vigolana Trail Run (65km) in Trento, Italy	77	43.6 (± 10.9)	Males: 83% (n=64) Females: 17% (n=13)	Not reported	2b	9/15
Costa et al. (2016)[35]	Injury and Illness	Data were collected at two races via a questionnaire (self-reported): MSUM*: Prospective: Data recorded over 4 days at the end of each stage. Continuous marathon (24hr): Cross-sectional: Data recorded at the end of the 24-hour race	Data were collected at two races: Al Andalus Ultimate Trail race in Lojo, Spain (2010 & 2011) Glenmore24 Trail Race in the Scottish Highlands (2010 & 2011)	MSUM: 54 24hr: 22	MSUM: 40 (± 8) 24hr: 40 (± 7)	MSUM: Males: 61% (n=33) Females: 39% (n=21) 24hr: Males: 73% (n=16) Females: 27% (n=6)	Not reported	2b	8/15
Hespanhol Junior et al. (2017)[9]	Injury	Prospective: Data recorded every 2 weeks over a 6-month period	Dutch trail runners participating in trail running in the Netherlands	228	43.4 (42.2-44.6)	Males: 75% (n=171) Females: 25% (n=57)	22.6 (22.3-22.8)	2b	10/15

Malliaropoulos et al. (2015)[42]	Injury	Cross-sectional: Data recorded via a questionnaire. No follow-up	Ultratrail runners residing in Greece	40	39.4 (22-59)	Males: 90% (n=36) Females: 10% (n=4)	23.35 (± 1.99)	2b	8/15
Hoffman and Stuempfle (2015)[37]	Injury	Cross-sectional: Data on muscle cramping recorded with online questionnaire post-race. No follow-up.	Western States Endurance Run, California, USA**. (161km)	280	Whole sample not specified	Whole sample not specified	Complete detail of the sample not specified	2b	9/15
González-Lázaro et al. (2020)[41]	Injury	Cross-sectional: Medical encounter injury data recorded via a self-reported participant form. Data were collected over 5-years (2015-2019) at 36 different races. No follow-up.	36 different mountain running races, Spain. (20-42km)	4831	40 (±7)	Males: 91% Females: 9%	Not reported	4	5/15
Matos et al. (2020)[43]	Injury	Cross-sectional: Sel-reported injuries recorded via an online questionnaire. No follow-up.	Portuguese trail runners.	719	38.01 (±7.78)	Males: 74% (n=529) Females 26% (n=190)	Not reported	2b	9/15
Banfi et al. (1996)[33]	Illness	Prospective: GIT*** symptoms recorded during and after the run. Self-reported during questioning	Marathon (Second Fila Skymarathon) on the Tibetan Plateau. 42 km, 4300m mean altitude	13	35 (SD 8)	Males: 100% (n=13) Female: 0% (n=0)	21 (SD 1.2)	2b	6/15
Stuempfle et al. (2016)[40]	Illness	Prospective: Recorded data on GIT*** distress at 46km, 90km, 126km and 161km.	Western States Endurance Run, California, USA**. (161km)	20	Not reported	Males: 75% (n=15) Females: 25% (n=5)	Not reported	2b	8/15
Stuempfle and Hoffman (2015)[38]	Illness	Cross-sectional: Participants completed a questionnaire post-race (between 1-15 days) to report on symptoms in the four distance categories of the race.	Western States Endurance Run, California, USA**. (161km)	272	41 (± 9.6)	Males: 79.4% (n=216) Female: 21.6% (n=56)	Not reported	2b	8/15
Stuempfle et al. (2013)[39]	Illness	Prospective: Data recorded data on GIT*** distress at every 25km loop of the 161km race.	Javelina Jundred 100 mile Endurance Run in Arizona, USA**. (161km)	15	Symptoms: 44 (26-52), no symptoms: 49.9 (37-67)	Males: 67% (n=10) Females: 33% (n=5)	Not reported	2b	7/15
Baska et al. (1990)[34]	Illness	Prospective: Data recorded data on GIT*** symptoms both pre and post-race 161km race.	Old Dominion 100 Mile Endurance Run in Virginia, USA**	34	39.8 (± 8)	Males: 97% (n=34) Females: 3% (n=1)	Not reported	2b	5/15

*Abbreviations: *MSUM (multi-stage ultramarathon), **USA (United States of America), ***GIT (gastrointestinal tract)*

3.4. Injury and illness outcomes

Injury outcomes are presented under the categories of injury definition, duration/follow-up periods, anatomical site of injury, tissue type, pathology type/specific diagnosis, and severity of injury (Table 2). Illness outcomes are presented under the categories of duration/follow-up periods, illness definition, symptoms, organ system involved, specific diagnosis, and illness severity (Table 3). Reporting of injuries and illnesses were based on the definitions used by authors of the included articles.

Due to the difference in study designs and follow-up periods, especially among the injury studies, the results are categorised in: 1) studies that recorded race-related injuries;[8, 21, 22, 24, 35-37] 2) cross-sectional study design that included training-related injuries:[9] and, 3) prospective cohort study design that included training-related injuries.[42] Even though some race-related injury studies prospectively collected data, they are grouped with the cross-sectional study designs, due to their extremely short follow-up periods.

Table 2: Trail running injury-related outcomes (race and training participation)

Author and publication date	*Injury definition*	*Follow-up*	*Injury site/anatomical region*	*Tissue type*	*Pathology type / Specific diagnosis*	*Severity*	*Incidence / Prevalence*
Cross-sectional and prospective studies with short follow-up periods (included only race participation injury outcomes)							
Graham et al. (2012)[36]	Medical encounter: Injury sustained during the race, reported to medical staff	Multi-stage event (seven stages, 241km): Data recorded twice per day over a seven-day period	Knee Achilles tendon Shin Feet	Skin Soft tissue Tendon	Abrasion: 100% (n=11) Blisters: 100% (n=11)	Not reported	Not reported
Krabak et al. (2011)[24]	Medical encounter: Disability sustained during the race that resulted in a medical encounter at medical checkpoint (every 10km and finish line)	Multi-stage events (four different events): Data recorded daily over a seven-day period, during each of the four events.	MSK [a] and skin Injuries 92.6% lower limb: Foot (73.7%) Lower leg (8.6%) Ankle (4.9%) Knee (3.5%)	MSK [a] Bursa (n=12) tendon (n=222)	Bursitis (n=12) Sprain (n=27) Strain (n=28) Tendonitis (n=122) Abrasion (n=43) Blister (n=652) Cellulitis (n=9) Hematoma (n=107) Other (n=55)	Severity definition: Major: unable to continue in race Minor: able to continue in race Minor injuries: - MSK [a] and skin injuries: minor (n=1029) Major injuries: - MSK [a] and skin injuries: major (n=26)	Injury rates per 1000 runners (95% CI) - All: 3871.3 (3652.9-4049-3) - MSK [a] (major): 46.2 (25.2-77.5) - MSK [a] (minor): 670.0 (581.0-768.7) - Skin (major): 39.6 (20.4–69.2) - Skin (minor): 2726.1 (2543.3-2918.5) Injury rates per 1000 h of running (95% CI) - All 65.0 (61.4-68.7) - MSK [a] (major): 0.8 (0.4-1.3) - MSK [a] (minor): 11.2 (9.8-12.9) - Skin (major): 0.7 (0.3-1.1) - Skin (minor): 45.8 (42.8–48.9)

Author and publication date	*Injury definition*	*Follow-up*	*Injury site/anatomical region*	*Tissue type*	*Pathology type / Specific diagnosis*	*Severity*	*Incidence / Prevalence*
Scheer and Murray (2011)[21]	Medical encounter: All self-referred clinical encounters with the medical team	Multi-stage event (five stages): Data recorded daily during a five-day ultramarathon stage race.	Number of consultations: Hip (n=3) Knee (n=9) Ankle (n=6) Achilles (n=2) Related to chafing and blisters: No of consultations unknown. Upper leg, lower leg, subungual, groin, foot	Bursa (hip) Cartilage (knee) Tendon (Achilles and ankle) Muscle (upper and lower leg) Soft tissue (under nail) Skin	Trochanteric bursitis (n=3) Patellofemoral pain syndrome (n=9) Achilles tendinopathy (n=2), Ultramarathoner's ankle (n=1) Ankle inversion injury (n=5) Quadriceps muscle pain (n=1) Tibialis Anterior muscle pain (n=1) Blisters (n=33), Chafing (n=9), Subungual hematoma (n=2), Laceration (n=1), Muscle cramps (n=3), Dog bite (n=2)	DNF [b] (n=4), further severity not defined or reported	Reported an overall incidence for participants seeking medical advice (injury and illness) = 56.5%
Costa et al. (2016)[35]	Self-reported: Dermatology symptoms reported to trained researchers (standardised interview)	Multi-stage event – four stages (MSUM [c]): Data recorded prospectively over four days at the end of each stage. Single stage event (continuous marathon): Data recorded at the end of a 24-hour race	Foot	Skin	Blisters	Not reported	Not reported
McGowan et al. (2015)[22]	All medical encounters at race aid station	Single stage event (161km): Race-day data recorded by medical staff at aid stations each year (2010-2013).	Unknown	Unknown	Sprain, strain or tendinitis n=7 (0.9%) Muscle cramping n=6 (0.8%) Muscular pain n=5 (0.7%) Contusion n=2 (0.3%) Concussion n=1 (0.1%) Skin wound n=1 (0.1%) Visual impairment n=1 (0.1%)	20 runners not able to finish the race, 6 cases due to injury	Not reported

Author and publication date	***Injury definition***	***Follow-up***	***Injury site/anatomical region***	***Tissue type***	***Pathology type / Specific diagnosis***	***Severity***	***Incidence / Prevalence***
Vernillo et al. (2016)[8]	Self-reported medical encounters at race finish	Single stage event (65km): Data recorded using a questionnaire post-race.	Ankle n=16 (28.6%) Knee n=8 (14.3%) Thigh n=8 (14.3%) Neck/Spine n=4 (7.1%)	Tendon n=20 (35.7%) Ligament n=24 (42.9%) Muscle n=12 (21.4%)	Cramps n=16 (26.2%), Plantar fasciitis n=16 (28.6 %), Ankle sprain n=16 (28.6%), Achilles tendinopathy n=4 (7.1%), Knee sprain n=8 (14.3%), Thigh strain n=8 (14.3%), Neck/cervical spine strain n=4 (7.1%), Laceration n=2 (15.4%), Subungual hematoma n=2 (15.4%), Chafing n=2 (15.4%), Foot blisters n=7 (53.8%)	Not reported	Total injuries and illnesses (n=132) Injury rates per 1000 runners (90% CI): MSK [a]: 614.3 (559.0-761.7) Skin: 314.3 (286.0-389.7) Injury rates per 1000 hours (90% CI): MSK [a]: 4285.0 (3899.3-5313.4) Skin: 2192.3 (1994.9-2718.4)
Hoffman and Stuempfle (2015)[37]	Self-reported muscle cramping, without clear given definition of muscle cramping	Single stage event (161km): Data recorded via a questionnaire 1-15 days post-race.	Calf (57.5%), Quadriceps (57.5%), Hamstring (45.0%), Hip flexors (17.5%), Trunk (10.0%), Hip adductors (2.5%), Ankle dorsiflexors (7.5%), Forearm (7.5%), Foot (5.0%), Upper arm (2.5%), Hand (2.5%)	Muscle	Muscle cramping	Not reported	Not reported
González-Lázaro et al. (2020)[41]	Medical encounters: Injuries sustained during a race that required medical attention. Major injury = the runner was not able to further participate in the race. Minor injury = the runner could continue with race participation.	Single stage events (20-42km): Date recorded at 36 different races using a self-reported participant form.	Ankle (32%) Knee (14%) Foot/toe (11%) Upper limb (18%) Trunk (7%)	Not reported	Not reported	Major injury (25%) Minor injury (75%)	Total number of injured partcipants (n=28) Injury rates: 5.9 injuries per 1000 runners 1.6 injuries per 1000 hours of running.
Prospective cohort study design (included training-related injury outcomes)							

Author and publication date	*Injury definition*	*Follow-up*	*Injury site/anatomical region*	*Tissue type*	*Pathology type / Specific diagnosis*	*Severity*	*Incidence / Prevalence*
Hespanhol Junior et al. (2017)[9]	Self-reported: Disorder of the musculoskeletal system which were sustained or experienced whilst running. Substantial RRIs [d] were defined as any injuries leading to moderate or major reductions in training volume or running performance	Training: Data collected. prospectively every two weeks over a six-month period	Lower leg n=49 (20.6%) Knee n=44 (18.9%) Foot n=36 (14.9%) Achilles n=31 (12.8%) Pelvis/hip/groin n=25 (10.3%) Upper leg n=23 (9.5%) Ankle n=22 (9.1%) Lower back n=5 (2.1%) Chest n=2 (0.8%) Wrist/hand n=2 (0.8%) Multiple regions n=3 (1.2%)	Muscle n=67 (27.7%) Tendon n=57 (23.6%) Ligament n=18 (7.4%) Bone n=13 (5.4%) Fascia n=9 (3.7%), skin n=8 (3.3%), cartilage n=7 (2.9%), joint (multiple tissues) n=2 (0.8%), nerve n=2 (0.8%), bursa n=1 (0.4%), unknown n=58 (24.0%)	Achilles tendon injury n=31 (12.8%), calf muscle trigger points/ spasm n=26 (10.7%), knee pain undiagnosed n=21 (8.7%), ankle sprains n=17 (7.0%), buttock muscle strain n=10 (4.1%), foot pain undiagnosed n=10 (4.1%), muscle strain lower limb (crossing anatomical boundaries) n=9 (3.7%), hamstring strain n=8 (3.3%), plantar fasciitis strain n=8 (3.3%), ITB [e] syndrome n=7 (2.9%), tenoperiostitis of lower leg n=7 (2.9%), blisters foot n=5 (2.1%), knee tendon injury n=5 (2.1%), lower leg pain undiagnosed n=5 (2.1%), hip/groin pain undiagnosed n=4 (1.7%), patellar tendinopathy n=3 (1.2%), lumbar pain undiagnosed n=3 (1.2%), patellofemoral pain n=3 (1.2%), thigh muscle strain/ spasm/ trigger points n=3 (1.2%)	Severity defined according to number of days lost to train at full capacity, according to the OSTRC [f] questionnaire Median severity score was 35.0 (25–75 %, IQR [g] 22.0–55.7), and the median of the duration of RRIs [d] was 2.0 weeks	Total number of injuries (n=242) Mean prevalence (95% CI) of RRIs: 22.4 % (20.9–24.0), and Injury rate (95 % CI): 10.7 RRIs injuries rate per 1000 h of running (95 %: CI 9.4-12.1).
Cross-sectional study design (included training-related injury outcomes)							

Author and publication date	Injury definition	Follow-up	Injury site/anatomical region	Tissue type	Pathology type / Specific diagnosis	Severity	Incidence / Prevalence
Malliaropoulos et al. (2015)[42]	Self-reported: Symptomatic with or without medical attention	Training: Data recorded cross-sectionally via a questionnaire.	Low back (42,5%) Hip (35.0%) Thigh (anterior) (5.0%) Thigh (posterior) (30.0%) Thigh (lateral) (35.0%) Thigh (medial) (20.0%) Knee (40.0%) Leg (anterior) (27.5%) Leg (posterior) (22.5%) Achilles tendon (20%) Foot dorsal (27.5%) Foot plantar (32.5%)	Not specifically reported	Only 31.85% of the injuries were diagnosed by a medical doctor Total injuries (n=135) Spinal disc injuries (14%) Hamstring strain (12%) ITB [e] (16%) Meniscus injuries (14%) Tibiofibular joint injury (2%) Adductor tendonitis (2%) Overuse bone stress injuries (22%) Achilles tendonitis (7%) Morton's Neuroma (5%) Plantar fasciitis (7%)	Severity definition: Grade 1 – symptoms that appear after running Grade 2 – appear hours after running Grade 3 – appear during running Grade 4 – chronic symptom Total injuries (n=135): Grade 1: 50.4% (n=68) Grade 2: 1.5% (n=2) Grade 3: 10.4% (n=14) Grade 4: 37.8% (n=51)	Total number injuries (n=135) Prevalence: 90% of runners reported at least on injury
Matos et al. (2020)[43]	Self-reported injuries via an online questionnaire.	No follow-up	Hip n=97 (4.5%), Spine (cervical zone) n=30 (1.4%), Spine (dorsal zone) n=25 (1.2%), Spine (lumbar zone) n=98 (4.5%), Anterior thigh n=108 (5%), Posterior thigh n=103 (4.8%), Thoracic zone (chest) n=11 (0.5%), Leg n=192 (8.9%), Knee n=377 (17.5%), Ankle n=312 (14.5%), Toes n=173 (8%), Ears n=9 (0.4%), Toenails n=535 (24.8%), Other n=85 (3.9%)	Not reported	Blisters n=554 (20%), Shin splints n=122 (4%), Contusion n=92 (3%), Luxation n=65 (2%), Sprains n=318 (11%), Plantar fasciitis n=108 (4%), Bone fracture n=22 (1%), Stress fracture n=30 (1%), Irritation (chafing) n=387 (14%), Superficial wound n=321 (12%), ITB [e] n=181 (7%), Patellofemoral syndrome n=78 (3%), Acilles tendinitis n=94 (3%), Thendinitis (other zones) n=108 (4%), Tendon strain n=35 (1%), Muscle strain n= 66 (2%), Micro strains n=126 (5%), Other 77 (3%)	Not reported	Total number of injured partcipants (n=631) Injury rate per 1000 hours of running All: 10.0 Males: 10.13 Females: 9.62

Abbreviations: [a] MSK (musculoskeletal), [b] DNF (did not finish), [c] MSUM (multi-stage ultramarathon), [d] RRIs (running-related injuries), [e] ITB (iliotibial band), [f] OSTRC (Oslo Sports Trauma Research Centre), [g] IQR (interquartile range)

3.5. Injury

3.5.1. Anatomical site

All injury-related studies: The foot as injured site occurred in nine studies[9, 21, 24, 35-37, 41-43] followed by the knee in eight studies,[8, 9, 21, 24, 36, 41-43] lower leg in seven studies,[9, 21, 24, 36, 37, 42, 43] thigh in six studies,[8, 9, 21, 37, 42, 43] and ankle in six studies.[8, 9, 21, 24, 41, 43]

Race participation studies: Four studies reported the foot as the most common site of injury[21, 24, 35, 36], although one study reported exclusively on dermatological injuries that mainly involved the foot.[35] All studies that were open to reporting any injury, indicated the knee as an injured site.[8, 21, 24, 36, 41] During a multi-stage ultramarathon, Scheer and Murray (2011) reported that complaints of the knee were responsible for the highest number of musculoskeletal consultations [21], while two studies reported the knee as the second most commonly injured site following the ankle.[8, 41] The lower leg as injury site were reported among four studies.[21, 24, 36, 37] The ankle was noted as a common injury site among trail runners.[21, 18, 8][41] Scheer and Murray (2011) reported the ankle as the second most commonly injured site, with acute ankle inversion sprains accounting for 83.3% of ankle injuries.[21] Similar results were found by Vernillo et al. (2016) (28.6%) and González-Lázaro et al. (2020) (32%) who reported the ankle as the most commonly injured site among trail runners that participate in mountainous terrains.[8, 41] The thigh as site of injury was reported by three studies.[8, 21, 37] The thigh (14.3%) presented to be just as commonly injured as the knee (14.3%) in the study of Vernillo et al. (2016), while the thigh muscles were also the most frequently reported site of cramping.[37] Two studies focussed on either cramping[37] or dermatological injuries,[35] while one study did not specify the anatomical site of injury.[22]

Training/race participation studies: The only prospective cohort study included in this review that, indicated the lower leg (20.6%) as the most frequently injured anatomical site, followed by the knee (18.2%), and foot (14.9%).[9] Two cross-sectional studies among Greek and Portuguese trail runners, who mostly ran on mountainous trails, were included.[42, 43] Among Greek trail runners[42] the most prevalent injury site was the thigh (90.0%), followed by the lower back (42.5%), and the knee (40.0%) while among Portuguese trail runners[43] the foot/toe (24.8%), knee (17.5%), and ankle (14.5%) were the most prevalent sites of injury.

Interesting sites of injury noted, not reported in road running literature, include the neck/spine[8] during races, and chest and wrist/hand[9] injuries during training.

3.5.2. Tissue type and pathology type/specific diagnosis

Race participation studies: Abrasions, lacerations and skin wounds occurred in five studies [21, 18, 19, 31, 8] while blisters and chafing were reported in three studies.[21, 18, 31] Two of the studies reported exclusively on dermatological injuries[35, 36], with 100% of participants in the Graham et al. (2012) study having blisters and abrasions.[36] In three studies, muscle strains and spasms were reported affecting only the lower limb muscles, specifically of the quadriceps and tibialis anterior muscle groups.[18, 19, 8] Muscle cramping was reported in four studies.[8, 21, 22, 37] One study reported on muscle cramping only, with the highest frequency noted in the calf (57.5%), quadriceps (57.5%), and hamstring (45.0%) muscles.[37] In two studies, acute ankle sprains were among the top five most frequently reported injury [18, 8] with Scheer and Murray (2011) specifically referring to ankle inversion injuries recorded.[21] Common lower limb overuse injuries, such as Achilles tendinopathy,[18, 8] patellofemoral pain syndrome (PFPS),[21] and plantar fasciitis [8, 34] were also reported at trail run races. Across all specific musculoskeletal injuries recorded by Scheer and Murray (2011), PFPS (9.1%) showed the highest frequency.[21]

Training/race participation studies: In a prospective cohort study, Hespanhol Junior et al. (2017) reported an overuse injury, namely Achilles tendinopathy (12.8%) as the most common injury among 228 Dutch trail runners.[9] The second most common injury reported was calf muscle trigger points/ spasm (10.7%), followed by undiagnosed knee pain (8.7%), ankle ligament sprains (7.0%), plantar fasciitis (3.3%), PFPS (1.2%), and iliotibial band (ITB) (2.9%). Lacerations/abrasions that were the highest reported injuries on race-day, were not frequently noted among a sample of runners where training injuries were also studied.[9] Among the two cross-sectional studies that also included training related injury outcomes,[42, 43] different injury patterns were reported. Overuse bone stress injuries (22.0%), followed by ITB injuries (16.0%) were the most commonly reported injuries among Greek trail runners,[42] while dermatological injuries including blisters (20%) and chafing (14%) were most commonly reported among Portuguese trail runners.[43]

In this review other injuries were noted, which have not been reported in road running literature. These injuries include: concussion, contusions,[22] and cervical spine strain[8] recorded at races, and spinal disc injuries, tibio-fibular joint injury, and knee meniscus injury[42] recorded during training.

3.5.3. Injury severity

Race participation studies: Injury that resulted in discontinuation of a race was rated as major in two studies.[24, 41] Krabak et al. (2011) reported that major musculoskeletal injuries presented with an incidence rate of 0.8 injuries per 1000 hours of running,[24] but the majority of all MEs (97.4%) were minor in nature, with specifically minor musculoskeletal injuries showing an incidence rate of 11.2 injuries per 1000 hours of running.[24] González-Lázaro et al. (2020) reported that 25% of all injuries were major.[41] Other studies did not define injury severity, but still reported on runners that did not finish the race.[21, 22] Scheer and Murray (2011) reported four runners not being able to finish the race due to knee pain, blister pain, and muscle cramps.[21] In the study of McGowan et al. (2015) injury severity was not defined, but 20 runners did not finish the race: six due to sprains, strains, concussion, and muscle cramping.[22]

Training/race participation studies: Among the three studies that included training-related injuries,[9, 42, 43] only two studies reported on injury severity.[9, 42] Hespanhol Junior et al. (2017) graded severity based on the onset of symptoms and used a severity grading system of symptoms that: 1=appear after running; 2=appear hours after running; 3=appear during running, and; 4=chronic symptoms. Grade 4 injuries accounted for 37.77% of all injuries, however, grade 1 injuries (50.37%) were mostly recorded.[42] The other training-related study[9] focused on how the presenting symptoms affected the participants' ability to run and used a severity grading established by Clarsen et al. (2013), as derived from the Oslo Sports Trauma Research Centre (OSTRC) questionnaire.[44] Substantial injuries were defined as "those leading to moderate or major reductions in training volume, moderate or major reductions in running performance, or complete inability to run". An incidence rate of 5.8 substantial injuries per 1000 hours of running was reported.[9] Even though higher severity injuries were noted, it remained far less frequently reported compared to the minor injuries.

Table 3: Trail running illness-related outcomes (race participation)

Author and publication date	*Illness definition*	*Follow-up*	*Organ system*	*Symptoms*	*Specific diagnosis*	*Severity*	*Total number of illnesses Incidence / Prevalence*
Graham et al. (2012)[36]	Medical attention: Injury sustained during the race, reported to medical staff	Multi-stage event (seven stages, 241km): Data recorded, twice per day over a seven-day period	Metabolic	Not reported	Heat stress: 100% (n=11) Heat exhaustion: 54% (n=6)	Not reported	Not reported
Krabak et al. (2011)[24]	Medical attention: Disability sustained during the race that resulted in a medical encounter at medical checkpoint (every 10km and finish line)	Multi-stage event (four different events): Data recorded daily over a seven-day period, during each of the four stages.	Respiratory CNS [a] CVS [b]	Not reported	EAC [c] (n=78) Altitude sickness (n=11) Serious medical diagnosis (n=2) Other (n=27)	Severity definition: Major: unable to continue in race Minor: able to continue in race Illness: - Major (n=36) - Minor (n=82)	Illness rates per 1000 runners (95% CI [d]) - All: 3871.3 (3652.9-4049.3) - Medical (major): 118.8 (83.2-164.4) - Medical (minor): 270.6 (251.2-355.9) Illness rates per 1000 hours of running (95% CI [d]) - All: 65.0 (61.4-68.7) - Medical (major): 2.0 (1.4-2.8) - Medical (minor): 4.5 (3.6-5.6)
Scheer and Murray (2011)[21]	All self-referred clinical encounters with the medical team over 5 days, from the start of the first stage to the end of the race	Multi-stage event (five stages): Data recorded daily during a 5-day ultramarathon stage race. No post-race follow-up	Metabolic CNS [a] CVS [b] ENT [e] GU [f] Immunological	Number of consultations: Palpitations (n=3) Fatigue (n=3) Vomiting (n=4) Headache (n=1)	EAC [c] Dehydration Allergy/hay fever Epistaxis Dog bite Haematuria UTI [g]	DNF [h] (n=5), further severity not defined or reported	Reported an overall incidence for participants seeking medical advice (injury and illness) = 56.5%

Author and publication date	*Illness definition*	*Follow-up*	*Organ system*	*Symptoms*	*Specific diagnosis*	*Severity*	*Total number of illnesses Incidence / Prevalence*
McGowan et al. (2015)[22]	All medical encounters at race aid station	Single stage event (161km): Data recorded by medical staff at aid stations each year (2010-2013).	Metabolic ENT [e] CVS [b]	Nausea vomiting n=15 (2.0%) Severe fatigue n=1 (0.1%)	Respiratory distress n=7 (0.9%) Hypothermia n=5 (0.7%) Dehydration n=4 (0.5%) Overhydration n=2 (0.3%) Allergic reaction n=1 (0.1%) Cardiovascular issue n=1 (0.1%) Hyponatraemic seizure n=1 (0.1%)	DNF [h] n=20, n=14 (1.9%) due to illness Race performance affected in 40.1% of participants Nausea/vomiting n=3 Respiratory distress n=4 Hypothermia n=5 Dehydration n=1 CVS [b] issue n=1	Not reported
Vernillo et al. (2015)[8]	Self-reported medical encounters at race finish	Single stage event: Data recorded using a questionnaire post-race.	Metabolic ENT [e]	Fatigue n=23 (37.7%) Palpitations n=2 (3.2%) Vomiting n=6 (9.8%) Headache n= 6 (9.8%)	Hypothermia n=1 (1.6%) Allergy/hay fever n=2 (3.2%) Dehydration n=4 (6.6%)	Not reported	Illness rates per 1000 runners (90% CI): Medical: 957.1 (871.0-1 186.8) Illness rates per 1000 hours (90% CI): Medical: 6676.6 (6075.7-8278.9)
Banfi et al. (1996)[33]	Self-reported symptoms of GIT [i] distress	Single stage event (65km): Data recorded during and post-race	GIT [i]	During the run: Nausea n=4 (31%) Side ache n=2 (15%) After the run: Nausea n=8 (62%) Vomiting n=2 (15%) Diarrhoea n=2 (15%)	Not reported	Not reported	Not reported
Stuempfle et al. (2016)[40]	Self-reported: Participants reported symptoms at checkpoints during the race	Single stage event (161km): Data recorded at checkpoints during the race and the finish	GIT [i]	Nausea (60%) Belching (45%) Flatulence (35%) Urge to defecate (30%) Vomiting (25%) Stomach cramps/pain (20.0%) Loose stool/diarrhoea (15%) Stomach bloating (15%) Reflex/heartburn (10%) Side ache/stitch (10%) Intestinal cramps/pain (5%)	Not reported	Severity rating: "None", "mild", "moderate", "severe" or "very severe" were converted to numeric values 0, 1, 2, 3 and 4 for analysis of symptom severity. Mean ± SD nausea severity was 1.6 ± 0.7 with a range of 1-3.	Total number of participants reporting illness (n=16) Prevalence: 80% of runners reported an illness

Author and publication date	*Illness definition*	*Follow-up*	*Organ system*	*Symptoms*	*Specific diagnosis*	*Severity*	*Total number of illnesses Incidence / Prevalence*
Stuempfle and Hoffman (2015)[38]	Self-reported symptoms of GIT [i] distress	Single stage event (161km): Data recorded via a questionnaire 1-15 days post-race	GIT [i]	Flatulence (65.9%) Belching (61.3%) Nausea (60.3%) Stomach bloating (48.7%) Urge to defecate (47.6%), Vomiting (35.4%) Stomach cramps/pain (31.9%) Intestinal cramps/pain (24.1%) Loose stool/diarrhoea (22.2%) Side ache/stitch (20.4%) Reflex/heartburn (11.8%) Intestinal, bleeding/bloody stools (1.5%)	Not reported	Severity rating: “none”, “mild”, “moderate”, “severe” or “very severe”. Negative for a symptom if they answered “none”. “None”, “mild”, “moderate”, “severe” or “very severe” were converted to numeric values 0, 1, 2, 3 and 4 for analysis of symptom severity. Stomach cramps/pain (mean value 1.1) and intestinal cramps/pain (mean value 1.1) had the highest severity ratings	Prevalence: 96% of runners reported an illness
Stuempfle et al. (2013)[39]	Self-reported: Participants reported symptoms of GIT [i] distress at checkpoints during the race	Single stage event (161km): Data recorded after every 25km loop	GIT [i]	Frequency: Nausea 89% Abdominal cramps 44% Diarrhoea 44% Vomiting 22%	Not reported	Not reported	Total number of participants reporting illness (n=9) Prevalence: 60% of runners reported an illness
Baska et al. (1990)[34]	Self-reported: Pre and post-race questionnaire, Stool samples - 3 week prior, and first 3 post-race	Single stage event (161km): Data recorded one week before, up to seven days post-race	GIT [i]	GIT [i] bleeding Positive n=29 Negative n=5	GIT [i] bleeding	Not reported.	Not reported

Author and publication date	*Illness definition*	*Follow-up*	*Organ system*	*Symptoms*	*Specific diagnosis*	*Severity*	*Total number of illnesses Incidence / Prevalence*
Costa et al. (2016)[35]	Self-reported: GIT [i] and Dermatology symptoms reported to trained researchers (standardised interview)	Multi-stage event – four stages (MSUM [j]): Data recorded prospectively over four days at the end of each stage. Single stage event (continuous marathon): Data recorded at the end of a 24-hour race	GIT [i]	GIT [i]: Nausea, urge to vomit, vomiting, belching, bloating, stomach pain, gastric acidosis, abdominal pain, constipation, diarrhoea	Not reported	Not reported	MSUM [j] Prevalence: 85% of runners reported an illness

Abbreviations: [a] CNS (central nervous system), [b] CVS (cardiovascular system), [c] EAC (Exercise-associated collapse), [d] CI (confidence interval), [e] ENT (ear nose and throat), [f] GU (Genito-urinary), [g] UTI (urinary tract infection), [h] DNF (did not finish), [i] GIT (gastrointestinal tract), [j] MSUM (multi-stage ultramarathon), [k] GIS (gastrointestinal symptoms)

3.6. Illness

3.6.1. Organ system

Six studies specifically investigated illness symptoms related to GIT distress and did not report on other illnesses.[33-35, 38-40] The metabolic system was reported on in four studies,[8, 21, 22, 36] followed by the cardiovascular system(CVS)[21, 22, 24] and, ear nose and throat (ENT) system[8, 21, 22] that were both accounted for in three of the illness-related studies. Other less frequently involved organ systems included the respiratory,[24] central nervous (CNS),[21, 24] genito-urinary, and immunological systems.[21]

3.6.2. Illness symptoms and specific diagnosis

Common GIT symptoms recorded were nausea, vomiting, diarrhoea, abdominal cramping, and pain.[8, 21, 22, 33, 35, 38-40] Although less frequent, flatulence, side aches, belching, constipation and GIT bleeding were also reported.[33, 35, 38, 40] Other symptoms reported included palpitations, headaches, and severe fatigue.[8, 21, 22]

Specific diagnosis of dehydration was indicated by three studies reporting on ultramarathon trail illnesses[8, 21, 22] and Graham et al. (2012) described heat exhaustion in a desert multi-stage ultramarathon.[36] Exercise-associated collapse (EAC) was described at a seven-day stage race and during the Western States 161km race with no fatalities.[21, 24] Krabak et al. (2011) studied a race with trails going up to 4300m above sea level and is the only study that diagnosed altitude sickness among participants.[24] Other illnesses diagnosed included: hypothermia,[8, 22] allergic reactions,[8, 21, 22] respiratory distress, cardiovascular event, hyponatraemic seizure,[22] haematuria, epistaxis, and urinary tract infection.[21]

3.6.3. Illness severity

An inability to complete a race due to illness was rated as major severity by Krabak et al. (2011).[24] An incidence rate of 2.0 major illnesses per 1000 hours of running was recorded, where the majority was due to EAC.[24] Scheer and Murray (2011) reported five runners not finishing the race due to palpitations, sickness, and fatigue.[21] During the 2010-2013 Western States Endurance Run, two cases of emergency evacuation were reported due to bronchospasm and hyponatraemic seizure, but 55% of runners that had a medical consultation were still able to complete the race.[22]

Even though severe illness related MEs were reported, the majority of illnesses were minor. Specifically referring to GIT illness severity, Stuempfle et al. (2016) used a grading system of 0-4; referring to none=0, mild=1, moderate=2, severe=4. Nausea was reported at a mean of 1.6, indicating mild to moderate severity.[42] A similar severity scale was used by Stuempfle and Hoffman (2015) and they found the highest severity for stomach and intestinal cramps/pain at mean values of 1.1. each.[38]

4. Discussion

To our knowledge, this is the first systematic review examining injury and illness among a trail running population. The findings of this systematic review need to be interpreted in the context of the limited literature available: mainly cross-sectional study designs at single-day events; race-related injury/illness focus; and inconsistent definitions of injury/illness across studies. The fact that certain studies had a single illness/injury focus may overestimate the foot as the most common anatomical site of injury and GIT symptoms as the most common illness reported. This review included predominantly middle-aged male runners, participating in ultramarathon trail run races. The considerable heterogeneity regarding study designs and injury definitions used among the included studies prevented strong conclusive findings regarding the epidemiology of injury and illness among trail runners. Despite the heterogeneity of the included studies, we could present an integrated discussion regarding similar characteristics of injury (anatomical location, tissue/pathology type, severity) and illness (symptoms, diagnoses, severity).

The main injury findings of this review are: 1) the foot, knee, lower leg, thigh and ankle are the most common anatomical sites of injury; 2) Skin lacerations/abrasions, followed by skin blisters, muscle strains, muscle cramping, and ligament sprains are the most common injury diagnoses, and; 3) most injuries are of minor severity. The main illness findings of this review are: 1) the GIT, followed by the metabolic, and CVS are the most common organ system involved; 2) symptoms of nausea and vomiting were most commonly reported with GIT distress and dehydration diagnosed most common, and: 3) most illnesses were of minor severity. These outcomes were reported among the 14 included studies (six studies reported on both injury and illness, three studies reported on injuries only, and five studies on illnesses only) that investigated trail running, as a sub-category of off-road running. [45]

4.1. Sub-categories of off-road running

Running on off-road surfaces have different sub-categories as per definition from the various sports governing bodies/federations. Some of these sub-categories include fell running, skyrunning, mountain running, and trail running.[45] The term "off-road running" only refers to running on natural surfaces (unsealed) with no specific reference to distance, percentage of total running surface to be off-road, terrain, elevation, distance, etc. However, trail running as defined by the ITRA[46] has the most encompassing definition that gives clarity of the running surface, terrain, support, route markings, and has no limitations regarding elevation or distance. Therefore, we decided to use the trail running definition as according to the ITRA to guide inclusion of studies into this systematic review.

4.2. Injury and illness definitions

Studies included in this review used a variety of methods and definitions to record and report on injury and illness. All injury/illness definitions met the requirements of either MEs or self-reported injuries/illnesses.[28, 29] A 2019 consensus statement that addressed the issue of definitions and recording of MEs at endurance sports events, defined a ME as a medical problem reported to the event medical team; i.e. not a self-reported injury or illness questionnaire. Schwellnus et al. (2019) also acknowledged that athletes can develop a medical problem during a race and can choose not to report their medical problems to the event medical team.[28] This was defined as a non-reported medical problem.[28] Self-reported injury/illness data were also included in this review as this allowed for the inclusion of a broader scope of injuries/illnesses as indicated by the International Olympic Committee (IOC) consensus statement.[29] Changes in biomarkers as a result of trail running can/cannot result in injury/illness and therefore poses a risk of overestimating injury or illness. We therefore excluded studies that investigated biomarkers related to potential injury/illness.

4.3. Trail running injury

Similar to previous running literature,[10, 16] this review indicated that the lower limb is the most commonly injured body region affecting the foot, knee, lower leg, thigh and ankle. The foot as injured anatomical site was reported by nine studies[9, 21, 24, 35-37, 41-43] and in five of these, the foot was noted as the most common site of injury.[21, 24, 35, 36, 43] However, four studies used cross-sectional designs to investigate multi-stage ultramarathons where the high frequency and magnitude of skin shears in the shoe affects the formation of foot blisters while running for extended time periods on consecutive days.[47] Further one study solely investigated dermatological-related injuries.[35] These dermatological injuries could have resulted in an overestimation of the foot as injured anatomical site.

The knee is a known common site for overuse RRI[10, 16] and this review showed similar results. Regardless of study design, race vs. training participation, running terrain, distance, and elevation change, the knee was previously reported as a common site of musculoskeletal injury.[8, 9, 21, 24, 36, 41-43] During ultramarathons, Scheer and Murray (2011) reported that complaints of the knee were responsible for the highest number of musculoskeletal consultations.[21] A cross-sectional study investigating trail runners that participated in a rough mountainous region reported the knee as the second most commonly injured site following the ankle.[8] Both these studies investigated ultramarathons where fatigue can result in altered knee joint kinematics[48] and pain as a result of overuse can increase the vertical ground reaction force with further loading at the knee joint.[49] Also, increased cumulative knee joint loading is observed with a slower running pace.[50]. These factors could contribute to the knee being reported as a commonly injured site, but the multifactorial complex nature of sports injuries is important to consider.[51] Among the three studies that included training-related injuries[9, 42, 43] the knee was also reported as the second most commonly injured site, indicating the knee as high risk for injury regardless of racing/training, running surface or distance. Similar to previous running literature[10, 16], PFPS[8, 9, 21, 43] and ITB injuries[9, 42, 43] are common overuse injuries reported in this review. Even though less commonly reported, it is important to notice that acute knee injuries such as knee sprains[8] and meniscus injuries[42] were also reported in this review. This may indicate the increased multidirectional loading the knee is exposed to on more technical uneven terrains compared to road running disciplines.

Muscle injuries of the thigh were reported in five studies. [8, 9, 21, 37, 42, 43] Two cross-sectional studies reported a high frequency of thigh muscle strains and both these studies investigated trail runners participating in mountainous regions.[8, 42] Running in mountainous regions involves larger elevation changes, which increase the volume of eccentric muscle work, especially in downhill running. Downhill running has shown to decrease quadriceps muscle performance and to increase muscle damage, compared to running on level surfaces[23] and provides a possible explanation for the muscular thigh injuries reported. The quadriceps (57.5%) and hamstring (45.0%) muscles were also reported as two of the most common sites of injury among ultramarathon runners in another study.[37] This particular race covers a distance of 161km and runners are exposed to high temperatures resulting in fatigue. Altered neuromuscular control that occurs during muscular fatigue is viewed as a plausible hypothesis for exercise-associated muscle cramping (EAMC). This is supported by the findings of Vernilllo et al. (2016) who also indicated cramping as the most common injury type among 65km trail runners in a mountainous region.[8] These findings highlight the need for conditioning of the thigh muscles in preparation for safe trail running participation.

The ankle was noted as a common injury site among trail runners.[8, 9, 21, 24, 41, 43] During trail running races, runners are exposed to high levels of fatigue and usually run on unknown trails with uneven surfaces. This may explain the high incidence of acute ankle injuries during race participation. However, a prospective cohort study among Dutch trail runners that typically train on more level trail surfaces, still reported that 77.27% of all ankle-related injuries were ankle sprains.[9] A cross-sectional study among Greek trail runners, who mostly ran on mountainous trails, included race and training injury outcomes.[42] The authors reported the thigh as most commonly injured site, but did not report on ankle injuries as they mentioned that due to the high frequency of repetitive ankle spraining, it was impossible to assess the correct occurrence of ankle injuries using a cross-sectional study design. [42] Among trail runners participating in mountainous regions in Spain, the ankle (32%) was reported as the most common injury over 5 seasons of running.[41] These results emphasise the need for multi-directional ankle stability during training for trail running.

The lower leg as injury site, was largely due to Achilles tendinopathy, reported as common overuse injury among race participation studies[8, 21, 36] and training-related injuries.[9, 42, 43] Although the Achilles tendon is a commonly injured structure among road runners,[16] the mechanism of injury in trail running may differ. Overload of the Achilles tendon can occur during uphill and downhill trail running on routes with higher elevation changes where the calf muscle is exposed to increased load over longer periods of time.[52] Overloading of the calf is further emphasised by the reported calf muscle injuries and cramping.[9, 37] Interesting to note was the high frequency of reported ankle dorsiflexor muscle cramping.[37] When running over uneven surfaces, the lower leg muscles are exposed to increased load during This can be the result of repetitive ankle dorsiflexion to prevent tripping over rocks/branches and adopted posterior patterns during downhill running[53] which increase eccentric muscle work. This may be a possible explanation for overload and cramping of the lower leg musculature.

Interesting sites of injury noted, not reported in road running literature, included the neck/spine[8, 43] and chest and wrist/hand[9] injuries. The wrist and hand body regions are not exposed to overuse injury during trail running participation and therefore could be related to acute injury. Lacerations and abrasions were diagnosed in most articles that studied trail run races[8, 9, 21, 22, 24, 36] which emphasise the potential risk of falling during trail running participation. Even though the mechanism of injury was not reported in these studies, trail running is not a contact sport, therefore the likelihood of falling or impact with tree branches, rock faces, etc. should be considered as potential reasons for specifically the lacerations/abrasions and wrist/hand injuries reported. Lacerations/abrasions that are the highest reported injuries on race-day, were not frequently noted among a sample of runners where training injuries were also studied.[9] This could be an indication of higher risk taken among race participants with a subsequent increased risk for falling. Hespanhol Junior et al. (2017) studied Dutch trail runners that are typically training on more level running surfaces, which could be an explanation for the lower frequency of lacerations/abrasions as result of potential falling.[9] Currently there is a lack of prospective cohort studies investigating trail runners pertaining to training and race participation and therefore a comparison between race participation and training-related injuries is challenging.

Various gradings were used to report injury severity. Minor injuries were more frequently reported compared to serious injuries. However, there were cases of runners that were unable to continue with a race.[21, 22, 41] It is important to note that in the context of trail running, any injury that limits the runner's ability to keep moving has serious implications as these runners enter remote regions, are semi-/self-sufficient, exposed to extreme weather conditions, and medical care is challenging. Future studies should follow the consensus guidelines of reporting injury severity,[28] which will allow for comparison between studies.

4.4. Trail running illness

The most commonly reported organ system affected across all illness studies was the GIT. Common GIT symptoms recorded were nausea, vomiting, diarrhoea, abdominal cramping, and pain.[8, 21, 22, 33, 35, 38-40] Although less frequent, flatulence, side aches, belching, constipation and GIT bleeding were also reported.[33, 35, 38, 40] The fact that GIT distress is common amongst trail runners need to be interpreted in the context of this review that included mostly studies investigating ultramarathons. Nutritional errors during prolonged exercise in ultra-endurance races, easily result in GIT distress.[54] A further limitation to this finding is that six of the nine studies specifically investigated illness symptoms related to GIT distress and did not report on other illnesses [33-35, 38-40]. This could have resulted in an overestimation of GIT-related illness among trail runners. Dehydration was common among ultramarathon runners during race participation [8, 21, 22] and could contribute to nausea as a common symptom. Graham et al. (2012) described heat exhaustion in a desert multi-stage ultramarathon.[36] Stuempfle et al. (2016) also reported that the severity of nausea increased during higher temperature segments of the race.[40] As trail running is a self-sufficient or semi self-sufficient sport,[55] it can be concluded that participants could easily mismanage their amount of carried fluids, leading to dehydration.

Exercise-associated collapse (EAC) was described at a seven-day stage race and during the Western States 161km race with no fatalities.[21, 24] Considering the challenges of medical care in remote regions,[12] EAC is of real concern considering the prolonged time for medical staff to reach a distressed runner. Krabak et al. (2011) studied a race with trails going up to 4300m above sea level and is therefore the only study that diagnosed altitude sickness among participants.[24] Two studies reported hypothermia.[8, 22] The first part of the Western States Endurance Run crossed over snow covered mountains, however, no specific detail on the Italian trail studied by Vernillo et al. (2016)[8] is available to explain the potential cause of hypothermia.

Allergic reactions were also reported.[8, 21, 22] Allergies are commonly reported among endurance athletes[56] and trail runners may perhaps have higher exposure due to environmental pollens, dust, and potential insect bites in natural environments. Additional illnesses diagnosed included respiratory distress, cardiovascular event, hyponatraemic seizure,[22] haematuria, epistaxis, and urinary tract infection.[21] Other symptoms reported included palpitations, headaches, and severe fatigue.[8, 21, 22]

Similar to the injury-related studies, various gradings for illness severity were used in the absence of a guiding consensus statement of reporting on illness severity.[28] In this review the majority of illnesses were graded as minor with serious illnesses noted only amongst ultramarathon trail runners.[21, 22, 24] Preparation for ultramarathons includes several months of training and possibly motivate runners to try and reach the finish line at all cost, exposing them to high physiological demands. This was evident during the 2010-2013 161km Western States Endurance Run, where two cases of emergency evacuation were reported due to bronchospasm and hyponatraemic seizure, but 55% of runners with a ME still completed the race.[22]

4.5. Limitations

Even though an extensive search strategy was used in this review, the search was restricted to English and French language.

The difference in injury and illness definitions and study designs limited our ability to group and compare results. Injury and illness definitions included ME's and self-reported injuries/illness. During race participation, a runner's main goal is to finish the race. Runners will likely continue to run even though injured or experiencing illness and only report more severe injury/illness to medical staff. Therefore, ME data might under report injury/illness and overestimate the severity of injury/illness. Self-reported data is potentially exposed to recall bias as a result of the recall period, and social desirability bias regarding honest reporting of sensitive data such as injury status.[57]

Our review mainly included cross-sectional studies that reported on injuries and illnesses related to race participation at single-day events. Few studies recorded injuries using similar injury definitions over time. This could have resulted in acute injuries being over presented in this review and thus providing limited insight into overuse injury related to training. Considering that a trail runner often needs to endure pain[58, 59] over an extended period of time to complete a race, it has to be acknowledged that self-reported injury or illness associated with pain, may have been underreported in the articles included in this review.

The injury and illness severity gradings also differed amongst studies included in this review. These differences in severity gradings limited our ability to group and compare results on the impact injury and illness have on trail runners.

The foot as injury site and GIT as organ system affected were most frequently involved in injury/illness, however, certain studies included in this review only focused on dermatological injuries (e.g.large number of feet blisters) and GIT symptoms. This may have resulted in an overestimation of these reported injuries and illness symptoms.

Our results can help to guide planning injury prevention and injury risk management strategies at races, but limited evidence is available to advise the trail runner regarding training towards a race.

4.6. Recommendations for future research

This review included participants exposed to trail run races consisting of various running surfaces, distances and environmental conditions. This presents as an advantage in generalising the results to the larger trail running community that participates in races, however, comparing the results between studies is challenging. Future studies that focus on trail running race participation should attempt to clearly define their race as a trail run according to the ITRA[30] and describe the surface, elevation change, and weather on race-day.[45] As pointed out by the Ultra Science Sports Foundation's position statement, there is a need to clearly define off-road running disciplines.[46] At this stage, events are classified according to governing bodies/federations that provide certification for races. However, not all race organisers seek certification and self-label their races according to distance (ultramarathon), popularity (trail running), altitude (skyrunning) etc. Therefore, future research should aim to clearly describe characteristics of races under investigation[46], with a smaller focus on which governing body/federation the race is hosted under. This will allow better comparisons between race-related studies.

Studies that investigate MEs at trail running races should follow the guidelines as stipulated in the 2019 consensus statement on recording and reporting of results collected at endurance events to help improve comparisons of injury and illness-related outcomes among studies.[28]

A bigger research focus is needed on prospectively recording training-related injuries and illness to help guide trail runners on prevention during preparation for races. Injury and illness among shorter distance trail runners need to be investigated as these races attract runners with very little or no experience in trail running. These runners might show different injury/illness profiles compared to experienced runners participating in ultramarathon distances.

5. Conclusion

Current evidence in trail running literature consists mainly of cross-sectional study designs at single-day events and focusses on injury and illness specifically in relation to race participation. Limited evidence is available on training-related injury and illness in trail running. Our review showed that, injury and illness are common among trail runners with an overall incidence range of 1.6-4285.0 injuries per 1000 hours of running and 65.0-6676.6 illnesses per 1000 hours of running. Certain studies included in this review only focused on dermatological injuries (e.g. large number of feet blisters) and GIT symptoms. Considerable heterogeneity regarding study designs and injury/illness definitions existed among the included studies. Future research should standardise definitions and study designs and report on all anatomical regions and organ systems, in both competition and training.

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