The association between running injuries and training parameters: A systematic review

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ABSTRACT

Objective: To synthesise the current evidence on the incidence of running-related injuries (RRI) and their association with training parameters (distance, duration, frequency, intensity), as well as recent changes in training parameters.

Data sources: Searches were conducted in Medline/Ovid, CINAHL, Embase and SportDiscus up to July 7, 2020.

Study selection: Included articles had to report prospective data on RRIs and training parameters, or any changes in parameters, and be published in English or French. Two reviewers independently screened titles, abstracts and full-texts.

Data extraction: Data extraction and quality assessment (QualSyst) were performed by two independent raters.

Data synthesis: Thirty-six articles totaling 23,047 runners were included. Overall, 6,043 runners (26.2%) sustained an RRI (incidence range: 8.8% to 91.3%). The incidence of RRI was 14.9% in novice runners (range: 9.4 to 94.9%), 26.1% in recreational runners (range: 17.9 to 79.3%) and 62.6% in competitive runners (range: 52.6 to 91.3%). The three most frequently injured body parts were the knee (25.8%), foot/ankle (24.4%) and lower leg (24.4%). Overall, there was conflicting evidence about the association between weekly running distance, duration, frequency, intensity or specific changes in training parameters and the onset of RRIs.

Conclusions: Despite high rates of RRIs, current evidence does not consistently link RRIs with specific training parameters or recent changes in training parameters. Therefore, caution should be taken when recommending optimal parameters or progressions. Given the multifactorial nature of RRIs, future studies also need to consider the interaction between...
training parameters, as well as psychosocial, hormonal, lifestyle and recovery outcomes to better understand the onset of RRIs.

**Keywords:** Sports medicine, Prevention, Incidence, Exercise.

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**Key points**

- There is conflicting evidence on the association between running distance, duration, frequency and intensity, or recent changes in these parameters, and the onset of lower limb RRIs.
- No universal recommendations on training parameters or progressions can be issued based on current evidence; the popular ‘10% rule’ for increasing weekly distance is not justified.
- The lack of reporting guidelines in the field of RRIs contributes to high heterogeneity in the definition of an injury, the definition of profiles of runners and follow up periods.
INTRODUCTION

Running is a popular activity due to the health and fitness benefits it provides. However, since running imposes forces of up to three times the body weight at each step, it is commonly associated with lower limb overuse injuries. The yearly incidence of running-related injuries (RRIs) can reach 85% across all populations of runners (novice, recreational, competitive). In a consensus article published in 2015, an RRI was defined as: “running-related (training or competition) musculoskeletal pain in the lower limbs that causes a restriction on or stoppage of running (distance, speed, duration, or training) for at least 7 days or 3 consecutive scheduled training sessions, or that requires the runner to consult a physician or other health professional.” Running-related injuries may occur when repetitive stress is applied to a joint, muscle, tendon, or bone beyond maximum tolerance to mechanical stress.

While mechanical (e.g. biomechanics) and non-mechanical (e.g. sleep) factors could play a role in the onset of RRI, it is hypothesised that runners who sustain RRIs have exceeded their limit of running distance and/or intensity (training loads), over one or more training sessions, resulting in injury instead of tissue adaptation.

Previous literature reviews have investigated the role of training parameters such as distance, duration, frequency, intensity, as well as recent changes in training parameters, with the onset of RRIs. Despite identifying greater weekly running distance as a risk factor for the onset of RRIs among male runners, Van Gent et al. found in their systematic review published in 2007 that a recent increase in weekly running distance was a protective factor against knee injuries. However, only limited evidence suggested that other training parameters such as greater training frequency (males), greater training distance (females), recent increase in training days per week and recent increase in distance per week were risk factors for overall RRIs. Another review from 2012 reported conflicting results on the
relationship between running distance, duration, frequency and intensity with the onset of
RRIs. Heterogeneity in determinants of injuries between the included studies precluded any
association between training parameters and RRIs. Finally, in 2018, Damsted et al. found
very limited evidence from only four articles that sudden changes in training loads were
associated with increased risk of RRIs. Considering new evidence published since these
previous literature searches, an updated and more comprehensive review combining RRI
incidence and their association with training parameters is warranted. This could potentially
change recommendations provided to sports medicine practitioners, exercise professionals
and runners regarding optimal training parameters to help reduce injury risk.

The aim of this systematic review was to synthesise the current prospective evidence on the
incidence of lower limb RRIs, and explore the relationship between their onset and training
parameters (distance, duration, frequency, intensity), as well as with recent changes in
training parameters.

METHODS
This systematic review was registered in PROSPERO (CRD42018112913) and is reported
according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-
Analyses) 2009 guidelines.

Literature search
Bibliographical searches were conducted in four databases (Medline/Ovid, CINAHL,
Embase, SportDiscus) in collaboration with experienced research librarians. All databases
were searched from their inception to July 7, 2020 exploring three concepts: 1) running, 2)
musculoskeletal lower limb injury, pain or pathology, 3) training parameters. The terminology employed for the search strategy is presented in Supplemental Digital Content 1.

The search strategy was tailored for each database, using the appropriate truncation and medical subject heading (MeSH).

**Study selection**

To be included in the review, articles had to: (1) be published in English or French; (2) study humans engaging in running (defined by the authors as novice, recreational, competitive or mixed cohorts); (3) include any running program (structured or unstructured); (4) report on prospective cohort studies or randomised clinical trials (RCT); (5) report data on RRIs and training parameters (distance, duration, frequency, intensity) OR any measure of change in training parameters. Systematic reviews, conference abstracts and articles from the gray literature were excluded. There were no restrictions based on age, sex or gender.

After conducting the database search, duplicate articles were removed. Then, all articles were independently screened for eligibility by two different reviewers (*blinded*). The same reviewers independently screened the publications’ titles and abstracts to identify studies eligible for full-text review. Thereafter, eligible articles were retrieved in full text and two different raters (*blinded*) independently scrutinized full-texts to confirm inclusion. In case of disagreement on final inclusion, a third reviewer (*blinded*) was available to make the final decision. Bibliographical references of the retrieved studies were also searched to identify additional relevant publications.
A first reader extracted the data from all included studies, before a second reader corroborated and completed the extraction if necessary. Data were extracted according to a pre-defined standardised form that included: authors, study design, population, methods, definition of RRI, running program, study variables (training parameters, changes in training parameters), outcomes (incidence of RRIs), results and conclusions.

Critical appraisal

Methodological quality and risk of bias of included studies were assessed using a structured and validated quality appraisal tool, *The Quality assessment for evaluating primary research studies (QualSyst)*. The evaluation checklist includes 14 items pertaining to the study question and design, outcome measurements, interventions, analyses, results and conclusions. The items are scored depending on the degree to which the specific criteria are met (“yes” = 2, “partial” = 1, “no” = 0). Items not applicable to a particular study design were marked “N/A” and excluded from total score.

In order to ensure consistency in scoring, all team members involved in critical appraisal (blinded) met after independently assessing one of the included studies. Then, two raters (blinded) independently evaluated each study using the QualSyst criteria checklist. A pre-consensus, inter-rater reliability score using an intraclass correlation coefficient (ICC) with 95% confidence interval was calculated for total quality score. Thereafter, ratings were compared to reach a scoring consensus between both raters. When consensus was not reached, a third rater (blinded) was available to contribute to the final decision. The following classification was used to categorise methodological quality: ‘high quality’ (HQ) ≥80.0%; ‘good quality’ (GQ) 65.0-80.0%; ‘moderate quality’ (MQ) 50.0-64.9%; ‘low quality’ (LQ) <50.0%.14
Data analysis

A qualitative review of the evidence was conducted. The level of evidence was adapted from recommendations of the Cochrane Group Collaboration, and was classified as strong, moderate, limited, very limited, or conflicting (Table 1) after considering the following domains: imprecision (number of studies/participants), risk of bias (methodological quality), indirectness (methodological and outcomes similarities) and inconsistency (direction of results). In order to provide quantitative data about the incidence of RRI, total sample size and the number of injured runners was extracted for each study. A weighted average (%) was calculated for each category of runners (novice, recreational, competitive, mixed) by dividing the number of injured runners by the total number of runners.

RESULTS

The search strategy identified a total of 9,299 articles. After removing duplicates, the title and abstracts screening process identified 91 articles eligible for full-text review. Nine additional articles were included after handsearching the selected studies’ reference lists. After full-text screening, 36 studies were included in this review (Figure 1).

Characteristics of the studies

Of the 36 included studies, 33 were prospective cohort studies and 3 were RCTs. Altogether, the studies involved 23,047 runners (44% female), which only included individuals aged 17 and older. Seven studies were conducted specifically in novice runners (n=3,315; 63% female), thirteen in recreational runners (n=7,888; 44% female), five in competitive
runners (n=414; 48% female),\textsuperscript{36-40} and ten in runners of mixed levels of ability and experience (n=11,430; 39% female)(Table 2).\textsuperscript{4, 41-49}

**Methodological quality**

Methodological quality scores ranged from 27.3\% to 96.2\% (Table 3). On average, studies were of high methodological quality with a median score of 86.4\% (interquartile range = 19.3\%). Twenty-two studies were classified as “high quality”, five as “good quality”, five as “moderate quality” and four as “low quality”. The pre-consensus, inter-rater reliability score for quality assessment was excellent with an ICC of 0.97 [95\% CI 0.95, 0.99].

The most common reasons for deducting points on the methodological quality assessment were: outcomes being self-reported or not measured objectively (item 8; n=28), inappropriate or unjustified sample size (item 9; n=20), not reporting the participants’ selection methods or inclusion/exclusion criteria (item 3; n=18), and inappropriate consideration of confounding variables (item 12; n=14).

**Description of RRI**

An overview of the incidence of injuries is presented in Table 2. Only 14 studies out of the 36 used definitions of RRI similar to the consensus definition developed by Yamato et al.,\textsuperscript{7} in terms of reducing or missing consecutive training sessions because of pain, or the need to consult a healthcare professional. In total, 6,043 (26.2\%) runners sustained an injury among all 23,047 runners enrolled in all included studies. The incidence of RRI among the studies varied between 8.8\% and 91.3\% depending on the study population, length of follow-up and definition of an RRI. More specifically, the incidence of RRI was 14.9\% in novice runners (703 RRI in 4,720 runners; range: 9.4 to 94.9\%; follow-up: 6 weeks to 18 months).\textsuperscript{16-22, 48}
26.1% in recreational runners (2,057 RRIs in 7,888 runners; range: 17.9 to 79.3%; follow-up: 1 to 24 months), \textsuperscript{23-35} 62.6% in competitive runners (259 RRIs in 414 runners; range: 52.6 to 91.3%; follow-up: 3 to 24 months), \textsuperscript{36, 40} and 27.6% in runners of mixed levels (3,158 RRIs in 11,430 runners; range: 8.8 to 51.3%; follow-up: 3 to 60 months). \textsuperscript{4, 41-49} 

Based on data from studies reporting details on diagnoses, the most frequently injured body parts were the knee, the foot/ankle and the lower leg with 25.8%, 24.4% and 20.9% of all injuries, respectively. Novice runners sustained RRIs mostly to their knee (30.8%), lower leg (29.7%) and foot/ankle (18.1%). \textsuperscript{16-18, 20, 22, 48} In recreational runners, the knee (26.5%), foot/ankle (20.5%) and lower leg (20.2%) were the most frequent, \textsuperscript{23, 25-32, 34, 35, 48} while competitive runners most often injured their foot/ankle (39.4%), knee (25.4%) and lower leg (20.8%). \textsuperscript{36, 37, 39} In cohorts of runners of mixed levels, the most commonly injured body parts were the foot/ankle (26.3%), the knee (26.1%) and the lower leg (23.1%).

Training parameters

An overview of the running programs and of the variables of interest for this review is presented in Table 2. Overall, we found conflicting evidence about the association between RRIs and running distance (20 studies), duration (12 studies), frequency (10 studies) and intensity (14 studies). High heterogeneity between studies (definition of RRI, categories of runners, length of follow up) prevented us from performing meta-analyses on the association between RRIs and training parameters.

Running distance

Four HQ, \textsuperscript{32, 35, 37, 42} two MQ \textsuperscript{16, 43} and two LQ \textsuperscript{27, 36} studies suggested that greater running distance could increase injury risk. Three of these HQ studies reported that weekly distances
of over 30 km (hazard ratio [HR] = 3.28; 95% CI 1.23, 8.75; P = 0.02),\(^{35}\) over 64 km (adjusted relative risk = 2.88)\(^{42}\) or between 60-70 km (99.7% and 94.7% increased risk vs. 40-50 km and 50-60 km, respectively)\(^{37}\) were found to increase the risk of RRI. Another HQ study stated that running less than 40 km per week was a strong protective factor against calf injuries in recreational runners.\(^{32}\) The incidence of RRI was linked with greater distance during the first \((r^2 = 0.36, P = 0.001)\) and third \((r^2 = 0.16, P = 0.015)\) phases of the running program for novice runners that was used in the first MQ study,\(^{16}\) while the second study reported a significantly greater average weekly distance in injured compared with uninjured male recreational and competitive runners (effect size: \(r = 0.32, P = 0.046)\).\(^{43}\) The LQ studies observed more RRIs in a study group that ran more weekly distance,\(^{27}\) and a significant correlation between the injury rate during any one month and the distance covered by long-distance marathon runners during the preceding month \((r = 0.59)\).\(^{36}\)

On the other hand, two HQ,\(^{45, 49}\) one GQ,\(^{33}\) and one LQ\(^{24}\) studies reported a tendency for greater running distance to be protective against RRIs. Specifically, the first HQ study found a 10% reduced risk of knee injury (relative risk = 0.901; 95% CI 0.820, 0.991) in novice and recreational athletes running greater distance,\(^{49}\) while the other observed fewer injuries in those running more than 15 km per week, compared to those who ran less (risk difference \((RD) = 11.3\%; 95\% \text{ CI} -27.2, 4.6)\).\(^{45}\) The GQ study concluded that, overall, greater weekly distance was protective against RRIs (odds ratio (OR) = 0.99; \(\beta = 0.012)\).\(^{33}\) The LQ study reported a trend for more injuries in those running <20 miles per week (80% injury incidence) compared with >40 miles per week (50% injury incidence).\(^{24}\)

Three HQ,\(^{20, 29, 46}\) two GQ,\(^{25, 40}\) one MQ\(^{28}\) and one LQ\(^{50}\) studies reported no association between weekly running distance and the risk of RRI in cohorts of novice,\(^{20}\) recreational\(^{25, 28}\),
and competitive runners as well as runners of mixed levels. One HQ study reported conflicting results, associating greater distance with increased risk of RRI at the 5-year time point, but not after 1 year.

**Running duration**

One HQ study suggested that recreational runners were more at risk of RRI when running for sessions of longer duration (OR = 1.01; 95% CI 1.00, 1.02) as did one MQ study, which reported RRI incidence in novice runners of 22.0%, 24.0% and 54.0% in the 15, 30, and 45-minute duration groups, respectively. In contrast, three HQ studies reported that longer running duration could lead to fewer injuries. Specifically, running more than 60 minutes in the previous 7 days was a protective factor for the occurrence of RRI (HR = 0.41; 95% CI 0.20, 0.86). Greater mean session distance was also found to be a significant protective factor among recreational runners (HR = 0.795; 95% CI = 0.725, 0.872), while more weekly training hours were associated with less injuries, especially at the knee and foot, in a mixed cohort of novice and recreational runners (relative risk = 0.575; 95% CI 0.451, 0.731).

Five HQ and two GQ studies found no association between running duration and the incidence of RRIIs in cohorts of novice, recreational and competitive runners as well as in runners of mixed levels.

**Running frequency**

Two HQ and one MQ studies found that more frequent running tended to yield more injuries. In recreational and competitive runners, greater weekly frequency was linked with
more RRIs (7 days vs. 0-2 days). Running 3 times per week showed a trend for more injuries compared with 2 weekly sessions in novice runners (HR = 1.42; 95% CI 0.97, 2.08), although it did not reach statistical significance.\textsuperscript{19} The MQ study observed a 39% prevalence of injuries in those running 5 days per week, 12% in runners running 3 days per week and 0% in those running one day per week.\textsuperscript{22}

However, two HQ studies\textsuperscript{31, 34} reported that running more often could lead to less injuries in recreational runners. The first one observed that, in comparison with running 2-5 days per week, running only one day a week was a significant risk factor overall and in female runners (OR = 3.6; 95% CI 1.1, 12.3), although the trend was not significant in males.\textsuperscript{31} In the second study, greater frequency was associated with lower risk of RRI in the unadjusted statistical model (HR = 0.707, P = 0.002).\textsuperscript{34}

Two HQ,\textsuperscript{46, 47} two GQ\textsuperscript{25, 33} and one MQ\textsuperscript{28} studies reported no association between running frequency and injury rates in cohorts of recreational runners\textsuperscript{25, 28, 33} and runners of various levels.\textsuperscript{46, 47}

**Running Intensity**

One HQ study\textsuperscript{19} reported that greater running intensity in novice runners was more hazardous (HR = 1.28; 95% CI 1.18, 1.40). One MQ study\textsuperscript{41} noticed significantly more injuries in runners of mixed levels taking part in tempo runs during the first 6 weeks of a training program (OR = 3.96; 95% CI 1.35, 11.61), and a trend for more injuries in those practicing speed intervals (P = 0.06). The latter study reported that almost all runners who sustained RRIs (96.4%) had tempo or interval runs as part of their marathon training.\textsuperscript{41}
Two HQ studies suggested that greater running intensity could yield less RRI losses.

Performing speed intervals regularly was a protective factor for the occurrence of knee injuries among recreational marathon runners (OR = 0.49; 95% CI 0.26, 0.93). In a cohort of runners of mixed abilities, there was a tendency for fewer injuries amongst runners with a faster pace (>10 km/h; RD = 17.4%; 95% CI -39.0, 4.5).

Four HQ, 3 GQ, and one LQ studies found no association between running intensity and RRI losses in cohorts involving mostly recreational runners, but also competitive runners and mixed cohorts. Two HQ studies reported conflicting results. The first one found that speed training was associated with more injuries, and interval training with less injuries. The other reported that greater intensity was linked with more injuries at the 1-year time point (only in men), but not after 5 years.

**Changes in training parameters**

We found conflicting evidence about the association between RRI losses and specific changes in training parameters, based on 11 studies. Five reported that a recent increase in running distance was associated with increased risk of RRI. Specifically, one HQ study in 58 novice runners noticed that, over a 10-week follow-up, injured runners had a significantly higher distance progression the week before the onset of injury compared to other weeks (86% difference, 95% CI 12.9, 159.9; P = 0.026). Injured runners also had an average increase in weekly running distance of 31.6 ± 3.1%, compared with 22.1 ± 2.1% in uninjured runners, although the difference did not reach statistical difference (P = 0.07). According to another HQ study in 873 novice runners (12 months), those progressing weekly distance by more than 30% seemed more vulnerable to ‘distance-based injuries’ compared with those who progressed less than 10% (HR = 1.59; 95% CI 0.96, -2.66), P = 0.07). However, that...
same study found no association between overall incidence of injuries and distance progression. Another MQ study in 73 novice runners (18 months) associated greater risk of RRI to a recent increase in distance between different training phases of a program leading to the completion of a marathon, especially when increasing from a mean weekly distance of 34.9 km to 43.6 km and duration from 3.2 to 4.0h.¹⁶ One GQ study noticed a trend for University-level competitive runners (n=97) to sustain more injuries when they had larger differences in running distance between regular and high-mileage weeks during a 3-month cross-country season (P = 0.06).³⁹ One MQ study in a mixed cohort of 76 recreational and competitive runners reported that injured runners often increased their weekly distance by >30%, and even >50% in the four weeks before sustaining an injury, over the course of a 12-month follow-up.⁴³

Five other studies (3 HQ,⁴, ¹⁸, ³⁰ 1 GQ,³⁸ 1 LQ,⁵⁰) found no association between recent changes in training parameters and the incidence of RRIs. There was no link between week-to-week changes in frequency or duration of running and RRIs in a mixed cohort of novice and recreational runners.⁴ An RCT from the same research group showed that a 10% average increase in weekly running distance had no preventive effect on RRIs in novice runners, when compared with a weekly distance progression greater than 10% (OR = 0.8; 95% CI 0.6, 1.3).¹⁸

Another RCT reported a similar incidence of injuries in 447 recreational runners whose schedule focused on increasing intensity or distance, although the average weekly increase in volume was only 3.25%.³⁰ One more study in 17 recreational runners reported no difference in RRIs after increasing running distance by 103% or intensity by 152% over a 4-week period.⁵⁰ As for competitive runners, the acute to chronic workload ratio was not associated with the onset of RRIs in a small sample of 23 runners.³⁸
One HQ study reported conflicting results in 261 runners of mixed levels. Indeed, more RRI were recorded during the first 3 weeks of a 14-week training program in those increasing weekly running distance between 20-60% compared with those increasing their weekly distance by <20%. However, this association became non-significant after 7 and 14 weeks, and those increasing by >60% did not sustain more injuries.

DISCUSSION

Given the high volume of research on running injuries, this systematic review provides a much-needed update of the current state of the literature. Overall, the incidence of RRI across studies was 26.2%. While previous data suggested greater injury rates in novice compared with recreational runners, our findings suggest the opposite, with a greater incidence in recreational (26.1%) compared with novice runners (14.9%). In contrast with that previous review, we reported the number of events rather than injuries per 1,000 hours of running. Analyses based on exposure are interesting to put numbers into perspective. However, we believe that considering injuries as events happening during a running program of any duration can better inform injury prevention strategies, especially in novice and recreational runners. Almost half (48%) of novice runners who abandon a running program do so because of an injury. Thus, avoiding RRI appears essential to maintaining participation in running, and its associated health benefits. It is possible, however, that injuries per exposure time may better apply to the training reality of competitive runners, in which incidence was reported to be as high as 62.6% during follow-up periods of up to 24 months that likely included much more running than what novice and recreational runners do.
Overall, our findings show conflicting evidence about the role of specific training parameters (distance, duration, frequency, intensity), as well as the influence of recent changes in training on the onset of RRIs. In 2007, based on 17 studies (13 prospective, 4 retrospective), van Gent et al. had already outlined the conflicting level of evidence linking training parameters and RRIs. In 2012, based on 33 studies (13 prospective, 9 retrospective, 6 case-control series and 3 RCTs), Nielsen et al. also reported conflicting results between distance, duration, intensity and frequency of training and RRIs. Finally, a more recent and smaller systematic review based on only 4 studies concluded that there was very limited evidence that sudden changes in training loads were associated with the onset of RRIs. In comparison, the current review included 33 prospective cohort studies and 3 RCTs. The sole intervention in all of these studies consisted of a running program, and combined training parameters at large and recent changes in training. In our opinion, the persistence of conflicting results over the years speaks to a lack of consistent definitions and reporting guidelines in the field of RRIs. In addition, the relationship between training parameters and RRIs is certainly more complex than looking at training parameters in isolation.

Running programs don’t tell the whole story

Conflicting evidence found for the association between running distance, duration, intensity, frequency as well as recent changes in training and RRIs outlines the complexity of running injuries. Factors related to movement biomechanics, load-capacity and lifestyle factors are but a few elements that can contribute to the etiology of RRI. Importantly, these need to be measured and reported objectively in order to provide meaningful insights. Unfortunately, only 5 studies (14%) out of the 36 included in this review reported collecting GPS-based data to improve the accuracy of actual training loads. Moving forward, researchers should consider using wearable devices to provide a better picture of actual training...
parameters, instead of prescribed parameters, and to minimise reporting errors from participating runners.\textsuperscript{54} They should also consider reporting multiple components of workload, like intensity and frequency – not just distance \textsuperscript{55} – as well as patterns of variation experienced during the running program and around the timing of injuries to provide a better picture of training loads. Recent examples of studies including different running populations emphasise the substantial underestimation of changes in week-to-week training loads when only distance or duration are considered.\textsuperscript{56, 57}

Attributing the cause of RRIs solely to training loads – or external loads – fails to address the plethora of factors related to the individual – or internal loads – which vary between individuals, and even in the same individual over the course of a running program.\textsuperscript{58} The common advice of increasing distance by 10\% per week for all runners,\textsuperscript{59} in every situation, is too simplistic, and should not be recommended based on results from this review. A 10\% increase for a novice runner who runs 10 km per week is likely much safer than for a competitive runner who runs 150 km per week, including high-intensity workouts. In addition to experience and previous adaptations to exercise that involves impact, subjective measures of well-being, such as psychological stress, fatigue and recovery can all affect an athlete’s response and adaptation to training.\textsuperscript{60} Only 10 studies included in this review reported outcomes related to personality and mental health,\textsuperscript{17, 24, 26, 29, 41} diet,\textsuperscript{22, 39, 50} smoking habits\textsuperscript{22, 33, 42} or alcohol intake.\textsuperscript{33, 39} Only two studies asked questions about sleeping habits,\textsuperscript{22, 39} and only one documented hormonal variations and the use of contraceptives in female runners.\textsuperscript{39} Monitoring and reporting of these variables along with measures of internal loads is crucial to gain better understanding of the etiology of RRIs in both females and males. This should be considered especially in competitive runners, for which the interaction between training parameters and recovery could explain the higher rate of RRIs.
Limitations of this review, or limitations of included articles?

The clinical applicability of this review is limited because of its conflicting findings. However, conflicting findings stem from the many limitations of the included studies. Results regarding the incidence of RRIs in different running populations are limited due to the heterogeneity of definitions used in the different articles. Findings about RRIs and training parameters, or changes in these parameters, are limited because of the lack of objective data about training loads, and the lack of data on factors related to the individual. We understand that collecting all of these adds burden on research teams, and might not always be feasible depending on budget. However, unless these are addressed in future studies, we predict that future reviews will still report conflicting findings about the etiology of RRIs. It is also possible that the wide variability of factors affecting the capacity for adaptation in different runners precludes us from making specific recommendations for novice, recreational or competitive runners about training parameters in order to reduce the risk of RRIs. Running biomechanics, footwear and surface, or changes in these variables, should also be considered when possible.

Calling for unity

Meaningful conclusions and recommendations are made possible with consensus definitions and reporting guidelines. Unfortunately, less than 40% (14/36) of included studies used RRI definitions that were in accordance with, or similar to, the consensus definition published by Yamato et al.\textsuperscript{7} regarding reduced or missed consecutive training sessions because of pain, or consultation of a healthcare professional. Results from this review also call for a better standardisation of follow-up periods when monitoring injury incidence. Included studies varied between 1 and 60 months, making results too heterogeneous to generalise to the
running population. A set of reporting guidelines could include, for example, details on injuries sustained during each 2-week period of a running program (e.g. during weeks 1-2, weeks 3-4, weeks 5-6 and so on until the end of the study period). This could help to identify trends in injury incidence using a meta-analysis process, which was not possible in this review, and compare data in different levels of runners.

Novice, recreational and competitive running populations should be defined better. For the purpose of this review, we relied on information provided in the articles, although they may not be comparable. Despite a previous classification suggested based on existing literature, a scientific process to determine consensus definitions could provide clear guidelines that experts in the field agree upon. This would make it easier to improve study design and tailor research questions to the different populations, and unite multiple research teams in their efforts towards a common goal. Standardised guidelines could also translate to better research uptake by the running community, coaches and healthcare professionals.

Despite high rates of RRIs, there is conflicting evidence on the association between weekly running distance, duration, frequency and intensity, or recent changes in these parameters, and the incidence of RRIs. Thus, at this time, no specific recommendations related to optimal training parameters or progressions can be issued to guide clinical decision-making and program planning. This result is largely due to a lack of consistent definitions and reporting guidelines. Finally, RRIs are multifactorial, and likely not explained solely by training parameters. Future prospective studies on the incidence of RRIs should consider how variations in objectively-measured training parameters interact with factors related to the individual using psychosocial, hormonal, lifestyle and recovery outcomes.
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FIGURE LEGENDS

Figure 1. Flow diagram of the article selection process presented according to 2009 PRISMA guidelines

SUPPLEMENTAL CONTENT

Supplemental content 1. Search strategy.
| Level of evidence         | Definition                                                                                                                                 |
|--------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| **Strong evidence**      | Multiple HQ studies with consistent results, regardless of methodological heterogeneity.                                                      |
| **Moderate evidence**    | Multiple studies, including at least one HQ study; or multiples MQ or GQ studies; or multiple LQ studies, homogeneous methodologies; always providing consistent results. |
| **Conflicting evidence** | Multiple studies regardless of the methodological quality, with inconsistent results.                                                        |
| **Limited evidence**     | Multiple studies, with heterogeneous methodologies and/or inconsistent results; or single GQ study or higher.                                 |
| **Very limited evidence**| Results from single LQ or MQ study                                                                                                          |

Abbreviations: HQ: High quality; MQ: Moderate quality; GQ: Good quality; LQ: Low quality.
| Authors                  | Study Design (Follow up) | Sample size | % females | Mean age (years ±SD) or range (type of runners) | Running program | Incidence of RRIs | Association between RRIs and training parameters or recent changes in training parameters |
|--------------------------|--------------------------|-------------|-----------|-----------------------------------------------|----------------|-----------------|-------------------------------------------------|
| Becker et al. 40         | Prospective (24 months)  | n=24        | 37.5%     | Mean age=19±1.2 years (Competitive)            | Usual training routine of the team | 75.0% of runners (18/24) reported RRIs | Running distance: No difference in weekly volume between injured (52 +/- 21.8 km) and not injured (54 +/- 24.1 km) (p = 0.684) |
| Begizew et al. 37        | Prospective (10 months)  | n=229       | 52.8%     | Mean age N/A 17-26 years old: n=205 >26 years old: n=24 (Competitive) | Self-selected running program | 62.4% of runners (143/229) reported RRIs | Running distance: 40-50 km/week = 99.7% lower risk of RRI than 60-70 km/week (OR = 0.003, 95% CI, 0.000, 0.073; p ≤ 0.0001). 50-60 km/week = 94.7% lower risk of RRI than 60-70 km/week (OR = 0.053, 95% CI, 0.004, 0.728; p ≤ 0.028). |
| Bovens et al. 16         | Prospective (18 months)  | n=73        | 13%       | Mean age=35.2±7.9 years (males); mean age=33.5±6.4 years (females) (Novice) | Training program with 3 phases; each phase finishing with a race (15, 25 and 42km) Phase 1=28 weeks (mean per week of 2.7 h, 3.8 trainings and 24.1 km) Phase 2=23 weeks (mean per week of 3.2 h, 3.6 trainings and 34.9 km) Phase 3=30 weeks (mean per week of 4.0 h, 3.5 trainings and 43.6 km) | 84.9% of runners (62/73) reported RRIs | Incidence of RRIs per phase: Phase 1=58% Phase 2=60% Phase 3=67% | Running distance: Greater distance was related to more injuries during Phase 1 (r² = 0.36, p = 0.001) and Phase 3 (r² = 0.16, p = 0.015). Running duration and frequency: No analyses were reported. Recent changes: Significant increase in injury rates between Phase 1-2, and between Phases 1-3. The amount of training during the last phase of preparation for the marathon brought an additional injury risk (from mean distance/week of 34.9km to 43.6km/ from mean duration h/week of 3.2 to 4.0h) |

Note: RRIs = Running Related Injuries
| Study            | Sample Size | Gender Distribution | Mean Age (Range) | Training Protocol | Injury Rate | Recent Changes |
|------------------|-------------|---------------------|------------------|-------------------|-------------|----------------|
| Buist et al. 18  | n=532       | 57.5% females       | 39.8±10.1 years  | 1. Graded training group (GTG): < 10% volume progression per week (13 weeks) 2. Standard training group (STG): > 10% volume progression per week (8 weeks) | 1. GTG: 20.8% of runners (52/250) reported RRIs 2. STG: 20.3% of runners (48/236) reported RRIss | Recent changes: No effect of a graded “10% rule” on RRIss, compared with a standard training program (p = 0.90) |
| Buist et al. 4    | n=629       | 67.1% females       | 43.7±9.5 years   | 8-week training program | 25.9% of runners (163/629) reported RRIss | Running duration: Not associated with RRIss (p > 0.38) |
| Buist et al. 17   | n=532 (486 did the running program) | 57.5% females | 39.8±10.1 years (Novice) | 1. Graded training group (GTG): < 10% volume progression per week (13 weeks) 2. Standard training group (STG): > 10% volume progression per week (8 weeks) | 20.6% of runners (100/486) reported RRIss | Running duration: Not associated with RRIss |
| Dallinga et al. 23| n=706       | 46.9% females       | 43.9±11.6 years  | Usual training routine in preparation for an 8 or 16 km run | 20.1% of runners (142/706) reported RRISS in preparation or during the event. | Running distance and duration: Not associated with RRIss  
Duration: OR (95%CI) = 1.00 (0.999, 1.002)  
Distance: OR (95%CI) = 1.24 (0.65, 2.38) |
| Damsted et al. 45 | n=508       | 62.2% females       | 37 years, range = 29-46 (All abilities) | 1) Distance-based schedule 2) Pace-based schedule 3) Mixed schedule 4) Self-chosen running program (not analyzed in this article) | 26.8% of runners (136/508) reported RRIss across all running schedules. | Running distance and intensity: Tendency (non-significant) for fewer injuries amongst runners with running distance >15 km/week (RD = -11.3%, 95% CI -27.2, 4.6), high pace (RD = -17.4%, 95% CI -39.0, 4.5), or a combination of both (RD = -8.1%, 95% CI -22.3, 6.1) |
| Study               | Prospective | n  | Gender   | Mean age | Range | All abilities |
|---------------------|-------------|----|----------|----------|--------|---------------|
| Damsted et al.       | 14 weeks    | 261| 60.2%    | 36 years | 27-45  | (All abilities) |
|                     |             |    |          |          |        |               |
| 1) Distance-based schedule |          |    |          |          |        | 21.5% of runners (56/261) reported RRI |
| 2) Pace-based schedule |          |    |          |          |        | 24.2% of runners (40/165) in the distance-based running schedule |
|                     |             |    |          |          |        | 16.7% of runners (16/96) in the pace-based running schedule |
| Recent changes:     |             |    |          |          |        | More runners were injured when increasing their weekly running distance between 20-60% compared with increasing ≤20% (only at 21 days, and not at 56 or 91 days. |
|                     |             |    |          |          |        | RD<sub>21</sub> days = 22.6%, 95% CI 0.9, 44.3 |
|                     |             |    |          |          |        | RD<sub>56</sub> days = 19.0%, 95% CI -11.9, 50.0 |
|                     |             |    |          |          |        | RD<sub>98</sub> days = 4.2%, 95% CI -26.2, 34.7 |
|                     |             |    |          |          |        | No difference between runners increasing distance >60%. |
|                     |             |    |          |          |        | RD<sub>21</sub> days = 5.8%, 95% CI -8.4; 20.1 |
|                     |             |    |          |          |        | RD<sub>56</sub> days = 7.8%, 95% CI -14.0; 29.6 |
|                     |             |    |          |          |        | RD<sub>98</sub> days = -4.3%, 95% CI -27.9; 19.3 |

| Study               | Prospective | n  | Gender   | Mean age | Range | All abilities |
|---------------------|-------------|----|----------|----------|--------|---------------|
| Dijkhuis et al.      | 24 months   | 23 | 30.4%    | 22.5±5.7 years |        | (Competitive) |
|                     |             |    |          |          |        |               |
| Individualised program designed by the running coach |          |    |          |          |        | 91.3% of runners (21/23) reported RRI |
| Running duration and intensity: |             |    |          |          |        | No associations between the acute workload, the chronic workload and the risk of RRI. (p > 0.05) |
| Recent changes:     |             |    |          |          |        | No associations between the weekly “acute to chronic workload ratio” and the risk of RRI. |
|                     |             |    |          |          |        | Week 1-2: p > 0.451 |
|                     |             |    |          |          |        | Week 2-3: p > 0.494, except for ‘low increase’ (p = 0.013) |
|                     |             |    |          |          |        | Week 3-4: p > 0.125 |

| Study               | Prospective | n  | Gender   | Mean age | Range | All abilities |
|---------------------|-------------|----|----------|----------|--------|---------------|
| Fields et al.       | 12 months   | 40 | 22.5%    | 37 years | 20-40 years | (Recreational) |
|                     |             |    |          |          | 41-60 years | (Recreational) |
| Self-selected running program |          |    |          |          |        | 42.5% of runners (17/40) reported RRI |
| Running distance:   |             |    |          |          |        | No significant association with RRIs, despite 80% of those running < 20 miles/week getting RRIs vs. 50% of those running > 40 miles/week. |

| Study               | Prospective | n  | Gender   | Mean age | Range | All abilities |
|---------------------|-------------|----|----------|----------|--------|---------------|
| Fokkema et al.      |             | 997| 35.0%    |          |        |               |
| Online running program for a half-marathon or a marathon |          |    |          |          |        | 51.3% of runners (511/997) reported RRI |
| Running distance, duration and intensity: |             |    |          |          |        | No associations with the risk of RRI. |
Mean age=42.2±11.7 years
(All abilities)

Weekly distance (vs. 20-32 km):
<20km: OR 1.41, 95%CI 0.86, 2.32
>32km: OR 0.97, 95%CI 0.63, 1.50

Duration of longest run (vs. 15-21 km):
<15km: OR 1.19, 95% CI 0.69, 2.04
>21: OR 0.83, 95% CI 0.52, 1.30

Intensity (vs. 5:15-6:00 min/km)
<5:15 min/km: OR 0.68, 95% CI 0.41, 1.11
>6:00 min/km: OR 1.23, 95% CI 0.77, 1.98

Hamstra-Wright et al.41
Prospective (18 weeks)
n=113
74.3% females
Age range=20-70 years
(All abilities)
18-week marathon training program
24.8% of runners (28/113) reported RRI

Running intensity:
96.4% (27/28) of runners injured during the first 6 weeks were doing tempo or interval runs.
56.9% (37/65) of runners non injured during the first 6 weeks were doing tempo or interval runs,
with similar mileage as the injured runners.

Participating in tempo runs during the first 6 weeks increased odds of RRI: OR = 3.96, 95% CI 1.35, 11.61.
Participating in interval runs during the first 6 weeks tended to increase odds of RRI (although not significant; p = 0.06)

Hayes et al.39
Prospective (3 months)
n=97
58.8% females
Mean age=19.2±0.2 years (females); Mean age=19.0±0.2 years (males)
(Competitive)
Cross-country season training program from University coach
52.6% of runners (51/97) reported RRI

Recent changes:
Athletes with larger differences in running volume between regular and high-mileage weeks were more likely to sustain an injury, however, the results did not reach statistical significance (p = 0.06)

Hespanhol Junior et al.26
Prospective (12 weeks)
n=200
26% females
Mean age=42.8±10.5 years
Self-selected running program
31.4% of runners (60/191) reported RRI.

Running duration:
Greater duration of training session associated with greater risk of RRI (OR = 1.01, 95% CI 1.00, 1.02)
Inconclusive results; Speed training associated with greater risk of RRI (OR = 1.46, 95% CI 1.02, 2.10), but interval training associated with lower risk of RRI (OR = 0.61, 95% CI 0.43, 0.88).

Running distance, duration, frequency, intensity:
No associations with the risk of RRI.
Distance: p = 0.51
Duration: p = 0.25
Frequency: p = 0.65
Intensity: p = 0.68

Running frequency:
No associations with the risk of RRI during the 5-year recall period, or during the 1-year recall period.

Running intensity:
No associations with the risk of RRI during the 5-year recall period. During the 1-year recall period, lower intensity (15+ minutes / mile) associated with lower risk of RRI only in men (OR = 0.51, 95% CI 0.35, 0.74).

Running distance:
Significantly more RRI's in study group (p < 0.001), who ran more weekly distance at the same pace.
RRIs / 1000 hours of running:
Study group: 7.4 during training and 30.7 during races;
Control group: 6.9 during training and 62.5 during races.

When adjusted for training time, the incidence of RRIs was similar in both groups.

Mean running distance (km/week):
Study group: 43.0, 95% CI 41.6, 44.4
Control group: 33.4, 95% CI 32.0, 34.9

Kemler et al.48
Prospective (3 months) n=4,621
41.8% females
Mean age=34.2 years (Novice, Experienced)
Usual training routine
8.8% of runners (405/4,621) reported RRIs within the 3-months recall period:
9.5% of novice runners (134/1,405) reported RRIs
8.4% of experienced runners (271/3,216) reported RRIs

Kluitenberge et al.19
Prospective (6 weeks) n=1,696
78.5% females
Mean age=43.3±10.0 years (Novice)
6 weeks “Start to Run” program
10.9% of runners (159/1,696) reported RRIs.

Lehmann et al.50
Prospective n=17
Unknown % females
Year 1: 103% increase in running volume (ITV; n=8)
Only minor injuries which did not alter the planned training were

Running duration:
No association with injury incidence - Novice: mean of 14.6 hours (interquartile range 32.5) vs. Experienced: mean of 30.0 hours (interquartile range 67.5) for similar injury rates.

Running duration:
Running more than 60 minutes in the previous 7 days was protective for the occurrence of RRI (multivariate analysis: HR 0.41; 95% CI 0.20, 0.86).

Running frequency:
Not significantly associated with RRI, but a trend that running three times per week is more hazardous than two times per week was observed (HR 1.42; 95% CI 0.97, 2.08).

Running intensity:
Higher intensity was associated with RRI occurrence (multivariate analyses: HR 1.28; 95% CI 1.18, 1.40).

Running distance:
Mean age = 33.5 years (Experienced distance runners)

Year 2: 152% increase in running intensity (ITI; n=9; 7 had participated in Year 1) observed. No details on number or type of injuries.

ITV: average distance increased from 85.9 km to 174.6 km (week-to-week increases of 33.9%, 32.6% and 36.8%). No more injuries than ITI, which increased from 61.7 km to 84.7 km (week-to-week increase of 1.9%, 20.0% and 12.2%).

Running intensity:
ITI: tempo-pace and interval runs increased week-to-week from 14.7% of total training (9.0 km) to 23.7% (14.9 km), 24.6% (18.6 km) and 26.8% (22.9 km). No more injuries than ITV, which changed from 7.3% of total training (6.3 km) to 4.0% (4.6 km), 3.8% (5.4 km) and 2.0% (3.5 km).

Recent changes:
No change in risk of RRI based on changes in distance and intensity outlined above.

Lun et al.\textsuperscript{28}
Prospective (6 months)
n=87
49.4% females
Mean age = 38 years (Recreational)

Usual training routine
79.3% of runners (69/87) reported RRI.

Incidence of RRI / 1000 h of running:
59%

Running distance:
No significant difference in incidence of RRI between non-injured (30.3 km) and injured (34.2 km)

Running frequency:
No difference between non-injured (3.8/week) and injured (3.7/week)

Lysholm et al.\textsuperscript{36}
Prospective (12 months)
n=41 (sprinters excluded)
9.8% females
Mean age = 18.6±2.4 years (middle-distance runners); 34.5±7.4 years (long-distance runners) (Competitive)

Training with their athletic clubs
76.9% of middle-distance runners (10/13) reported RRI.
57.1% of long-distance runners (16/28) reported RRI.

5.6 RRI / 1000 h in middle-distance runners
2.5 RRI / 1000 h in long-distance runners

Running distance:
A significant correlation was found in long-distance runners, between greater distance covered during a given month and the number of injury days the following month (r = 0.59).
Malisoux et al.34
Prospective (22 weeks)
n=264 26.1% females
Single shoe (SS; n=116): Mean age=40.5±9.8 years
Multiple shoes (MS; n=148): Mean age=44.2±8.8 years
Usual training routine (at least once a week)
33.1% of runners (87/264) reported RRI
7.64 RRI / 1000 hours of running

Running duration:
Greater session duration associated with lower risk of RRI in unadjusted model (HR = 0.963, p < 0.001)

Running frequency:
Greater frequency associated with lower risk of RRI in unadjusted model (HR = 0.707, p = 0.002)

Running intensity:
Greater intensity not associated with risk of RRI (HR = 0.873, p = 0.248)

Messier et al.29
Prospective (24 months)
n=300 42.7% females
Mean age (injured)=42.3±9.7 years
Mean age (uninjured)=40.0±10.3 years
Self-selected running program
66.3% of runners (199/300) reported RRI
55.8% of injured runners (111/199) were injured more than once within the 24-month observation period.

Running distance:
No association with risk of RRI (p = 0.16)

Running intensity:
No association with risk of RRI (OR = 1.058, 95% CI 0.727, 1.540), p = 0.20

Nielsen et al.20
Prospective (10 weeks)
n=58 48.3% females
Mean age=39.8±9.2 years
Not reported
22.4% of runners (13/58) reported RRI

Running distance:
No association with risk of RRI (p = 0.23)

Recent changes:
Although not statistically significant (P=0.07), injured runners had an average increase in weekly running distance of 31.6 ± 3.1%, compared with a 22.1 ± 2.1% increase in uninjured runners.

Injured runners had a significantly higher weekly progression in running distance the week before the onset of injury compared to the other weeks (86% difference, 95% CI 12.9, 159.9; P=0.026).
Nielsen et al.21
Prospective (12 months)
n=873
49.5% females
Mean age=37.2±10.2 years (Novice)
Self- selected running program
23.1% of runners (202/873) reported RRI

Recent changes:
No difference in the risk of RRI between different progressions in weekly distance (rolling average calculated after each running session – not cumulative average change in volume).
<10%, HR=1.00 (reference)
10%-30%, HR = 0.99 (95% CI 0.55, 1.82);
>30%, HR = 1.17 (95% CI 0.84, 1.63).
Those progressing >30% were more vulnerable to distance-related injuries compared with <10% (HR = 1.59, 95% CI 0.96, 2.66; p = 0.07).

Pollock et al.22
RCT (20 weeks)
Cohort 1:
n=87 (18 controls)
0% females
Mean age=N/A
Cohort 2:
n=71 (13 controls)
0% females
Mean age=N/A (Novice)

Cohort 1, Duration study: 3 days per week for 15, 30, or 45-minutes. Total = 20 weeks.
Cohort 2, Frequency study: 30-minute runs 1, 3, or 5 days/week. Total = 20 weeks.
26.0% of runners (33/127) reported RRI
1. Duration study: 33.3% of runners (23/69) reported RRI
RRI reported in 20.0% (4/20), 24.0% (6/25) and 54.2% (13/24) of the 15, 30, and 45-min duration groups respectively.
2. Frequency study: 17.2% of runners (10/58) reported RRI
RRI reported in 0% (0/15), 12.0% (3/25), and 38.9% (7/18) of the 1, 3, and 5-day/week groups, respectively.

Running duration:
Greater running duration (45 min/session) was associated with increased risk of RRI

Running frequency:
Greater running frequency (5x/week) was associated with increased risk of RRI

Ramskov et al.30
RCT (24 weeks)
n=839 (447 considered in analyses)
62.1% females
Mean age=39.1±10.2 years (Recreational)
16-week running program based on progression of either running intensity (S-I) or volume (S-V)
3 runs per week, 4-week periodisation cycle repeated 6 times. Week 1 in every cycle progressed volume by 23%.
17.9% of runners (80/447) reported RRI
S-I group: 16.3% of runners (36/221) reported RRI, of which 8/36 were intensity-related, and 5/36 were volume-related.
S-V group: 19.5% of runners (44/226) reported RRI, of which 11/44 were

Recent changes:
No differences in overall incidence of RRI between progression of distance or intensity, or the type of injuries sustained by runners of each group.
Distance: p > 0.14
Intensity: p > 0.32
Weeks 2-3 were adaptation weeks, with 0% progression in running. Week 4 regressed volume by 10%. Progression/regression of running in S-I consisted of a percentage change in weekly kilometers at an intensity equal to or above 88% maximal oxygen consumption.

No difference in risk of intensity RRI and volume RRI between runners in the S-I and S-V groups at any time points over the 16-week follow-up.

Running frequency:
Running less often (only one day per week) was associated with increased risk of RRI in the overall cohort and in female runners (OR = 3.6, 95% CI 1.1, 12.3), but not in male runners.

Running distance:
Weekly distance over 30 km was associated with a greater risk of RRI (HR = 3.28, 95% CI 1.23, 8.75)
< 10 km: 28.3% of runners (41/145) reported RRs
10-20 km: 25.0% of runners (30/120) reported RRs
21-30 km: 34.8% of runners (16/46) reported RRs
> 30 km: 46.2% of runners (6/13) reported RRs

Running intensity:
Weekly running volume < 40 km was a protective factor for calf injuries (OR = 0.36, 95% CI 0.17, 0.78).

| Study            | Design | n   | Gender Ratio | Age Categories | Program Duration | Target Race | Duration Leading to Marathon | Weekly Distance | Weekly Volume | RRIs | Injury Risk Factor(s) |
|------------------|--------|-----|--------------|----------------|------------------|-------------|-------------------------------|----------------|--------------|------|----------------------|
| Taunton et al.31 | Prospective 13 weeks | 844 | 75.2% females | Age by category: ≤ 30 years (16.8%), 31-49 years (59.8%), 50-55 years (13.2%), >56 years (8.8%) | 13-week program to complete a 10-km race | 29.5% of runners (249/844) reported RRIs |
| Van Der Worp et al.35 | Prospective 12 weeks | 417 | 100% females | Mean age=38.7± 11.5 years | Self-selected running program | 22.3% of runners (93/417) reported RRIs |
| Van Middelkoop et al.32 | Prospective 4 weeks | 694 | 0% females | Mean age=44±9.6 years | Self-selected running program during the 4 weeks leading up to a marathon | 28.1% of runners (195/694) reported RRIs |
| Study            | Sample Size | Gender Distribution | Age Distribution | Usual Running Routine | Risk Factors |
|------------------|-------------|---------------------|------------------|-----------------------|--------------|
| Van Poppel et al. | n=3,768     | 39.2% females       | Mean age=42.8±11.2 years (Recreational) | Usual running routine | 21.5% of runners (811/3,768) reported RRIs | Consistently performing interval training was a protective factor for the occurrence of knee injuries (OR = 0.49, 95% CI 0.26, 0.93). |
| Running distance: |             |                     |                  |                       | 17.5% of the 5-km runners (67/250) reported RRIs | |
|                  |             |                     |                  |                       | 18.7% of the 10-km or 15-km runners (257/981) reported RRIs | |
|                  |             |                     |                  |                       | 23.1% of the half marathon runners (214/708) reported RRIs | |
|                  |             |                     |                  |                       | 25.2% of the marathon runners (266/762) reported RRIs | |
| Running frequency: |             |                     |                  |                       | No association with risk of RRI (OR =1.3; 95% CI 0.99, 1.7) | |
| Running intensity: |             |                     |                  |                       | No association with risk of RRI | |
| Walter et al.     | n=1,288     | 23.5% females       | Age by category: | Usual running routine | 48.1% of runners (620/1,288) reported RRIs | A greater weekly distance was associated with a lower risk of RRI (OR = 0.99; 95% CI 0.98, 1.0). |
| (12 months)       |             |                     | 14-19 years=11.3% |                       |                  | |
|                  |             |                     | 20-29 years=21.2% |                       |                  | |
|                  |             |                     | 30-39 years=39.3% |                       |                  | |
|                  |             |                     | 40-49 years=21.0% |                       |                  | |
|                  |             |                     | >50 years=7.1%    |                       |                  | |
| (Recreational, Competitive) |     |                     |                  |                       |                  | |
| Running distance: |             |                     |                  |                       | A greater weekly distance (over 64 km) was associated with a higher risk of RRI (adjusted relative risk = 2.88). Relative risk in males = 2.22, 95% CI 1.30, 3.68. Relative risk in females = 3.42, 95% CI 1.42, 7.85. | |
| Running frequency: |             |                     |                  |                       | Running 7 days per week was associated with significantly greater risk of RRI compared with 0-2 days per week in both males (relative risk = 5.92, 95% CI 2.49, 12.75) and females (relative risk = 5.50, 95% CI 1.44, 17.39). | |
| Running intensity: |             |                     |                  |                       | No association with risk of RRI | |
| Wen et al.        | n=108       | 52.8% female        | Mean age=43.2±9.8 years (Novice, Recreational) | 32-week program leading up to a marathon. Organised sessions weekly, and own program during the week. | 45.4% of runners (49/108) reported RRIs | Greater distance associated with lower risk of RRI at the knee (relative risk = 0.901, 95% CI 0.820, 0.991). |
| (32 weeks)        |             |                     |                  |                       | 1.22 injuries / 1000 miles (0.97-1.48) | |
| Running distance: |             |                     |                  |                       | | |
| Running frequency: |             |                     |                  |                       | | |
| Running intensity: |             |                     |                  |                       | | |
Winter et al.\textsuperscript{43} Prospective (12 months) n=76 40.8% females Mean age=40.7±12.5 years (injured); 44.8±12.5 years (non injured) (Recreational, Competitive) Self-selected running program 51.3% of runners (39/76) reported RRIs

More training hours per week associated with less overall RRIs (relative risk = 0.575, 95% CI 0.451, 0.731), less knee injuries (relative risk = 0.486, 95% CI 0.297, 0.795) and less foot injuries (relative risk = 0.206, 95% CI 0.096, 0.444).

Running distance:
Injured male runners had a significantly greater average weekly distance compared with uninjured male runners (P = 0.046; r = 0.32). No difference in female runners.

Recent changes:
Injured male (n=20; 91%) and female (n=10; 59%) runners increased weekly distance by >10% between consecutive weeks at least once in the 4 weeks prior to injury.

Of the 18 injured male runners who increased running distance by >10% on 1 occasion, 11 (61%) increased by >30% and 5 (28%) increased by >50%.

Of the 9 injured female runners who increased running distance by >10% on 1 occasion, 5 (56%) increased by >30% and 3 (33%) increased by >50%.

Abbreviations: CI, Confidence interval; HR, Hazard ratio; NR, Not reported; OR, Odds ratio; RCT, Randomised clinical trial; RD, Risk difference; RRI, Running related injury; SD, Standard deviation.
| Study                        | Methodological quality | Total score (%) |
|------------------------------|------------------------|-----------------|
| Becker et al.                | GQ                     | 72.7            |
| Begizew et al.               | HQ                     | 86.4            |
| Bovens et al.                | MQ                     | 59.1            |
| Buist et al.                 | HQ                     | 85.5            |
| Buist et al.                 | MQ                     | 59.1            |
| Damsted et al.               | HQ                     | 86.4            |
| Damsted et al.               | HQ                     | 86.4            |
| Dijkhuis et al.              | GQ                     | 75.0            |
| Fields et al.                | LQ                     | 50.0            |
| Fokkema et al.               | HQ                     | 90.9            |
| Hamstra-Wright et al.        | MQ                     | 63.6            |
| Hayes et al.                 | GQ                     | 77.3            |
| Hespanhol Junior et al.      | HQ                     | 95.5            |
| Hespanhol Junior et al.      | GQ                     | 72.7            |
| Hootman et al.               | HQ                     | 90.9            |
| Jakobsen et al.              | LQ                     | 27.3            |
| Kemler et al.                | HQ                     | 86.4            |
| Kluitenberg et al.           | HQ                     | 90.9            |
| Lehmann et al.               | LQ                     | 45.5            |
| Lun et al.                   | MQ                     | 68.2            |
| Lysholm et al.               | LQ                     | 36.5            |
| Maisouix et al.              | HQ                     | 90.9            |
| Messier et al.               | HQ                     | 90.9            |
| Nielsen et al.               | HQ                     | 90.9            |
| Nielsen et al.               | HQ                     | 90.9            |
| Pollock et al.               | HQ                     | 81.8            |
| Ramskov et al.               | MQ                     | 96.2            |
| Taunton et al.               | HQ                     | 90.9            |
| Van Der Worp et al.          | HQ                     | 90.9            |
| Van Middelhoop et al.        | HQ                     | 86.4            |
| Van Poppel et al.            | GQ                     | 77.3            |
| Walter et al.                | HQ                     | 81.8            |
| Wen et al.                   | HQ                     | 90.9            |
| Winter et al.                | MQ                     | 68.2            |

The Quality assessment for evaluating primary research studies (QualSys) includes the following items: Item 1, Description of study question/objective; Item 2, Appropriate study design for objective; Item 3, Description of subject selection strategy; Item 4, Description of subjects’ characteristics; Item 5, Random allocation; Item 6, Blinding of investigators; Item 7, Blinding of participants; Item 8, Outcomes and exposures well-defined and robust; Item 9, Appropriate sample size; Item 10, Appropriate
statistical analyses; Item 11, Estimates of variance; Item 12, Controlled for confounding; Item 13, Sufficiently reported results; Item 14, Results support conclusions.

Scoring: Y, Yes=2; P, Partial=1; N, No=0; N/A, Not applicable. The items n/a were excluded from the total score. Methodological quality: “high quality” (HQ) >80.0 %; “good quality” (GQ) between 65.0 and 80.0 %; “moderate quality” (MQ) between 50.0 and 64.9 %; “low quality” (LQ) <50.0 %.
Records identified through database searching 
\( n = 9,299 \)  
(Medline/Ovid \( n = 2,129 \))  
(Embase \( n = 4,103 \))  
(CINHAL \( n = 1,324 \))  
(SPORTDiscus \( n = 1,743 \))

Articles identified by screening of reference list of eligible articles 
\( n = 9 \)

Records after duplicates removed 
\( n = 5,028 \)

Records screened 
\( n = 5,028 \)

Records excluded 
Animal research, irrelevant topics 
\( n = 4,083 \)  
Did not satisfy selection criteria, gray literature, systematic reviews 
\( n = 845 \)

Full-text articles assessed for eligibility 
\( n = 100 \)

Full text excluded 
Outcomes of interest 
\( n = 41 \)  
Shoes intervention 
\( n = 3 \)  
Military studies, not running-specific 
\( n = 9 \)  
Biomechanical studies 
\( n = 4 \)  
Full text not available 
\( n = 7 \)

Studies included in qualitative analysis 
\( n = 36 \)
Supplemental Content 1. Search strategy

Part A. Terminology used for the search strategy

| Concept 1: Running | Concept 2A: Musculoskeletal lower limb injury or pain | Concept 2B: Diagnosis | Concept 3A: Training | Concept 3B: Parameters |
|-------------------|-----------------------------------------------------|------------------------|----------------------|------------------------|
| Run               | Leg                                                 | tendinopathy           | train*               | characteristic*        |
| runs              | Legs                                                | patellofemoral pain    | exercise             | parameter*             |
| Running*          | Ankle*                                              | stress fracture*        | circuit              | progression*           |
| Runner*           | Femoral*                                            | iliotibial band         | aerobic              | schedule*              |
| Jog               | Foot                                                | syndrome                | cardio*              | frequenc*              |
| Joggs             | Knee*                                               | metatarsalgia           | fitness              | duration*              |
| Jogging*          | Tibial                                              | bone injury             | physical             | intensit*              |
| Jogger*           | Hip*                                                | medial tib* stress      | therapy              | speed                  |
| Foot race         | Lower limb                                          | syndrome                | program              | error*                 |
|                   | Lower extremity                                     |                         | intervention*         | mileage*               |
|                   | lower extremities                                   |                         | protocol*             |                       |
|                   | Athletic                                            |                         |                       |                       |
|                   | Sport                                               |                         |                       |                       |
|                   | Sports                                              |                         |                       |                       |
|                   | musculoskeletal                                     |                         |                       |                       |
|                   | overuse                                             |                         |                       |                       |
|                   | Soft-tissue                                        |                         |                       |                       |
|                   | strain                                              |                         |                       |                       |
|                   | injury                                              |                         |                       |                       |
|                   | pain                                                |                         |                       |                       |
|                   | trauma                                              |                         |                       |                       |
|                   | damage                                              |                         |                       |                       |
Part B. Search terms used in each database

**Medline/Ovid**

Exp Running OR (run or runs or running* or runner* or jog or jogs or jogging* or jogger* or foot race* or marathon* or ultramarathon* or sprint* or ultrarunner*)

AND

((exp Leg Injuries/) OR (Athletic Injuries/ or exp Running/in) OR (hip injuries/ or hip fractures/) OR (Soft Tissue Injuries/) OR (Musculoskeletal Pain/) OR (exp musculoskeletal diseases/ or bone diseases/ or cartilage diseases/ or fasciitis/ or foot OR diseases/ or joint diseases/ or muscular diseases/) OR (exp Lower Extremity/in)) OR ((injury or injuri* or pain or pains or damage* or trauma or traumas) adj4 (leg or legs or ankle* or femoral* or foot or feet or knee or knees or hip or hips or "lower limb*" or "lower extremi*" or athletic* or sport or sports or running or musculoskeletal or overuse or "over use*" or "soft tissue*" or strain or tendon* or muscle*)) OR ((Patellofemoral Pain Syndrome/) OR (fractures, bone/ or ankle fractures/ or femoral fractures/ or fractures, stress/ or tibial fractures/) OR (muscular diseases/ or compartment syndromes/ or medial tibial stress syndrome/ or muscle cramp/ or musculoskeletal pain/ or tendinopathy/) OR ("Sprains and Strains") OR (joint diseases/ or arthritis/gia) OR (Fasciitis, Plantar/) OR (achilles tendon/in or hamstring tendons/in)) OR (tendinopathy* or "patellofemoral pain" or "stress fracture*" or "iliotibial band syndrome*" or metatarsalgia or "bone injury" or "medial tibia stress syndrome*" or "medial tibial stress syndrome*" or "muscle strain*" or arthropath* or "plantar fasciitis" or "tissue inflammation"))

AND

((exp Athletic Performance/) OR (exercise/ or physical conditioning, human/) OR ("Physical Education and Training") OR (exp Physical Fitness/ or physical endurance/ or exercise tolerance/)) OR (train* or exercise or circuit or aerobic or cardio* or fitness or physical or program* or protocol* or activity* or regim* or conditioning or performance)

AND

(characteristic* or parameter* or progression* or volume* or schedul* or frequent* or duration* or intensit* or speed or error* or pace or mileage*)

**Embase**

('running'/de OR 'runner'/de OR 'jogging'/de) OR (run:ab,ti OR 'runs':ab,ti OR 'running*':ab,ti OR 'runner*':ab,ti OR 'jog':ab,ti OR 'jogs':ab,ti OR 'jogging*':ab,ti OR 'jogger*':ab,ti OR 'foot race':ab,ti OR 'marathon':ab,ti OR 'ultramarathon*':ab,ti OR 'ultrarunner*':ab,ti OR 'sprint*':ab,ti OR 'ultrarunner*':ab,ti)

AND

('leg injury'/exp OR 'sport injury'/de OR 'soft tissue injury'/de OR 'musculoskeletal pain'/de OR 'musculoskeletal disease'/exp) OR ('injury':ab,ti OR 'injur*:ab,ti OR 'pain':ab,ti OR 'pains':ab,ti OR 'damage*':ab,ti OR 'trauma':ab,ti OR ('traumas') NEAR/4 ('leg':ab,ti)) OR ('leg':ab,ti OR 'ankle*':ab,ti OR 'femoral*':ab,ti OR 'foot':ab,ti OR 'feet':ab,ti OR 'knee':ab,ti OR 'knees':ab,ti OR 'hip':ab,ti OR 'hips':ab,ti OR 'lower limb*':ab,ti OR 'lower extremi*':ab,ti OR 'athletic*':ab,ti OR 'sport':ab,ti OR 'sports':ab,ti OR 'running':ab,ti OR 'musculoskeletal':ab,ti OR 'overuse*':ab,ti OR 'overuse':ab,ti OR 'soft tissue*':ab,ti OR 'strain':ab,ti) OR (tendinopathy*:ab,ti OR patellofemoral pain:ab,ti OR stress fracture*:ab,ti OR iliobial band syndrome*:ab,ti OR metatarsalgia:ab,ti OR 'bone injury':ab,ti OR 'medial tibia stress syndrome*':ab,ti OR 'medial tibial stress syndrome*':ab,ti OR 'muscle strain*':ab,ti OR 'arthropath*':ab,ti OR 'plantar fasciitis':ab,ti OR 'tissue inflammation*':ab,ti)

AND

('athletic performance'/de OR 'training'/de OR 'exercise'/de OR 'aerobic exercise'/de OR 'fitness'/de OR 'physical performance'/de OR 'resistance training'/de OR 'physical education'/de OR 'endurance training'/de OR 'exercise tolerance'/de) OR (train*:ab,ti OR 'exercise':ab,ti OR 'circuit':ab,ti OR 'aerobic':ab,ti OR 'cardio*':ab,ti OR 'fitness':ab,ti OR 'physical':ab,ti OR 'program*':ab,ti OR 'protocol*':ab,ti OR 'activity*':ab,ti OR 'regim*':ab,ti OR 'conditioning':ab,ti OR 'performance':ab,ti)

AND

('characteristic*':ab,ti OR 'parameter*':ab,ti OR 'progression*':ab,ti OR 'volume*':ab,ti OR 'volume*':ab,ti OR 'schedul*':ab,ti OR 'frequenc*':ab,ti OR 'duration*':ab,ti OR 'intensit*':ab,ti OR 'speed':ab,ti OR 'pace':ab,ti OR 'error*':ab,ti OR 'mileage*':ab,ti)
(MH "Running+") OR (TI (run or runs or running* or runner* or jog or jogs or jogging* or jogger* or "foot race*" or marathon* or ultramarathon* or sprint* or ultrarunner*) ) OR AB (run or runs or running* or runner* or jog or jogs or jogging* or jogger* or "foot race*" or marathon* or ultramarathon* or sprint* or ultrarunner*) )
AND
(MH "Leg Injuries+") OR (MH "Hip Injuries+") OR (MH "Soft Tissue Injuries+") OR (MH "Knee Pain+") OR (MH "Running Injuries+") OR (MH "Cumulative Trauma Disorders+") OR (MH "Athletic Injuries+") (MH "Musculoskeletal Diseases") OR (MH "Bone Diseases") OR (MH "Cartilage Diseases") OR (MH "Fasciitis") OR (MH "Foot Diseases") OR (MH "Plantar Fasciitis") OR (MH "Muscular Diseases") OR (MH "Compartment Syndromes") OR (TI (injury or injury* or pain or pains or damage* or trauma or traumas) ) AND TI (leg or legs or ankle* or femoral* or foot or feet or knee or knees or hip or hips or "lower limb*" or "lower extremity*" or athletic* or sport or sports or running or musculoskeletal or overuse* or "over use*" or "soft tissue*" or strain or tendon* or muscle*) ) OR AB (injury or injury* or pain or pains or damage* or trauma or traumas) ) AND AB (leg or legs or ankle* or femoral* or foot or feet or knee or knees or hip or hips or "lower limb*" or "lower extremity*" or athletic* or sport or sports or running or musculoskeletal or overuse* or "over use*" or "soft tissue*" or strain or tendon* or muscle*)
AND
(MH "Patellofemoral Pain Syndrome") OR (MH "Fractures") OR (MH "Femoral Fractures") OR (MH "Hip Fractures") OR (MH "Foot Fractures") OR (MH "Calcaneus Fractures") OR (MH "Metatarsal Fractures") OR (MH "Metatarsal Fractures, Stress") OR (MH "Fractures, Cartilage") OR (MH "Fractures, Stress") OR (MH "Hip Fractures, Stress") OR (MH "Tibial Fractures") OR (MH "Knee Fractures") OR (MH "Muscular Diseases") OR (MH "Joint Diseases") OR (MH "Medial Tibial Stress Syndrome") OR (MH "Muscle Cramp") OR (MH "Compartment Syndromes") OR (MH "Sprains and Strains") OR (MH "Ankle Sprain") OR (MH "Calf Strain") OR (MH "Cumulative Trauma Disorders") OR (MH "Tendon Injuries") OR (MH "Iliotibial Band Friction Syndrome") OR (MH "Achilles Tendinopathy") OR (MH "Patellar Tendinopathy") OR (MH "Plantar Fasciitis") OR (TI (tendinopath* or "patellofemoral pain" or "stress fracture*" or iliobibial band syndrome* or metatarsalgia or "bone injury" or "medial tibial stress syndrome*" or "medial tibial stress syndrome*" or "muscle strain*" or arthropath* or "plantar fasciitis" or "tissue inflammation*")) OR AB ((tendinopath* or "patellofemoral pain" or "stress fracture*" or iliobibial band syndrome* or metatarsalgia or "bone injury" or "medial tibial stress syndrome*" or "medial tibial stress syndrome*" or "muscle strain*" or arthropath* or "plantar fasciitis" or "tissue inflammation*"))
AND
(MH "Athletic Performance") OR (MH "Athletic Training") OR (MH "Exercise+") OR (MH "Aerobic Exercises") OR (MH "Physical Fitness+") OR (MH "Physical Performance") OR (MH "Resistance Training") OR (MH "Physical Education and Training") OR (MH "Physical Endurance+") OR (TI (train* or exercise or circuit or aerobic or cardio* or fitness or physical or program* or protocol* or activity* or regim* or conditioning or performance or physical endurance) OR AB (train* or exercise or circuit or aerobic or cardio* or fitness or physical or program* or protocol* or activity* or regim* or conditioning or performance or physical endurance)
AND
(TI (characteristic* or parameter* or progression* or volume* or schedul* or frequene* or duration* or intensit* or speed or pace or error* or mileage*) ) OR AB (characteristic* or parameter* or progression* or volume* or schedul* or frequene* or duration* or intensit* or speed or pace or error* or mileage*)}
(DE "RUNNING" OR DE "BAREFOOT running" OR DE "CROSS-country running" OR DE "GAIT in humans" OR DE "JOGGING" OR DE "LONG-distance running" OR DE "MIDDLE distance running" OR DE "MINIMALIST running" OR DE "ROAD running" OR DE "RUNNING -- Social aspects" OR DE "RUNNING for children" OR DE "RUNNING for older people" OR DE "RUNNING for people with disabilities" OR DE "RUNNING for women" OR DE "SPRINTING" OR DE "STREAKERS & streaking" OR DE "TRAIL running" OR DE "RUNNING races" OR DE "HALF marathons (Running)" OR DE "MARATHON running" OR DE "ULTRAMARATHON running" OR DE "RUNNING") OR (TI ( run or runs or running* or runner* or jog or jogs or jogging* or jogger* or "foot race*" or marathon* or ultramarathon* or sprint* or ultrarunner* ) ) OR AB ( run or runs or running* or runner* or jog or jogs or jogging* or jogger* or "foot race*" or marathon* or ultramarathon* or sprint* or ultrarunner* ) )

AND

((((DE "LEG injuries" OR DE "ANKLE injuries" OR DE "FOOT injuries" OR DE "KNEE injuries" OR DE "SHIN splints" OR DE "TIBIA injuries") OR (DE "TOE injuries")) AND (DE "PATELLAR ligament injuries" OR DE "PLICA syndrome" OR DE "ILIOTIBIAL band syndrome") OR (DE "SHIN splints") OR (DE "TIBIA injuries") OR (((((DE "SOFT tissue injuries") OR (DE "SPORTS injuries" OR DE "ACHILLES tendinitis") OR "JOGGING injuries" OR DE "JUMPER'S knee" OR DE "RUNNING injuries") OR (DE "MUSCULOSKELETAL system injuries")) AND (DE "BONE injuries" OR DE "ANKLEBONE injuries" OR DE "BONE fractures" OR DE "HEEL bone injuries" OR DE "TIBIA injuries") OR (DE "JOINT injuries" OR DE "HIP joint injuries") OR DE "PATELLOFEMORAL joint injuries" OR DE "SPRAINS") ) OR (DE "MUSCLE injuries" OR DE "SKELETAL muscle injuries" OR DE "QUADRICEPS muscle injuries" OR DE "HAMSTRING muscle injuries" OR DE "CALF muscle injuries") OR TI ( injury or injuri* or pain or pains or damage* or trauma or traumas ) AND TI ( leg or legs or ankle* or femoral* or foot or feet or knee or knees or hip or hips or "lower limb*" or "lower extremit*" or athletic* or sport or sports or running or musculoskeletal or overuse* or "over use*" or "soft tissue*" or strain or tendon* or muscle* ) OR AB ( injury or injuri* or pain or pains or damage* or trauma or traumas ) AND AB ( leg or legs or ankle* or femoral* or foot or feet or knee or knees or hip or hips or "lower limb*" or "lower extremit*" or athletic* or sport or sports or running or musculoskeletal or overuse* or "over use*" or "soft tissue*" or strain or tendon* or muscle* )) OR (((((DE "BONE fractures" OR DE "ANKLE fractures" OR DE "CARTILAGE fractures" OR DE "HEEL bone fractures" OR DE "STRESS fractures (Orthopedics)") OR (DE "TENDINOSIS" OR DE "TENDINITIS") OR (DE "ACHILLES tendinitis") OR (DE "COMPARTMENT syndrome") OR (DE "ANTERIOR compartment syndrome") OR (DE "MUSCLE diseases") OR (DE "MUSCLE cramps") ) OR (DE "PLANTAR fasciitis") ) OR TI ( tendinopath* or "patellofemoral pain" or "stress fracture*" or "iliotibial band syndrome*" or metatarsalgia or "bone injury" or "medial tibia stress syndrome" or "medial tibial stress syndrome*" or "muscle strain*" or arthropath* or "plantar fasciitis" or "tissue inflammation*" ) ) OR AB ( tendinopathy* or "patellofemoral pain" or "stress fracture*" or "iliotibial band syndrome*" or metatarsalgia or "bone injury" or "medial tibia stress syndrome*" or "medial tibial stress syndrome*" or "muscle strain*" or arthropath* or "plantar fasciitis" or "tissue inflammation*" )

AND

((((DE "EXERCISE" OR DE "AEROBIC exercises" OR DE "PHYSICAL fitness" OR DE "PHYSICAL training & conditioning") OR (DE "PHYSICAL fitness" OR DE "EXERCISE tolerance") ) OR (DE "EXERCISE tolerance") ) OR (DE "HIGH-intensity interval training") OR (DE "RUNNING training") OR (DE "ULTRAMARATHON running training") OR (DE "MARATHON running training") ) OR TI (train* or exercise or circuit or aerobic or cardio* or fitness or physical or program* or protocol* or activit* or regim* or conditioning or performance or physical endurance ) OR AB ( train* or exercise or circuit or aerobic or cardio* or fitness or physical or program* or protocol* or activit* or regim* or conditioning or performance or physical endurance )

AND

(TI (characteristic* or parameter* or progression* or volume* or schedule* or frequency* or duration* or intensiti* or speed or pace or error* or mileage* ) ) OR AB ( characteristic* or parameter* or progression* or volume* or schedule* or frequency* or duration* or intensiti* or speed or pace or error* or mileage* )