Accepted Manuscript online: 2022-09-29 Article published online: 2022-12-23

Risk Factors for Musculoskeletal Injury in CrossFit: A Systematic Review

OPEN ACCESS

Authors

Mirwais Mehrab[1]*, Robert Kaspar Wagner[2,3,4]*, Gwendolyn Vuurberg[2,3,4], Vincent Gouttebarge[2,3,4,5], Robert-Jan de Vos[1], Nina Maria Cornelia Mathijssen[6]

Affiliations

1 Department of Orthopaedic Surgery and Sports Medicine, Erasmus MC University Medical Centre, Rotterdam, Netherlands
2 Department of Orthopaedic Surgery, Amsterdam UMC location University of Amsterdam, Department of Orthopedic Surgery and Sports Medicine, Amsterdam, The Netherlands, Amsterdam, Netherlands
3 Amsterdam Movement Sciences, Sports, Amsterdam, The Netherlands, Amsterdam, Netherlands
4 Academic Center for Evidence-based Sports medicine (ACES), Amsterdam, The Netherlands, Amsterdam, Netherlands
5 Section Sports Medicine, University of Pretoria, Pretoria, South Africa
6 Reinier Haga Orthopedic Center, Zoetermeer, Netherlands

Key words

CrossFit, high intensity functional training, fitness, sports injury, risk factor

accepted 27.09.2022
published online 23.12.2022

Bibliography

Int J Sports Med 2023; 44: 247–257
DOI 10.1055/a-1953-6317
ISSN 0172-4622

Georg Thieme Verlag KG, Rüdigerstraße 14, 70469 Stuttgart, Germany

Correspondence

Dr. Mirwais Mehrab
Erasmus Medical Center, Orthopaedic Surgery and Sports Medicine
Doctor Molewaterplein 40
Rotterdam
Netherlands, 3000 CA
Tel.: +31633895914
m.mehrab@erasmusmc.nl

Supplementary Material is available under https://doi.org/10.1055/a-1953-6317

ABSTRACT

The objective of this systematic review was to identify potential risk factors for injury in CrossFit participants. Embase, Medline, Web of Science, Cochrane, CINAHL, Google Scholar, and SportDiscuss databases were all searched up to June 2021. Cohort studies that investigated risk factors for CrossFit injuries requiring medical attention or leading to time loss in sports were included. A best-evidence synthesis was performed combining all the outcomes from prospective cohort studies. From 9,452 publications identified, we included three prospective cohort studies from which two had a low risk of bias and one a high risk of bias. The studies examined 691 participants of whom 172 sustained an injury. There was limited evidence that switching between prescribed and scaled loads during training is associated with increased injury risk and that increased duration of participation is a protective factor for injury. This could mean that novice CrossFit athletes and those increasing their training load should have closer supervision by CrossFit coaches. These risk factors should be considered when developing preventive interventions.

Introduction

CrossFit is a relatively new strength and conditioning sport, defined as "constantly varied, functional exercises, performed at high intensity" [1]. With over 15,000 affiliated CrossFit gyms worldwide, it has emerged as one of the most popular forms of high-intensity functional training in the global fitness community [2]. Typical CrossFit workouts incorporate a wide range of training modalities, including aspects of weightlifting, gymnastics, and endurance

* These authors contributed equally.

training, to promote general physical preparedness [1]. Positive health effects, such as improvements in cardiorespiratory fitness, have been reported in various populations of CrossFit participants [3–6].

Injury risk is a potential drawback of sports participation. The injury rate for CrossFit ranges from 0.2 to 18.9 per 1,000 hours of participation [7], which is comparable to similar training forms and other sports (e. g. weightlifting, traditional training modalities and common forms of exercise or strength training) [8–10]. Identifying injury risk factors is a key step to develop effective injury prevention programs [11]. CrossFit is a relatively new sport and has little injury research compared to older sports. Only two systematic reviews have specifically explored risk factors for CrossFit injuries and concluded that several factors such as previous injury and lack of coach supervision were associated with higher injury rates [7, 12]. However, the limited quality and cross-sectional design of the studies included have prevented researchers from drawing solid conclusions about risk factors in addition to lacking a comprehensive best-evidence synthesis for risk factors.

Therefore, the objective of the current study was to determine potential risk factors for injury in CrossFit participants through a systematic review and – if possible – meta-analysis of the current literature. This is the first systematic review on risk factors for CrossFit injury that provides a best-evidence synthesis combining outcomes of prospective cohort studies. Cross-sectional studies will also be explored to identify potential novel risk factors to be assessed in future research. This should provide updated and structured insight into all potential risk factors to inform future prevention strategies and to comprehensively summarize the current available literature.

Materials and Methods

Protocol and registration

Prior to study initiation we registered our study in the PROSPERO international prospective register of systematic reviews (registration number CRD42020185452). A protocol revision was performed in November 2020 as we decided to use the Quality in Prognostic Studies (QUIPS) tool to assess risk of bias since we observed that this was more appropriate for the studies included than the Newcastle-Ottawa Scale (NOS). This change was made before we started the risk of bias assessment. We deviated from our study protocol as (1) we determined that all cross-sectional studies had a predetermined high risk of bias (ROB) and therefore were not assessed with the QUIPS tool, and (2) we decided to pool only data from cohort studies with a low risk of bias if pooling of data were possible. We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guideline for designing and reporting systematic reviews [13].

Search and data collection

We searched the following databases without time restrictions up to June 2021 to identify relevant CrossFit injury studies: Embase, Medline, Web of Science, Cochrane, CINAHL, Google Scholar, and SportDiscuss. Our search strategy was assisted by a biomedical information specialist and was based on terms including “CrossFit”, “High Intensity Interval Training”, “High Intensity Functional Training”, “Functional Fitness”, “Injury” and (database specific) synonyms (see Appendix 1 for the full search strategy). In addition, references of included articles and of systematic reviews found on CrossFit injuries were hand-searched for relevant studies that were missed by our initial electronic search.

Eligibility criteria

We set the following study inclusion criteria: (i) the study reported on male or female CrossFit participants of all ages; (ii) the study investigated at least one independent variable in association with an injury; (iii) the injury definition included requiring medical attention or time-loss injury; (iv) studies were prospective cohort studies or case-control studies with ≥20 participants [14].

We also included cross-sectional studies to identify potential novel risk factors. While the level of evidence from cross-sectional studies is lower than that from cohort or case-control studies, they can identify factors to explore in future research.

We excluded (i) conference abstracts and (ii) studies not written in English.

Study selection

After duplicate removal, two researchers (MM and RW) independently screened titles and abstracts using the Rayyan web application [15]. The same researchers assessed all potentially eligible full-text articles to confirm eligibility. Disagreement regarding eligibility was resolved in a consensus meeting. If no consensus was reached, a third researcher (GV) was consulted.

Data extraction

Two authors (MM and RW) independently performed the data extraction of all studies included using standardized data extraction forms, and discrepancies were resolved in a consensus meeting. If no consensus was reached, a third researcher (GV) was consulted. The following data were extracted: publication details, study design, data collection method, study duration, injured vs. non-injured participant numbers, description of the study population, injury definition, and dependent and independent variables (i. e., type of injury and risk factors respectively).

We extracted risk ratios (RRs), odds ratios (ORs), and mean differences (MDs) with corresponding 95 % confidence intervals (CIs) and significance (p-value) for each risk factor. If available, we displayed effects adjusted for confounders. Otherwise, unadjusted effects were displayed. In case of categorical data, we extracted the number of injured and non-injured participants per risk factor and in case of continuous data, we extracted the means with standard deviations (SD). We contacted the corresponding authors of included studies in case any required data were missing, requesting them to provide us the additional needed data for our analyses. If corresponding authors did not reply, reminders were sent in a period of at least two months. If no response after two reminders or if the authors were not able to deliver these data, we finally considered these data as “missing”.

Risk factors were categorized into modifiable and non-modifiable risk factors. Modifiable risk factors were subcategorized into athlete, coaching, and training characteristics.

Risk of bias assessment

We assessed the ROB of cohort studies using the QUIPS tool [16]. The QUIPS scores six distinct topics on multiple criteria: study participation, study attrition, prognostic factor measurement, outcome measurement, study confounding and statistical analysis and reporting (Appendix 2).

Each criterion met scores one point. Studies were then classified similar to previous studies: each topic had to score ≥ 75 % of potential points to be deemed "low ROB." In case of < 75 % points, the topic was deemed "high ROB." A study had a "low ROB" if at least five categories including the topic "outcome measurement" were deemed "low ROB." Otherwise, the study had a "high ROB" [17]. Two authors (MM and RW) individually scored ROB and discussed discrepancies until consensus was reached. If no consensus was reached, a third researcher (GV) was consulted.

We did not assess ROB for cross-sectional studies as these are subject to an inherent high ROB for determining risk factors [18]. Therefore, all cross-sectional studies were predetermined considered of having a high ROB.

Best-evidence synthesis of the risk factors

A best-evidence synthesis according to van Tulder et al. was performed combining all outcomes from cohort studies (▶ **Table 1**) [19]. The scale rates evidence as strong, moderate, limited, or conflicting based on the risk of bias (ROB) and consistency of the available evidence. Outcomes of cross-sectional studies were not included in the best-evidence synthesis and were analyzed separately to identify potential novel risk factors for future research.

Meta-analysis

If ≥ 3 cohort studies with low ROB assessed the same outcome, a quantitative analysis would be performed. We decided to not pool studies with a high ROB to avoid further compounding of the bias [20].

Results

Study selection

Our electronic search identified 9,452 potential studies, and after duplicate removal 5,129 articles remained. After screening title and abstract, we assessed 57 studies in full text.

▶ **Table 1** Level of Evidence

Level of Evidence	Description
Strong Evidence	≥ 2 studies with low risk of bias and generally consistent findings in all studies (≥ 75 % of the studies reported consistent findings).
Moderate Evidence	One study with low risk of bias and ≥ 2 studies with high risk of bias and generally consistent results (≥ 75 % of the studies reported consistent findings).
Limited Evidence	Finding from 1 study with low risk of bias or generally consistent findings in ≥ 1 study with high risk of bias (≥ 75 % of the studies reported consistent findings).
Conflicting Evidence	< 75 % of the studies reporting consistent findings.
No Evidence	No studies could be found.

A total of 42 studies was excluded after full-text evaluation, as shown in the PRISMA flow chart (▶ **Figure 1**). We included the remaining 15 studies [8, 21–34] for analysis. These were 3 prospective cohort studies which we included in our best-evidence synthesis and 12 cross-sectional studies informing us about potential novel risk factors. There were no case-control studies that met our inclusion criteria.

Characteristics of the included prospective cohort studies

The characteristics of the prospective cohort studies included are displayed in ▶ **Table 2**. The studies had follow-up periods ranging from 8 to 12 weeks [24, 28, 31]. A total of 691 participants were included, of whom 172 sustained an injury. Publication dates ranged from 2017 to 2020 and studies were performed in Brazil [31], Denmark [28], and the United Kingdom [24]. The studies included 117 (14 injuries) [24], 168 (25 injured) [28], and 406 (133 injured) [31] participants, respectively. Heterogenous injury definitions were used and are presented in Appendix 4.

Study population across prospective studies

There were 315 male and 376 female participants. The mean (standard deviation, SD) age was 32 ± 8 years. Larsen et al. [28] included only novice participants. All other studies included participants with mixed experience. More detailed characteristics are summarized in ▶ **Table 2**.

Characteristics of the included cross-sectional studies

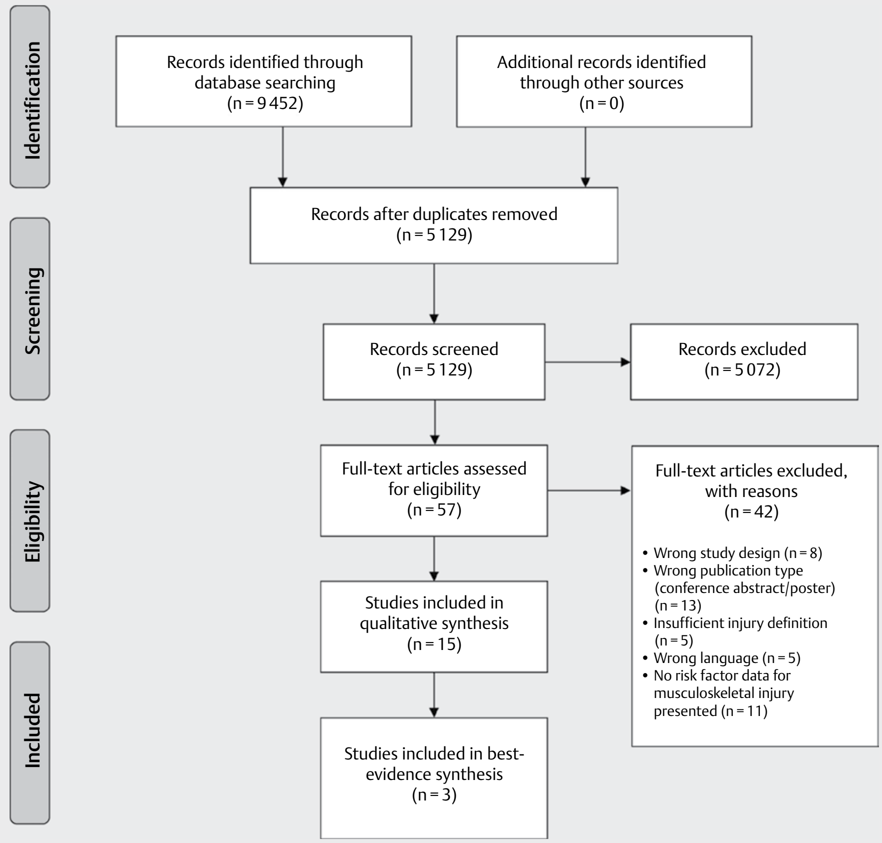
The characteristics of the cross-sectional studies are displayed in Appendix 5.

Twelve studies investigated injuries in CrossFit participants that they had sustained over periods of 6 months [22, 23, 25, 26], 12 months [8, 21, 23, 29, 30], or practice lifetime [23, 27, 32–34]. A total of 6,062 participants were included, of whom 2,050 sustained an injury. We included two studies of Feito et al. [8, 30] that were based on the same dataset but investigated different risk factors in the respective studies. Publication dates ranged from 2014 to 2021 and the studies were performed in the United States [8, 22, 25, 26, 30, 34], Brazil [27, 32, 33], Costa Rica [21], Portugal [23], and the Netherlands [29]. Sample sizes ranged from 121 to 3,049 participants (median 270). The number of injured participants per study ranged from 43 to 931 (median 80). Summitt et al. [26] analyzed risk factors for shoulder injuries only and Tawfik et al. [34] for hand and wrist injuries, respectively. All other studies analyzed risk factors for injuries without differentiating for injury location. Heterogenous injury definitions were used among the included studies which are presented in Appendix 4.

Study population across cross-sectional studies

There were 3,153 male and 2,716 female participants. The sex of 192 participants was not described [22, 26].

From the available data, the mean age was 35 ± 9 years, the mean bodyweight was 74 ± 14 kilograms, and the mean height was 1.72 ± 0.6 meters. Three studies used experience in CrossFit as an eligibility criterion: Minghelli et al. [23] and Paiva et al. [33] excluded participants with less than six months of experience. All other



▶ **Figure 1** PRISMA flowchart [13].

studies included participants with mixed experience. More detailed study characteristics are summarized in Appendix 3.

Risk of bias assessment

The prospective cohort studies were assessed using the QUIPS tool. There was no disagreement on the ROB across studies based on the independent assessments of the reviewers.

The studies scored 78 % of potential points on average. Based on the predefined criteria, two studies were considered having a low and one study of having a high ROB (▶ **Table 3**). Overall, there was a low ROB in the outcome measurement, study confounding and statistical analysis, and reporting domains. The highest ROB across studies was found in the study participation (57 % of points) and study attrition domains (40 % of points). None of the included studies provided a sample size calculation, two studies did not meet the requirements for an adequate description of the methods used to identify the population and the place of recruitment, and one study did not report on any measures of attrition.

Best-evidence synthesis of the risk factors

Seventeen different risk factors were investigated (▶ **Table 4**) in the three prospective cohort studies. Results of the best-evidence synthesis are presented in ▶ **Figure 2**.

Non-modifiable risk factors

Age

There is conflicting evidence that age affects injury risk. One study with low ROB found that lower age is associated with an increased injury risk (OR: 0.998 (0.996–0.999 95 % CI), $p < 0.05$) [31], while one study with low ROB [28] and one study with high ROB [24] found no association.

Sex

There is conflicting evidence that sex affects injury risk. One study with high ROB [24] found that male participants had increased injury risk compared to female participants, whereas two studies with low ROB found no association [28, 31].

Athletic history and background

There is limited evidence that athletic history and previous sports exposure do not affect injury risk as one study with low ROB [28] and one study with high ROB [24] found no association.

Previous injury

There is conflicting evidence that having sustained any sports injury in the past affects injury risk. One study with low ROB [31] reported that previous injury was associated with increased injury

▶ **Table 2** Study characteristics prospective cohort studies.

First Author and Year	Data collection duration	Study design	Data collection method	Participants, recruiting Location(s) and Country	Number of Subjects	Number of Injured participants (number of injuries, if available)	n Male; n Female	Age;length; weight; BMI. (± SD)
Larsen 2020	8 Weeks	Prospective cohort	Online survey, attendance through online operating system of the facility	Novice participants; 1 CrossFit gym in Copenhagen	168	25 (28 injuries)	51 M 117 F	29.2 (7.9) years BMI: 24.3 (2.9)
Moran 2017	12 weeks	Prospective cohort	Baseline questionnaire and Functional Movement Screen conducted by research team	Participants with mixed experience; 2 CrossFit gyms the United Kingdom, owned by same owner	117	14 injuries	66 M 51 F	35 (10) years BMI: 25.9 (3.5)
Szeles 2020	12 weeks	Prospective cohort	Printed baseline questionnaire, online follow- up surveys	Participants with mixed experience; 13 CrossFit gyms in a single Brazilian city.	406	133	198 M 208 F	32.1 (31.4–32.8 95 % CI) years 74.3 (72.9–75.7 95 % CI) kg 1.7 (1.7–1.7 95 % CI) m BMI: − 18.5–24.9: n = 206 (50.7 %) − 25.0–29.9: n = 158 (38.9 %) − >30.0: n = 42 (10.3 %)

Abbreviations: n. a., not available; M, male; F, female. Length is displayed in meters (m); weight is displayed in kilograms (kg); BMI is displayed in kg/m^2.

▶ **Table 3** QUIPS – Risk of Bias of Individual Studies

	Study Participation	Study Attrition	Prognostic Factor Measurement	Outcome Measurement	Study Confounding	Statistical Analysis and Reporting	Conclusion
Szeles 2020	Low risk	High risk	Low risk	Low risk	Low risk	Low risk	Low risk
Larsen 2020	High risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
Moran 2017	High risk	High risk	High risk	Low risk	Low risk	Low risk	High risk

risk, whereas one study with low ROB [28] and one study with high ROB [24] found no association.

Modifiable risk factors

Athlete characteristics

Bodyweight and BMI There is limited evidence from one study with low ROB [31] that bodyweight does not affect injury risk. There is limited evidence from one study with low ROB [28] and one study with high ROB [24] that BMI does not affect injury risk.

Lifestyle parameters There is limited evidence that achieved recommended daily physical activity and weekly alcohol use do not affect injury risk based on one study with low ROB [28].

Strength and movement competency There is limited evidence that movement competency assessed by the Functional Movement Screen (FMS) score does not affect injury risk based one study with high ROB [24].

Coaching characteristics

CrossFit class characteristics

There is limited evidence from one study with low ROB [28] that introduction classes do not affect injury risk.

There is limited evidence that variation in coaching (always having the same coach vs. alternating coaches) and demonstration of proper form by coaches do not affect injury risk based on one study with low ROB [31].

Coach involvement

There is limited evidence that the level of involvement and coach's presence do not affect injury risk based on one study with high ROB [24].

Training characteristics

Duration of participation

There is limited evidence from one study with low ROB [31] that increased duration of participation is associated with decreased injury risk (OR: 0.7 (0.5–1.0 95 % CI), $p < 0.05$).

Weekly training days, rest days, and exposure characteristics

There is strong evidence from two studies with low ROB [28, 31] that the number of training days per week does not affect injury risk.

▶ **Table 4** Results per risk factor from prospective cohort studies

Means are displayed with corresponding standard deviations (± SD). Brackets behind the adjusted effect size indicate the factors for which results have been adjusted.
Abbreviations: OR, odds ratio; RR, risk ratio; CS, cross-sectional; PC, prospective cohort
*Symbols: =, no effect; ↑, indicates higher, more, or increase; ↓, indicates lower, less, or decrease; ¶, hand and wrist injuries only; *, shoulder injuries only; $, beginning participants included only*
Not performed: no adjusted analyses were performed.
Not available: adjusted analyses were performed, but the risk factor was not included in the multivariate or final analyses.

Participation in other sports

There is strong evidence from two studies with low ROB [28, 31] that participation in other sports does not affect injury risk.

Training level

There is limited evidence that switching between prescribed and scaled loads (back and forth) during training is associated with increased injury risk as demonstrated in one study with low ROB (OR 3.5, CI 1.7–7.3, $p < 0.05$) [31].

Training forms and modalities

There is limited evidence that the number of open gym training days per week (i. e., unsupervised training) does not affect injury risk based on a single study with low ROB [28].

There is limited evidence that the following measures do not affect injury risk based on a single study with low ROB [31]: performing stretching exercises, performing preventive exercises, and using protective equipment during exercise.

Potential risk factors evaluated in cross-sectional studies

In the 12 cross-sectional studies, 33 potential risk factors were explored. The following risk factors were associated with increased injury risk: being a male participant [22, 34], increased body height [25], increased bodyweight [25], engaging in physical activity outside CrossFit [25], being a recreational (versus beginner) athlete [32], and performing intense weight training (compared to light or moderate weight training) [33]. Higher levels of coach involvement was associated with decreased injury risk [22].

Increased injury risk in competitive athletes was reported in two studies [21, 32], whereas one study [23] reported decreased injury risk for this group. Increased duration of participation was associated with increased injury risk in six studies [21, 25, 27, 29, 32, 34] whereas a single study decreased injury risk instead [30]. Training less than three times a week was a risk factor for injury in two studies [8, 23] contrasting another single study that showed that increased weekly training exposure was associated with increased injury risk [25].

No association was found for several risk factors as shown in Appendix 5.

Meta-analysis

As only two studies had a low ROB, we did not meet our predetermined criterium of ≥ 3 studies assessing the same outcome to pool data and therefore no meta-analysis was performed. Furthermore, there was substantial clinical heterogeneity between the populations included: one study only included novice participants while two other studies included participants with mixed experience.

Discussion

Summary of main findings

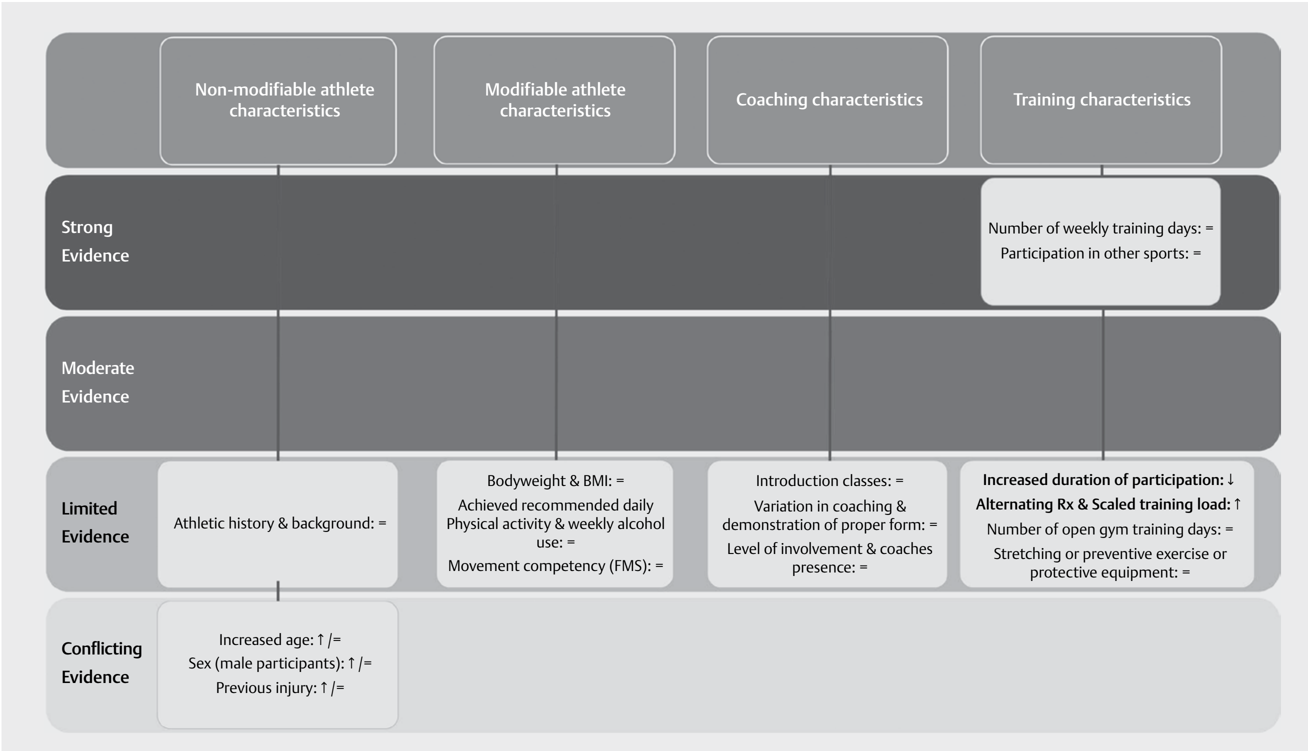
This study is the first comprehensive systematic review of risk factors for CrossFit injury that provides a best-evidence synthesis. Our study was designed to identify potential risk factors for injury in CrossFit participants, which subsequently may be used for future research and for the development of injury prevention programs. We identified two prospective cohort studies with a low risk of bias and one prospective cohort study with A high risk of bias. Additionally, we identified 12 cross-sectional studies on potential risk factors.

We found limited evidence that switching between prescribed and scaled loads during training is associated with increased injury risk and that increased duration of participation is a protective factor for injury. There is conflicting evidence for the following risk factors: higher age, male sex, and previous injury. For other potential risk factors there is currently no evidence that they are associated with increased injury risk.

Implications

These findings are relevant in both the clinical and research context given the growing popularity of CrossFit worldwide. We found that training load and level of experience with CrossFit are potentially important factors in injury etiology. This could mean that novice CrossFit athletes and those increasing their training load should have closer supervision by CrossFit coaches. It could also mean that progressive scaling, which is the practice of continually adjusting the difficulty of a workout so that an exhausted athlete can keep moving, should be avoided in (novice) participants [35]. As there are no injury prevention studies based on these risk factors, we cannot be sure whether this would actually decrease injuries. The limited evidence for these risk factors and the relatively small effect sizes should also be taken into account, but these factors are worthy of further exploration in future research.

We found insufficient evidence to establish the presence or absence of a relationship between CrossFit injury and the following factors: previous injury, male participants, and increased age. Previous injury history has been suggested to modify the complex interaction between other injury factors [36] and several studies in other sports have reported previous injury as an important risk factor [37, 38]. Next, several sex differences in sports injury risk and differences in specific injuries between sexes have been reported in previous research in other sports. A potential aspect that possibly plays a part in higher injury risk for males is their higher risk-taking behavior. Compared to females, males are less prone to seek coach supervision [22] and are characterized by more aggressive and competitive behavior, which may contribute to increased injury risk [39]. Nonetheless, some of these sex differences in sports injury risk seemed to be explained by differences in the amount of training [40, 41]. For illustration in a large CrossFit injury study of



▶ **Figure 2** Results of the best-evidence synthesis. For presentation, some separately investigated risk factors have been combined in this figure. Abbreviations: Rx, prescribed training load; FMS, functional movement screen; BMI, body mass index. Symbols: =, indicates no effect on injuries; ↑, indicates an increase in injury risk; ↓, indicates a decrease in injury risk. Bold text: indicates factors that were associated with an increase or decrease in injuries.

3,049 participants, Feito and colleagues found no significant differences in injury rates between male and female CrossFit participants (0.26 vs. 0.28 per 1,000 hours of training) [8].

In regard to age, the ability to adapt to high training loads gradually diminishes at a certain point in time as athletes age, which is believed to be due to degenerative aging processes, and as a result relatively older athletes may be more prone to sustain injuries [42, 43].

Comparison with existing literature

Several systematic reviews examined risk factors for CrossFit injury, mainly in the context of summarizing the existing CrossFit literature [9, 10, 44–47]. Two systematic reviews specifically explored risk factors for CrossFit injury and provided a clear overview of the available literature at that time [7, 12]. Our study significantly adds to these earlier systematic reviews: first, by using a more elaborate search strategy and searching for eligible articles in a larger number of databases. We screened 5,129 articles compared to 280 [7] and 718 [12] articles screened in previous reviews. Two studies from last year are included in our study that have not been previously reviewed. We also provide a best-evidence synthesis for all potential risk factors, resulting in an expanded and comprehensive overview of the currently available CrossFit injury-related literature.

Strengths and limitations

A strength of this systematic review is that we performed this structured analysis according to the PRISMA guidelines and prospectively registered our study protocol. We provided a best-evidence synthesis including levels of evidence for all potential risk factors, resulting in a comprehensive overview of the currently available CrossFit injury-related literature. Despite our robust research design, there are also methodological limitations. First, we included only studies written in the English language. This may have resulted in selection bias. Second, we were unable to pool data since we identified only two prospective studies with a low ROB. From the 15 identified publications eligible for our study, the majority had a cross-sectional study design with a predetermined high ROB. The strength of the associations could therefore be evaluated only with a best-evidence synthesis and not with a meta-analysis.

Another important consideration is that there is to date no clear consensus of what a CrossFit injury constitutes, as studies used heterogeneous injury definitions. These variations in injury definitions together with varying data collection methods may lead to differing results, making between-study comparisons difficult. We recommend experts involved in the study of CrossFit injuries to reach consensus on injury definitions and data collection for more consistency in methodologies in future CrossFit injury studies, as has been done in soccer injury research [48].

Recommendations for future research

We recommend that future large prospective cohort studies further evaluate duration of participation and training load characteristics as independent risk factors for CrossFit injuries [14]. Follow-up periods from studies in our review were 8–12 weeks: longer follow-up periods in future studies are desirable. The current CrossFit-related literature is inconclusive whether previous injury, male participants, and increased age are associated with increased injury risk: they may be interesting factors to explore. Finally, higher levels of coach involvement were associated with decreased injury risk in a cross-sectional study: future studies should investigate this potential protective factor in prospective studies (▶**Table 4a-d**).

Conclusion

Based on three prospective cohort studies from which the majority (67 %) had a low risk of bias, there is limited evidence that switching between prescribed and scaled loads during training is associated with increased injury risk and that increased duration of participation is a protective factor for injury. This could mean that novice CrossFit athletes and individuals increasing their training load should have closer supervision by CrossFit coaches. These risk factors should be considered when developing future preventive interventions.

▶ **Table 4a** Non-modifiable athlete characteristics

Risk factor	Details	Author	Year	n Subjects	Effect	Effect size, means, percentages, significance	Adjusted effect size (confounders)
Age		Larsen$	2020	168	=		
		Moran	2017	115	=		
		Szeles	2020	406	=	OR: 0.998 (0.996–0.999 95 % CI), p < 0.05	Not available
Sex		Larsen$	2020	168	=		
		Moran	2017	117	↑ injury risk for male participants	RR: 4.62 (1.32–16.10 90 % CI), p = 0.04	RR: 4.44 (1.35–14.61 90 % CI), p = 0.04 (previous injury and number of asymmetries)
		Szeles	2020	406	=		
Athletic history and background	Sports or exercise participation before CrossFit	Larsen$	2020	167	=		
	Previous Olympic lifting or gymnastics experience	Moran	2017	115	=		
Previous injury	Pain, soreness, stiffness or swelling within the last two weeks prior to CrossFit	Larsen$	2020	168	=		
	Previous injury	Moran	2017	116	=		
	Previous injury	Szeles	2020	406	↑ injury odds for participants with previous injury	OR: 3.0 (1.3–6.9 95 % CI), p < 0.05	OR: 3.2 (1.4–7.7 95 % CI), p < 0.05 (training load Rx, scaled or alternating Rx and scaled and CrossFit experience)

▶ **Table 4b** Modifiable athlete characteristics

Risk factor	Details	Author	Year	n Subjects	Effect	Effect size, means, percentages, significance	Adjusted effect size (confounders)
Bodyweight		Szeles	2020	406	=		
BMI		Larsen$	2020	168	=		
		Moran	2017	109	=		
Lifestyle parameters	Daily physical activity	Larsen$	2020	168	=		
	Alcohol use	Larsen$	2020	168	=		
Movement competency (Functional Movement Screen)	Composite score	Moran	2017	70	=		
	Number of asymmetries	Moran	2017	70	=		

▶ **Table 4c** Coaching characteristics

Risk factor	Details	Author	Year	n Subjects	Effect	Effect size, means, percentages, significance	Adjusted effect size (confounders)
Beginners' program	Introduction classes (3 vs. 1 vs. 2 vs. none)	Larsen$	2020	166	=		
Variation in coaching	Always the same coach vs. coach with assistant vs. alternating coaches	Szeles	2020	406	=		
Demonstration of proper form		Szeles	2020	406	=	OR: 0.30 (0.07–0.97), $p<0.05$	Not available
Involvement	Coaching involvement (all of the time vs. most of the time vs. some of the time vs. never)	Moran	2017	115	=		

▶ **Table 4d** Training characteristics

Risk factor	Details	Author	Year	n Subjects	Effect	Effect size, means, percentages, significance	Adjusted effect size (confounders)
Duration of participation		Szeles	2020	406	↑ injury risk for ↓ duration of participation	OR: 0.8 (0.6–1.1 95 % CI), not significant	OR: 0.7 (0.5–1.0 95 % CI), $p<0.05$ (training load Rx, scaled or alternating Rx and scaled and previous injury)
Weekly training days and exposure	Number of system-registered CrossFit class attendance	Larsen$	2020	164	=		
	CrossFit exposure	Szeles	2020	406	=	OR: 0.9 (0.8–1.0 95 % CI), not significant	Not available
Participation in other sports	Number of minutes reported for participation in other sports	Larsen$	2020	168	=		
	Participation in other sports	Szeles	2020	406	=		
Training level and intensity	Alternating between Rx and scaled vs. solely scaled	Szeles	2020	406	↑ odds for injury for those that alternate between Rx and scaled	OR: 3.6 (1.8–7.4 95 % CI), $p<0.05$	OR: 3.5 (1.7–7.3 95 % CI), $p<0.05$ (CrossFit experience and previous injury)
	Rx vs. scaled	Szeles	2020	406	=		
Training forms and modalities	Open gym training minutes per week	Larsen$	2020	168	=		
	Stretching exercises	Szeles	2020	406	=		
	Preventive exercises	Szeles	2020	406	=		
	Use of protective equipment	Szeles	2020	406	=		

Acknowledgements

The authors would like to thank Wichor Bramer (Medical Library, Erasmus MC University Medical Center Rotterdam, The Netherlands) for assistance with designing and performing the literature search. Next, the authors would like to thank Adam Weir (Erasmus MC University Medical Center Rotterdam) for reviewing the manuscript and making textual edits. Mirwais Mehrab and Robert Kaspar Wagnar contributed equally to this work.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

[1] Glassman G. Understanding crossfit. CrossFit Journal 2007; 56: 1–2

[2] Feito Y, Heinrich KM, Butcher SJ et al. High-intensity functional training (HIFT): definition and research implications for improved fitness. Sports (Basel) 2018; 6: 76. doi:10.3390/sports6030076

[3] Choi E-J, So W-Y, Jeong TT. Effects of the CrossFit exercise data analysis on body composition and blood profiles. Iran J Public Health 2017; 46: 1292–1294

[4] Eather N, Morgan PJ, Lubans DR. Improving health-related fitness in adolescents: the CrossFit Teens randomised controlled trial. J Sports Sci 2016; 34: 209–223. doi:10.1080/02640414.2015.1045925

[5] Murawska-Cialowicz E, Wojna J, Zuwala-Jagiello J. CrossFit training changes brain-derived neurotrophic factor and irisin levels at rest, after Wingate and progressive tests, and improves aerobic capacity and body composition of young physically active men and women. J Physiol Pharmacol 2015; 66: 811–821

[6] Wylie R, Uptgraft J, Paine J. CrossFit Study, May 2010. BiblioScholar 2012

[7] Rodríguez M, García-Calleja P, Terrados N et al. Injury in CrossFit: A systematic review of epidemiology and risk factors. Phys Sportsmed 2020; 50: 3–10. doi:10.1080/00913847.2020.1864675

[8] Feito Y, Burrows EK, Tabb LP. A 4-Year Analysis of the incidence of injuries among CrossFit-trained participants. Orthop J Sports Med 2018; 6: 2325967118803100

[9] Klimek C, Ashbeck C, Brook AJ et al. Are injuries more common with CrossFit training than other forms of exercise? J Sports Rehabil 2018; 27: 295–299. doi:10.1123/jsr.2016-0040

[10] Tibana RA, de Sousa NMF. Are extreme conditioning programmes effective and safe? A narrative review of high-intensity functional training methods research paradigms and findings. BMJ Open Sports Exerc Med 2018; 4: e000435. doi:10.1136/bmjsem-2018-000435

[11] Finch C. A new framework for research leading to sports injury prevention. J Sci Med Sport 2006; 9: 3–9. discussion 10. doi:10.1016/j.jsams.2006.02.009

[12] Gardiner B, Devereux G, Beato M. Injury risk and injury incidence rates in CrossFit: A brief review. J Sports Med Phys Fitness 2020; 60: 1005–1013. doi:10.23736/S0022-4707.20.10615-7

[13] Moher D, Liberati A, Tetzlaff J et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 2009; 6: e1000097. doi:10.1371/journal.pmed.1000097

[14] Bahr R, Holme I. Risk factors for sports injuries — a methodological approach. Br J Sports Med 2003; 37: 384–392. doi:10.1136/bjsm.37.5.384

[15] Ouzzani M, Hammady H, Fedorowicz Z et al. Rayyan—a web and mobile app for systematic reviews. Syst Rev 2016; 5: 210. doi:10.1186/s13643-016-0384-4

[16] Hayden JA, van der Windt DA, Cartwright JL et al. Assessing bias in studies of prognostic factors. Ann Intern Med 2013; 158: 280–286. doi:10.7326/0003-4819-158-4-201302190-00009

[17] Green B, Bourne MN, van Dyk N et al. Recalibrating the risk of hamstring strain injury (HSI): A 2020 systematic review and meta-analysis of risk factors for index and recurrent hamstring strain injury in sport. Br J Sports Med 2020; 54: 1081–1088. doi:10.1136/bjsports-2019-100983

[18] Coggon D, Rose G, Barker DJP. Epidemiology for the Uninitiated. 4th ed. Available from https://www.bmj.com/about-bmj/resources-readers/publications/epidemiology-uninitiated

[19] van Tulder M, Furlan A, Bombardier C et al. Updated method guidelines for systematic reviews in the Cochrane collaboration back review group. Spine (Phila Pa 1976) 2003; 28: 1290–1299. doi:10.1097/01.Brs.0000065484.95996.Af

[20] Weir A, Rabia S, Ardern C. Trusting systematic reviews and meta-analyses: all that glitters is not gold!. Br J Sports Med 2016; 50: 1100–1101. doi:10.1136/bjsports-2015-095896

[21] Escalante G, Gentry C, Kern B et al. Injury patterns and rates of Costa Rican CrossFit participants-a retrospective study. Med Sport 2017; 2: 2927–2934

[22] Weisenthal BM, Beck CA, Maloney MD et al. Injury Rate and patterns among CrossFit athletes. Orthop J Sports Med 2014; 2: 2325967114531177. doi:10.1177/2325967114531177

[23] Minghelli B, Vicente P. Musculoskeletal injuries in Portuguese CrossFit practitioners. J Sports Med Phys Fitness 2019; 59: 1213–1220. doi:10.23736/s0022-4707.19.09367-8

[24] Moran S, Booker H, Staines J et al. Rates and risk factors of injury in CrossFit: a prospective cohort study. J Sports Med Phys Fitness 2017; 57: 1147–1153. doi:10.23736/s0022-4707.16.06827-4

[25] Montalvo AM, Shaefer H, Rodriguez B et al. Retrospective injury epidemiology and risk factors for injury in CrossFit. J Sports Sci Med 2017; 16: 53–59

[26] Summitt RJ, Cotton RA, Kays AC et al. Shoulder injuries in individuals who participate in CrossFit training. Sports Health 2016; 8: 541–546. doi:10.1177/1941738116666073

[27] Sprey JWC, Ferreira T, de Lima MV et al. An epidemiological profile of CrossFit athletes in Brazil. Orthop J Sports Med 2016; 4: 2325967116663706. doi:10.1177/2325967116663706

[28] Larsen RT, Hessner AL, Ishoi L et al. Injuries in novice participants during an eight-week start up CrossFit program-a prospective cohort study. Sports (Basel) 2020; 8: 21. doi:10.3390/sports8020021

[29] Mehrab M, de Vos R-J, Kraan GA et al. Injury incidence and patterns among Dutch CrossFit athletes. Orthop J Sports Med 2017; 5: 2325967117745263. doi:10.1177/2325967117745263

[30] Feito Y, Burrows E, Tabb L et al. Breaking the myths of competition: a cross-sectional analysis of injuries among CrossFit trained participants. BMJ Open Sport Exerc Med 2020; 6: e000750. doi:10.1136/bmjsem-2020-000750

[31] Szeles PRDQ Costa TSD, Cunha RAD et al. CrossFit and the epidemiology of musculoskeletal injuries: A prospective 12-week cohort study. Orthop J Sports Med 2020; 8: 2325967120908884. doi:10.1177/2325967120908884

[32] da Costa TS, Louzada CTN, Miyashita GK et al. CrossFit: Injury prevalence and main risk factors. Clinics (Sao Paulo) 2019; 74: e1402. doi:10.6061/clinics/2019/e1402

[33] Paiva TMM, Kanas M, Astur N et al. Correlation between previous sedentary lifestyle and CrossFit-related injuries. Einstein (Sao Paulo) 2021; 19: eAO5941. doi:10.31744/einstein_journal/2021AO5941

[34] Tawfik A, Katt BM, Sirch F et al. A study on the incidence of hand or wrist injuries in CrossFit athletes. Cureus 2021; 13: e13818. doi:10.7759/cureus.13818

[35] CrossFit I. Responsible Training. In: Level 1 Training Guide. Available from https://assets.crossfit.com/pdfs/seminars/CertRefs/L1TrainingGuideResponsibleTraining.pdf; Accessed on 21 September 2022

[36] Bittencourt NFN, Meeuwisse WH, Mendonça LD et al. Complex systems approach for sports injuries: moving from risk factor identification to injury pattern recognition—narrative review and new concept. Br J Sports Med 2016; 50: 1309–1314. doi:10.1136/bjsports-2015-095850

[37] Hägglund M, Waldén M, Ekstrand J. Previous injury as a risk factor for injury in elite football: a prospective study over two consecutive seasons. Br J Sports Med 2006; 40: 767–772. doi:10.1136/bjsm.2006.026609

[38] Toohey LA, Drew MK, Cook JL et al. Is subsequent lower limb injury associated with previous injury? A systematic review and meta-analysis. Br J Sports Med 2017; 51: 1670–1678. doi:10.1136/bjsports-2017-097500

[39] Tamás V, Kocsor F, Gyuris P et al. The young male syndrome--an analysis of sex, age, risk taking and mortality in patients with severe traumatic brain injuries. Front Neurol 2019; 10: 366. doi:10.3389/fneur.2019.00366

[40] Lin CY, Casey E, Herman DC et al. Sex differences in common sports injuries. PM R 2018; 10: 1073–1082. doi:10.1016/j.pmrj.2018.03.008

[41] Ristolainen L, Heinonen A, Waller B et al. Gender differences in sport injury risk and types of inju-ries: a retrospective twelve-month study on cross-country skiers, swimmers, long-distance runners and soccer players. J Sports Sci Med 2009; 8: 443–451

[42] Carmeli E, Coleman R, Reznick AZ. The biochemistry of aging muscle. Exp Gerontol 2002; 37: 477–489. doi:10.1016/s0531-5565(01)00220-0

[43] Kallinen M, Markku A. Aging, physical activity and sports injuries. An overview of common sports injuries in the elderly. Sports Med 1995; 20: 41–52. doi:10.2165/00007256-199520010-00004

[44] Claudino JG, Gabbett TJ, Bourgeois F et al. CrossFit overview: Systematic review and meta-analysis. Sports Med Open 2018; 4: 11. doi:10.1186/s40798-018-0124-5

[45] Dominski FH, Siqueira TC, Serafim TT et al. Perfil de lesões em praticantes de CrossFit: revisão sistemática. Fisioterapia e Pesquisa 2018; 25: 229–239

[46] Gean RP, Martin RD, Cassat M et al. A systematic review and meta-analysis of injury in CrossFit. J Surg Orthop Adv 2020; 29: 26–30

[47] Gianzina E, Kassotaki O. The benefits and risks of the high intensity CrossFit training. Sport Sci Health 2019; 15: 21–33. doi:10.1007/s11332-018-0521-7

[48] Fuller CW, Ekstrand J, Junge A et al. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. Clin J Sports Med 2006; 16: 97–106. doi:10.1097/00042752-200603000-00003