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Risk factors for musculoskeletal injury in CrossFit: a systematic review

Mirwais Mehrab, Robert Wagner, Gwendolyn Vuurberg, Vincent Gouttebarge, Robert-Jan de Vos, Nina M Mathijssen.

Affiliations below.

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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 3 prospective cohort studies from which 2 had a low risk of bias and 1 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.

Corresponding Author:
Mirwais Mehrab, Erasmus MC University Medical Centre, Department of Orthopaedic Surgery and Sports Medicine, Rotterdam, Netherlands, m.mehrab@erasmusmc.nl

Affiliations:
Mirwais Mehrab, Erasmus MC University Medical Centre, Department of Orthopaedic Surgery and Sports Medicine, Rotterdam, Netherlands
Robert Wagner, Amsterdam UMC location University of Amsterdam, Department of Orthopedic Surgery and Sports Medicine, Amsterdam, The Netherlands, Department of Orthopaedic Surgery, Amsterdam, Netherlands
Robert Wagner, Amsterdam Movement Sciences, Sports, Amsterdam, The Netherlands, ., Amsterdam, Netherlands
[...]
Nina M Mathijssen, Reinier Haga Orthopedic Center, ., Zoetermeer, Netherlands

Risk factors for musculoskeletal injury in CrossFit: a systematic review

Mirwais Mehrab, MD
Department of Orthopaedic Surgery and Sports Medicine, Erasmus MC University Medical Center, 3000 CA Rotterdam, the Netherlands
Reinier Haga Orthopedic Center, Toneellaan 2, 2725 NA Zoetermeer, The Netherlands
Electronic address: m.mehrab@erasmusmc.nl
ORCID: 0000-0002-1891-1406

Robert Kaspar Wagner, MD
Amsterdam UMC location University of Amsterdam, Department of Orthopedic Surgery and Sports Medicine, Amsterdam, The Netherlands
Amsterdam Movement Sciences, Sports, Amsterdam, The Netherlands
Academic Center for Evidence-based Sports medicine (ACES), Amsterdam, The Netherlands
Electronic address: r.k.wagner@amsterdamumc.nl
ORCID: 0000-0002-7031-1643

Gwendolyn Vuurberg , MD, PhD
Amsterdam UMC location University of Amsterdam, Department of Orthopedic Surgery and Sports Medicine, Amsterdam, The Netherlands
Amsterdam Movement Sciences, Sports, Amsterdam, The Netherlands
Academic Center for Evidence-based Sports medicine (ACES), Amsterdam, The Netherlands
Department of Radiology and Nuclear Medicine, Rijnstate Hospital, Arnhem, The Netherlands
Academic Center of Evidence-based Sports Medicine (ACES), Amsterdam, The Netherlands
Electronic address: g.vuurberg@amsterdamumc.nl
ORCID: 0000-0001-5008-890X

Vincent Gouttebarge, MSc., PhD
Amsterdam UMC location University of Amsterdam, Department of Orthopedic Surgery and Sports Medicine, Amsterdam, The Netherlands
Amsterdam Movement Sciences, Sports, Amsterdam, The Netherlands
Section Sports Medicine, University of Pretoria, Pretoria, South Africa
Amsterdam Collaboration on Health & Safety in Sports (ACHSS), Amsterdam UMC IOC Research Center, Amsterdam, The Netherlands
Electronic address: v.gouttebarge@amsterdamumc.nl
ORCID: 0000-0002-0126-4177

Robert-Jan de Vos, MD, PhD.

Department of Orthopaedic Surgery and Sports Medicine, Erasmus MC University Medical Center, 3000 CA Rotterdam, the Netherlands
Electronic address: r.devos@erasmusmc.nl
ORCID: 0000-0003-0372-0188

Nina Maria Cornelia Mathijssen, PhD
Reinier Haga Orthopedic Center, Toneellaan 2, 2725 NA Zoetermeer, The Netherlands
Electronic address: n.mathijssen@rhoc.nl
ORCID: 0000-0002-4368-5463

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, atnd 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 3 prospective cohort studies from which 2 had a low risk of bias and 1 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.

Key words: CrossFit, high intensity functional training, fitness, sports injury, risk factor

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 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 to draw 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 an updated and structured insight for 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 only pool data from cohort studies with low risk of bias if pooling of data would be 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 1 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 (RR), odds ratios (OR) and mean differences (MD) with corresponding 95% confidence intervals (CI) 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. In case corresponding authors did not reply, reminders were sent in a period of at least two months. In case of no response after two reminders or in case 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 6 distinct topics on multiple criteria: study participation, study attrition, prognostic factor measurement, outcome measurement, study confounding and statistical analysis and reporting (Appendix 2).

Each criterium 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 analysed separately to identify potential novel risk factors for future research.

Meta-analysis

In case ≥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.

42 studies were 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. 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] only included 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 6062 participants were included of whom 2050 sustained an injury. We included 2 studies of Feito et al.[8] [30] which 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] 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 6 months of experience. All other 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, 2 studies were considered having a low and 1 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, 2 studies did not meet the requirements for an adequate description of the methods used to identify the population and the place of recruitment, and 1 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 3 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 increased injury risk (OR: 0.998 (0.996-0.999 95%CI), $p<0.05$) [31], while 1 study with low ROB[28] and 1 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 2 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 1 study with low ROB[28] and 1 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 risk, whereas 1 study with low ROB[28] and 1 study with high ROB[24] found no association.

Modifiable risk factors

<u>Athlete characteristics</u>

Bodyweight and BMI

There is limited evidence from 1 study with low ROB[31] that bodyweight does not affect injury risk. There is limited evidence from 1 study with low ROB[28] and 1 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 1 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 1 study with high ROB.[24]

<u>*Coaching characteristics*</u>

CrossFit class characteristics

There is limited evidence from 1 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 1 study with low ROB.[31]

Coaches involvement

There is limited evidence that the level of involvement and coach's presence do not affect injury risk based on 1 study with high ROB.[24]

<u>*Training characteristics*</u>

Duration of participation

There is limited evidence from 1 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 2 studies with low ROB[28, 31] that the number of training days per week does not affect injury risk.

Participation in other sports

There is strong evidence from 2 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 1 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., training unsupervised) 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 coaches 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 6 studies,[21, 25, 27, 29, 32, 34] whereas a single study decreased injury risk instead.[30] Training less than 3 times a week was a risk factor for injury in 2 studies,[8, 23] contrasting another single study which 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: 1 study only included novice participants while 2 other studies included participants with mixed experience.

DISCUSSION

<u>Summary of main findings</u>

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 2 prospective cohort studies with a low risk of bias and 1 prospective cohort study with 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.

<u>Implications</u>

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 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 athlete age, believed to be due to degenerative aging processes and as a result relatively older athletes may be more prone to sustain injuries.[42, 43]

<u>Comparison with existing literature</u>

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 which are not 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.

<u>Strengths and limitations</u>

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 only included studies written in the English language. This may have resulted in selection bias. Second, we were unable to pool data since we only identified two prospective studies with 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 only be evaluated with a best evidence synthesis and not with 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 was associated with decreased injury risk in a cross-sectional study: future studies should investigate this potential protective factor in prospective studies.

CONCLUSION

Based on 3 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.

REFERENCES

1. Glassman G. Understanding crossfit. CrossFit Journal 2007; 56
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. Paine J UJ, Wylie R. CrossFit study. In; May 2010
7. Rodríguez M, García-Calleja P, Terrados N et al. Injury in CrossFit: A Systematic Review of Epidemiology and Risk Factors. Phys Sportsmed 2020. doi:10.1080/00913847.2020.1864675. 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: 2325967118803100-2325967118803100. doi:10.1177/2325967118803100
9. Klimek C, Ashbeck C, Brook AJ et al. Are Injuries More Common With CrossFit Training Than Other Forms of Exercise? J Sport 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 Sport Exerc Med 2018; 4: e000435-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 Phys Fit Sports Med 2020. doi:10.23736/S0022-4707.20.10615-7. 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 Medicine 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. 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. Systematic Reviews 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. BMJ. Epidemiology for the uninitiated. In

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. 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. 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: 2325967117745263-2325967117745263. 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-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. 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 Trainer Guide. Accessed on 21 September 2022. URL: https://assets.crossfit.com/pdfs/seminars/CertRefs/L1TrainingGuideResponsibleTraining.pdf
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. 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. 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 Sport Med 2006; 16: 97-106. doi:10.1097/00042752-200603000-00003

Figure captions/legends

Figure 1: PRISMA flowchart [13]

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.

Table captions/legends

TABLE 1: Level of Evidence

TABLE 2 – Study characteristics prospective cohort studies

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

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 was performed.
Not available: adjusted analyses was performed, but the risk factor was not included in the multivariate or final analyses.

TABLE 4a. Non modifiable athlete characteristics

TABLE 4b. Modifiable athlete characteristics

TABLE 4c. Coaching characteristics

TABLE 4d. Training characteristics

APPENDIX 1 – Search Strategy and Results

Embase	**2619**
(('high intensity interval training'/de OR 'functional training'/de OR 'circuit training'/de OR ((high-intens* NEAR/3 (training OR exercise* OR fitness)) OR ((functional* OR circuit OR circuit-based) NEAR/1 (training OR fitness OR exercise*)) OR hift OR hipt OR hiit OR fhit):ab,ti) AND ('injury'/exp OR 'safety'/de OR (injur* OR tear* OR rupture OR damage* OR trauma* OR safet*):ab,ti)) OR (cross-fit OR crossfit):ab,ti NOT ([animals]/lim NOT [humans]/lim)	
Medline	**1590**
((High-Intensity Interval Training/ OR Circuit-Based Exercise/ OR ((high-intens* ADJ3 (training OR exercise* OR fitness)) OR ((functional* OR circuit OR circuit-based) ADJ (training OR fitness OR exercise*)) OR hift OR hipt OR hiit OR fhit).ab,ti.) AND (exp "Wounds and Injuries"/ OR Safety/ OR (injur* OR tear* OR rupture OR damage* OR trauma* OR safet*).ab,ti.)) OR (cross-fit OR crossfit).ab,ti. NOT (exp animals/ NOT humans/)	
Web of Science	**2123**
TS=(((((high-intens* NEAR/2 (training OR exercise* OR fitness)) OR functional-training OR functional-fitness OR functional-exercise* OR circuit-training OR circuit-fitness OR circuit-exercise* OR circuit-based-training OR circuit-based-fitness OR circuit-based-exercise* OR hift OR hipt OR hiit OR fhit)) AND ((injur* OR tear* OR rupture OR damage* OR trauma* OR safet*))) OR (cross-fit OR crossfit))	
Cochrane	**708**
((((high-intens* NEAR/3 (training OR exercise* OR fitness)) OR ((functional* OR circuit OR circuit-based)	

APPENDIX 2 – QUIPS form

Texts in italics indicate criteria that have been established for our study specifically. If the judgement is classified as "Yes" the criterion is given one point.

Topic	Bias	Issues to consider for judging overall rating of "Risk of bias"	Judgement
Study Participation	**Goal: To judge the risk of selection bias (likelihood that relationship between PF and outcome is different for participants and eligible non-participants).**		
	Source of target population	The source population or population of interest is adequately described for key characteristics. *CrossFit participant and affiliation status.*	Yes/No
	Method used to identify population	The sampling frame and recruitment are adequately described, including methods to identify the sample sufficient to limit potential bias (number and type used, e.g., referral patterns in health care)	Yes/No
	Recruitment period	Period of recruitment is adequately described	Yes/No
	Place of recruitment	Place of recruitment (setting and geographic location) are adequately described	Yes/No
	Inclusion and exclusion criteria	Inclusion and exclusion criteria are adequately described: *at least one exclusion and inclusion criterium needs to be described.*	Yes/No
	Adequate study participation	There is adequate participation in the study by eligible individuals. *Sample size needs to be stated and sufficed.*	Yes/No
	Baseline characteristics	The baseline study sample (i.e., individuals entering the study) is adequately described for key characteristics: *sex, age, length of participation*	Yes/No
	Summary Study participation	**The study sample represents the population of interest on key characteristics, sufficient to limit potential bias of the observed relationship between PF and outcome.**	**If ≥75% 'yes': low risk of bias**
Study Attrition	**Goal: To judge the risk of attrition bias (likelihood that relationship between PF and outcome are different for completing and non-completing participants).**		
	Proportion of baseline sample available for analysis	Response rate (i.e., proportion of study sample completing the study and providing outcome data) is adequate.	Yes/No
	Attempts to collect information on participants who dropped out	Attempts to collect information on participants who dropped out of the study are described.	Yes/No
	Reasons and potential impact of subjects lost to follow-up	Reasons for loss to follow-up are provided.	Yes/No
	Outcome and prognostic factor information on those lost to follow-up	Participants lost to follow-up are adequately described for key characteristics. Or there are no participants lost to follow-up.	Yes/No
		There are no important differences between key characteristics and outcomes in participants who completed the study and those who did not. Or there are no participants lost to follow-up.	Yes/No

	Study Attrition Summary	**Loss to follow-up (from baseline sample to study population analyzed) is not associated with key characteristics (i.e., the study data adequately represent the sample) sufficient to limit potential bias to the observed relationship between PF and outcome.**	**If ≥75% 'yes': low risk of bias**
Prognostic Factor Measurement	**Goal: To judge the risk of measurement bias related to how PF was measured (differential measurement of PF related to the level of outcome).**		
	Definition of the PF	A clear definition or description of 'PF' is provided (e.g., including dose, level, duration of exposure, and clear specification of the method of measurement).	Yes/No
	Valid and Reliable Measurement of PF	Method of PF measurement is adequately valid and reliable to limit misclassification bias	Yes/No
		Continuous variables are reported or appropriate cut-points (i.e., not data-dependent) are used.	Yes/No
	Method and Setting of PF Measurement	The method and setting of measurement of PF is the same for all study participants.	Yes/No
	Proportion of data on PF available for analysis	Adequate proportion of the study sample has complete data for PF variable. *>80%, or method described to assure that all participants have completed data for the prognostic factor.*	Yes/No
	Method used for missing data	Appropriate methods of imputation are used for missing 'PF' data.	Yes/No
	PF Measurement Summary	**PF is adequately measured in study participants to sufficiently limit potential bias.**	**If ≥75% 'yes': low risk of bias**
Outcome Measurement	**Goal: To judge the risk of bias related to the measurement of outcome (differential measurement of outcome related to the baseline level of PF).**		
	Definition of the Outcome	A clear definition of outcome is provided, including duration of follow-up and level and extent of the outcome construct.	Yes/No
	Valid and Reliable Measurement of Outcome	The method of outcome measurement used is adequately valid and reliable to limit misclassification bias	Yes/No
	Method and Setting of Outcome Measurement	The method and setting of outcome measurement are the same for all study participants.	Yes/No
	Outcome Measurement Summary	**Outcome of interest is adequately measured in study participants to sufficiently limit potential bias.**	**If ≥75% 'yes': low risk of bias**
Study Confounding	**Goal: To judge the risk of bias due to confounding (i.e., the effect of PF is distorted by another factor that is related to PF and outcome).**		
	Important Confounders Measured	All important confounders, including treatments are measured: *Length of participation, sex, age, and previous injury*.	Yes/No
	Definition of the confounding factor	Clear definitions of the important confounders measured are provided	Yes/No
	Valid and Reliable Measurement of Confounders	Measurement of all important confounders is adequately valid and reliable	Yes/No
	Method and Setting of Confounding Measurement	The method and setting of confounding measurement are the same for all study participants.	Yes/No
	Method used for missing data	Appropriate methods are used if imputation is used for missing confounder data.	Yes/No

	Appropriate Accounting for Confounding	Important potential confounders are accounted for in the study design *Requires an initial assembly of comparable groups.*	Yes/No
		Important potential confounders are accounted for in the analysis (i.e., appropriate adjustment).	Yes/No
	Summary	**Important potential confounders are appropriately accounted for, limiting potential bias with respect to the relationship between PF and outcome.**	**If ≥75% 'yes': low risk of bias**
Statistical Analysis and Reporting	**Goal: To judge the risk of bias related to the statistical analysis and presentation of results.**		
	Presentation of analytical strategy	There is sufficient presentation of data to assess the adequacy of the analysis.	Yes/No
	Model development strategy	The strategy for model building (i.e., inclusion of variables in the statistical model) is appropriate and is based on a conceptual framework or model.	Yes/No
		The selected statistical model is adequate for the design of the study.	Yes/No
	Reporting of results	There is no selective reporting of results.	Yes/No
	Statistical Analysis and Presentation Summary	**The statistical analysis is appropriate for the design of the study, limiting potential for presentation of invalid or spurious results.**	**If ≥75% 'yes': low risk of bias**

APPENDIX 3– Study characteristics of cross-sectional studies

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.

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)
Da Costa 2019	Injuries lifetime practice	Cross-sectional	Printed questionnaire, researcher present during completion	Participants with mixed experience; CrossFit gyms in Sao Paulo, Brazil	414	157	243 M 171 F	31.0 (6.6) years 73.7 (13.6) kg 1.72 (0.09) m BMI: 24.8 (2.9)
Escalante 2017	Injuries in the past 12 months	Cross-sectional	Online survey	Participants with mixed experience; various CrossFit gyms and a competition in Costa Rica	159	74 (127 injuries)	88 M 71 F	Male - 31.3 (8.4) years - 1.74 (0.06) m - 79.45 (12.02) kg Female - 31.3 (9.1) years - 1.62 (0.07) m - 60.75 (9.37) kg
Feito 2020	Injuries in the past 12 months	Cross-sectional	Online survey	Participants with mixed experience; mostly in the United States	3049	931 (from 1551 competitors: 501 injured)	1566 M 1483 F	37.3 (9.6) years
Feito 2018	Injuries in the past 12 months	Cross-sectional	Online survey	Participants with mixed experience; mostly in the United States	3049	931	1566 M 1483 F	36.8 (9.8) years
Mehrab 2017	Injuries in the past 12 months	Cross-sectional	Online survey	Participants with mixed experience; the Netherlands	449	252 (at least 332	266 M 183 F	31.9 (8.3) years 1.77.0 (0.92) m

						injuries)		76.8 (12.8) kg BMI: 24.4 (2.8)
Minghelli 2019	Injuries in i) at time of data collection ii) training lifetime iii) the past 6 months iv) in the past 12 months	Cross-sectional	Questionnaire completed through a structured interview	Participants with at least 6 months experience; 5 CrossFit gyms in the South of Portugal	270	<u>Training lifetime:</u> 80 (108 injuries) <u>6 months</u>: 61 (80 injuries)	152 M 118 F	30.67 (8.04) years
Montalvo 2017	Injuries in the past 6 months	Cross-sectional	Survey administered by researchers	Participants with mixed experience; 4 CrossFit gyms in South Florida	191	50 (62 injuries)	94 M 97 F	31.69 (9.40) years 1.68 (0.10) m 74.32 (15.49) kg
Paiva 2021	Injuries lifetime practice	Cross-sectional	Digital questionnaire	Participants with at least 6 months experience; CrossFit centers in Brazil	121	43	53 M 68 F	70.91 (15.07) kg 1.70 (0.10) m BMI: 24.34 (3.40)
Sprey 2016	Injuries in practice lifetime	Cross-sectional	Online survey	Participants with mixed experience; various CrossFit gyms in Brazil	566	176	323 M 243 F	31.3 (7) years 1.71 (0.91) m 74.2 (15.4) kg BMI: 25.1 (3.8)
Summitt 2016	Shoulder injuries in the past 6 months	Cross-sectional	Online survey	Participants with mixed experience; 4 CrossFit gyms in the United States	187	Shoulder: 44	n.a.	<u>Age</u> 18-25: n=46 (26%) 26-30: n=108 (61%) >31: n= 23 (13%) BMI: median 25.1
Tawfik 2021	Hand and wrist injuries lifetime practice	Cross-sectional	Electronic questionnaire	Participants with mixed experience; CrossFit gyms in New York and Pennsylvania	270	168 Hand and wrist: 55 (at least 83 injuries)	137 M 132 F	34.0 (interquartile range 29.0-40.0) years
Weisenthal 2014	Injuries in the past 6 months	Cross-sectional	Online survey	Participants with mixed experience; United States	386	75 (89 injuries)	231 M 150 F	<u>Male age</u> - 18-29: n=98 (42%) - 30-39: n=84 (36%) - 40-49: n=34 (10%) - 50-59: n=10 (4%) - 60-69: n=5 (2%) <u>Female age</u> - 18-29: n=64 (42%) - 30-39: n=49 (32%) - 40-49: n=28 (18%) - 50-59: n=7 (5) - 60-69: n=2 (1%)

APPENDIX 4 – Injury definitions

First Author	Publication year	Injury Definition
Da Costa Mehrab Sprey Summitt Weisenthal	2019 2017 2016 2016 2014	Any new musculoskeletal pain, feeling, or injury that results from a CrossFit workout and leads to 1 or more of the following options: i) total removal from CrossFit training and other outside routine physical activities for >1 week; ii) modification of normal training activities in duration, intensity, or mode for >2 weeks; iii) any physical complaint severe enough to warrant a visit to a health professional.
Escalante	2017	One of the following criteria, and as a direct result of CrossFit participation: i) required the individual to seek a healthcare professional to diagnose/treat the injury; ii) modification of normal training activities for more than two weeks; iii) total removal from CrossFit and other physical activity for more than one week; iv) any injury that required loss of time from employment.
Feito	2018 & 2020	Any muscle, tendon, bone, joint, or ligament injury sustained while doing CrossFit that resulted in your consultation with a physician, or health care provider, AND caused you to stop or reduce your usual physical activity, your typical participation in CrossFit, or caused you to have surgery.
Larsen	2020	An injury was defined when two criteria were present: i) reporting a problem defined as having pain, soreness, stiffness or swelling in one or more body regions; ii) being affected by the problem to an extent that resulted in reduced participation in CrossFit training for at least seven days.
Minghelli	2019	Any condition or symptom that occurred as a result of CrossFit practice and had at least one of the following effects: i) stop the activity (training, competition) for at least one day; ii) modify the activity (fewer hours of practice or training, lower intensity of effort, or being less able to perform certain gestures or movements/techniques; iii) seek advice or treatment from health professionals to address the condition or symptom.
Montalvo	2017	Any physical damage to a body part that caused the participant to miss or modify one or more training sessions or hindered activities of daily living.
Moran	2017	Any physical complaint that was sustained during CrossFit training that resulted in a participant being unable to take a full part in future CrossFit training.
Paiva	2021	Any condition requiring training modification or discontinuation, or visit to a health professional for treatment or diagnosis.
Szeles	2020	Any musculoskeletal injury or pain (in joints, bones, ligaments, tendons, or muscles) that prevented an athlete from exercising for at least 1 day.
Tawfik	2021	Any of the following which occurred as the result of CrossFit training: i) inability to train for greater than one week; ii) needing to modify training duration, activity, or intensity for greater than two weeks; iii) any complaint that led to a doctor visit.

APPENDIX 5. Results per risk factor from cross-sectional 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 was performed.
Not available: adjusted analyses was performed, but the risk factor was not included in the multivariate or final analyses.

APPENDIX 5a. Non modifiable athlete characteristics

Risk factor	Details	Author	Year	n Subjects	Effect	Effect size, means, percentages, significance	Adjusted Effect size (confounders)
Age		Da Costa	2019	414	=		
		Feito	2020	3049	=		
		Mehrab	2017	449	=	OR: 1.032 (1.008-1.056 95%CI), p=0.009	Not significant (participation in other sports and CrossFit experience)
		Minghelli	2019	270	=		
		Montalvo	2017	191	=		
		Sprey	2016	566	=		
		Summitt*	2016	187	=		
		Tawfik¶	2021	270	=	OR: 1.00 (0.964 – 1.04 95%CI), p=0.960	Not performed
		Weisenthal	2014	381	=		
Sex		Da Costa	2019	414	=		
		Escalante	2017	159	=		
		Feito	2020	3049	=		
		Mehrab	2017	449	=		
		Minghelli	2019	270	=		
		Montalvo	2017	191	=		
		Sprey	2016	566	=		
		Tawfik¶	2021	270	↑ injuries in male participants	OR: 2.10 (1.13 - 3.89 95%CI), p=0.016	Not performed
		Weisenthal	2014	381	↑ injuries in male participants	p=0.03	Not performed
Body height		Da Costa	2019	414	=		
		Montalvo	2017	191	↑ injuries in taller participants	Means: injured 1.72 (0.09) vs. not injured 1.68 (0.10), p=0.011	OR: 1.12 (1.01-1.24 95%CI), p=0.029 (years of participation, participation in competitions, physical activity outside CrossFit and weekly athlete exposures)
		Sprey	2016	566	=		
Athletic history and background	Sports participation before CrossFit	Escalante	2017	159	=		
	Years of physical activity	Montalvo	2017	191	=		
	Fitness level before CrossFit	Montalvo	2017	191	=		
	Lifestyle before CrossFit (sedentary vs. physically active)	Paiva	2021	121	=		
	Sports participation before CrossFit	Sprey	2016	566	=		
	Level of sport practiced beforepracticed before CrossFit	Sprey	2016	566	=		

APPENDIX 5b. Modifiable athlete characteristics

Risk factor	Details	Author	Year	n Subjects	Effect	Effect size, means, percentages,	Adjusted Effect size (confounders)

						significance	
Bodyweight		Da Costa	2019	414	=		
		Montalvo	2017	191	↑ body weight in injured participants	Means: injured: 78.24 (16.86) vs. not injured: 72.91 (72.91 (14.77), p=0.037	Not available
		Sprey	2016	566	=		
BMI		Da Costa	2019	414	=		
		Feito	2020	3049	=		
		Mehrab	2017	449	=		
		Sprey	2016	566	=		
Competitor status	Participation in competitions	Da Costa	2019	179	↑ injuries in competitors	OR: 5.262 (2.700-10.254 95%CI), p<0.001	Not performed
	Participation in competitions	Escalante	2017	159	↑ injuries in competitors	p=0.02	Not performed
	Participation in competitions	Feito	2020	3049	=		
	Participation in competitions	Minghelli	2019	270	↓ injuries in competitors	OR: 2.69 (1.40-5.19 95%CI), p= 0.003	OR: 2.64 (1.37-5.09 95%CI), p= 0.004 (sex and age)
	Participation in competitions	Montalvo	2017	191	=	p=0.001	OR: 1.937 (0.873-4.298 95%CI), p = 0.1041 (years of participation, physical activity outside CrossFit, weekly athlete exposures and Body height)
	Participation in competitions	Sprey	2016	566	=	OR: 1.681 (1.16-2.436 95%CI), p=0.006	OR: 1.02 (0.705-1.475) 95%CI p=0.917 (sex, age, length of training sessions, length of participation, professional monitoring)
	Participation in competitions	Tawfik[¶]	2021	270	=	OR: 1.59 (0.875 - 2.88 95%CI), p=0.129	Not performed
	Competition level (open vs. regionals vs. games)	Feito	2020	3049	=		
Lifestyle parameters	Smoking	Tawfik[¶]	2021	270	=	OR: 0.84 (0.393 - 1.79 95%CI), p=0.652	Not performed
Physical exertion at occupation		Mehrab	2017	449	=		
Strength		Weisenthal	2014	383	=		
Monitoring by healthcare professionals		Sprey	2016	566	=		
Affiliation status	Training at a CrossFit affiliate vs. not training at a CrossFit affiliate	Feito	2020	3049	=		

APPENDIX 5c. Coaching characteristics

Risk factor	**Details**	**Author**	**Year**	**n Subjects**	**Effect**	**Effect size, means, percentages, significance**	**Adjusted Effect size (confounders)**
Beginners' program	Beginners' program (mandatory vs. voluntary vs. none)	Mehrab	2017	449	=		
	Fundamentals program (required vs. none vs. not sure)	Summitt*	2016	187	=		
	Beginners' class (offered vs. none vs.	Summitt*	2016	187	=		

	not sure)						
	Beginner's training period	Weisenthal	2014	383	=		
Number of coaches per class		Montalvo	2017	191	=		
Class size		Montalvo	2017	191	=		
Coaches rating		Escalante	2017	159	=		
Involvement	Coaching involvement	Weisenthal	2014	384	↓ injuries for coaching involvement	No OR or RR presented, p=0.028	Not performed

APPENDIX 5d. Training characteristics

Risk factor	**Details**	**Author**	**Year**	**n Subjects**	**Effect**	**Effect size, means, percentages, significance**	**Adjusted Effect size (confounders)**
Duration of participation		Da Costa	2019	411	↑ injuries for ↑ (> 12 months) duration of participation	OR: 1.822 (1.215-2.732 95%CI), p=0.004; Median: injured 13 vs. not injured 10 months, p<0.001	Not performed
		Escalante	2017	159	↑ injuries for ↑ duration of participation	No OR or RR presented, p<0.01	Not performed
		Feito	2020	3049	↑ injuries for ↓ (< 6 months) duration of participation	not available	OR: 1.82 (1.15-2.92 95%CI), p<0.05 (participation in competitions, affiliation status, BMI, sex and age)
		Mehrab	2017	449	↑ injuries for ↑ (> 24 months) duration of participation	OR 0.271 (0.154-0.478 95%CI), p<0.01	Significant, (age, participation in other sports, sex)
		Minghelli	2019	270	=		
		Montalvo	2017	191	↑ injuries for ↑ duration of participation	Means: injured: 2.71 (1.82) vs. not injured: 1.80 (1.52) years, p=0.001	OR: 1.25 (1.00-1.056 95%CI), p=0.048 (participation in competitions, physical activity outside of CrossFit, weekly athlete exposures and Body height)
		Sprey	2016	566	↑ injuries for ↑ (> 6 months) duration of participation	OR: 1.816 (1.21-2.727 95%CI), p=0.004	OR: 1.697 (1.12-2.572 95%CI), p=0.013 (sex, age, length of training sessions, participation in competitions, professional monitoring)
		Tawfik[¶]	2021	270	↑ injuries for ↑ duration of participation	OR: 2.75 (1.50 - 5.05 95%CI), p=0.001	Not performed
		Weisenthal	2014	386	=		
Weekly training days and exposure	Weekly training days	Feito	2018	3049	↑ injuries for ↓ (<3) weekly training days	No OR or RR presented, p<0.05	Not performed
	Increasing number of training days	Mehrab	2017	449	=		
	Training multiple times a day	Mehrab	2017	449	=		
	Weekly training days	Minghelli	2019	270	↑ injuries for ↓ (<3) weekly training day	OR: 3.30 (1.82-5.99 95%CI), p<0.001	OR: 3.24 (1.78-5.89 95%CI), p<0.001 (age and sex)
	Weekly training days	Montalvo	2017	191	=		
	Weekly athlete exposure	Montalvo	2017	191	↑ injuries for ↑ weekly athlete exposure	Means: injured: 6.41 (3.80) vs. not injured:	OR: 1.17 (1.00-1.37 95%CI), p=0.048

						4.65 (2.14), p=0.003	(years of participation, participation in competitions, physical activity outside of CrossFit and body height)
	Weekly training hours	Montalvo	2017	191	=		
	Intensity, frequency (light/moderate vs. intense)	Paiva	2021	121	=		
	Weekly training days	Sprey	2016	566	=		
	Weekly training days	Tawfik[¶]	2021	270	=		
	Weekly training days	Weisenthal	2014	383	=		
Rest days per week		Escalante	2017	159	=		
		Sprey	2016	566	=		
		Summitt*	2016	187	=		
Duration of training session		Mehrab	2017	449	=		
		Minghelli	2019	270	=		
		Sprey	2016	566	=		
		Escalante	2017	159	=		
		Weisenthal	2014	384	=		
Participation in other sports	Participation in other sports	Da Costa	2019	366	=		
	Participation in other sports	Escalante	2017	159	=		
	Number of training days in other sports	Mehrab	2017	449	=		
	Physical activity outside CrossFit	Montalvo	2017	191	↑ injuries for physical activity outside CrossFit	No OR or RR presented, p<0.05	OR: 2.31 (1.01-5.28 95%CI), p=0.047 (years of participation, participation in competitions, weekly athlete exposure and Body height)
	Participation in other sports	Sprey	2016	566	=		
	Number of weekly participations in other sports	Sprey	2016	566	=		
Training level and intensity	Recreational vs. Beginner	Da Costa	2019	348	↑ injuries for recreational athletes	OR: 2.275 (1.367-3.786), p=0.002	Not performed
	CrossFit for fitness	Montalvo	2017	191	=		
	Intensity, weight (light/moderate vs. intense)	Paiva	2021	121	↑ injuries for ↑ intense weights	light/moderate injured: 53.5% vs. intense injured: 46.5%, p=0.043	Not performed
	Intensity, speed (light/moderate vs. intense)	Paiva	2021	121	=		
Training forms and modalities	Warmup, General warmup	Mehrab	2017	449	=		
	Warmup, Specific warmup	Mehrab	2017	449	=		
	No warmup	Mehrab	2017	449	=		
	Warmup, Static stretching warmup	Mehrab	2017	449	=		
	Warmup, Dynamic stretching warmup	Mehrab	2017	449	=		
	Mobility training	Mehrab	2017	449	=		
	Skill or technique training days per week	Mehrab	2017	449	=		
	Strength training days per week	Mehrab	2017	449	=		
	Warm up included	Montalvo	2017	191	=		

	Cool down included	Montalvo	2017	191	=

TABLES

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.

Table 2 – Study characteristics prospective cohort studies

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.

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%)

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

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 was performed.
Not available: adjusted analyses was performed, but the risk factor was not included in the multivariate or final analyses.

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	=		

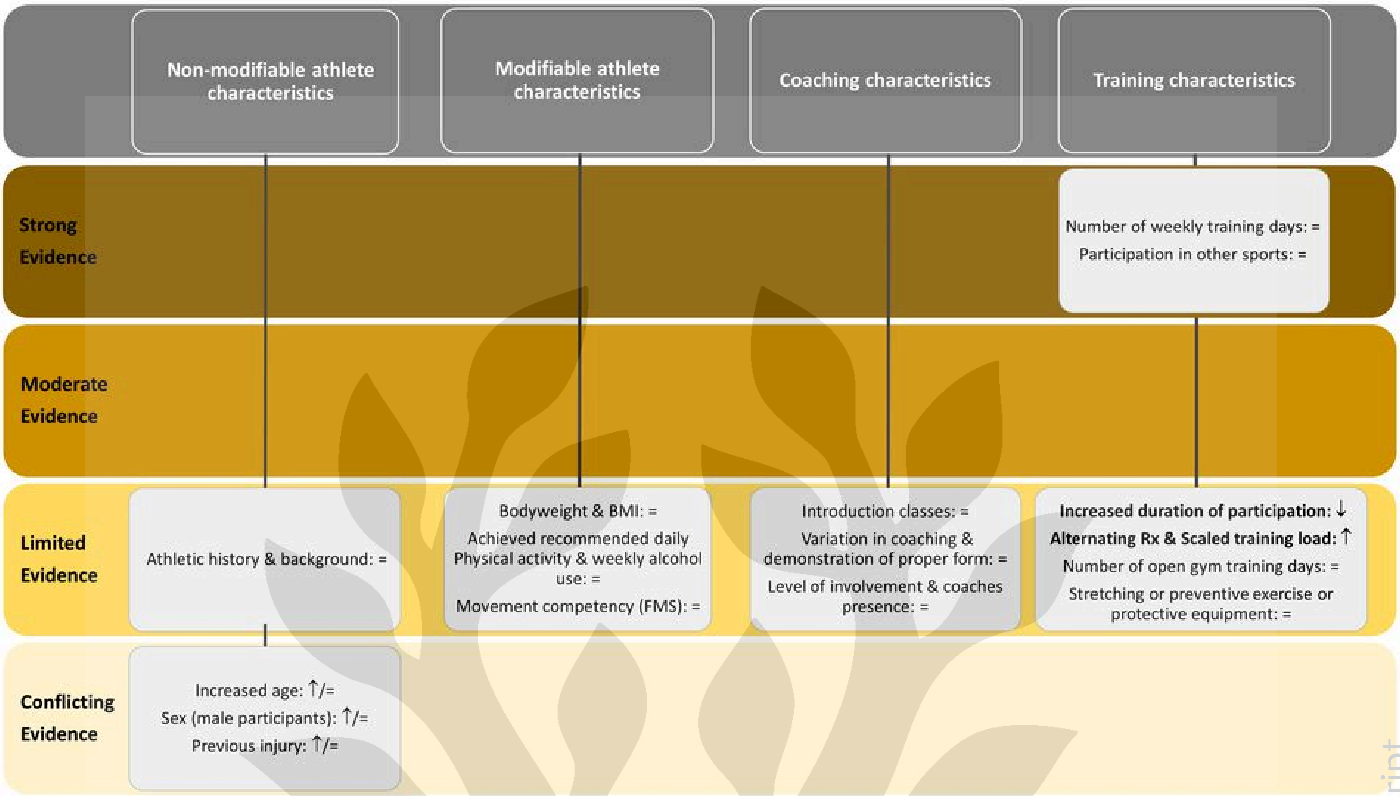
TABLE 4c. Coaching characteristics

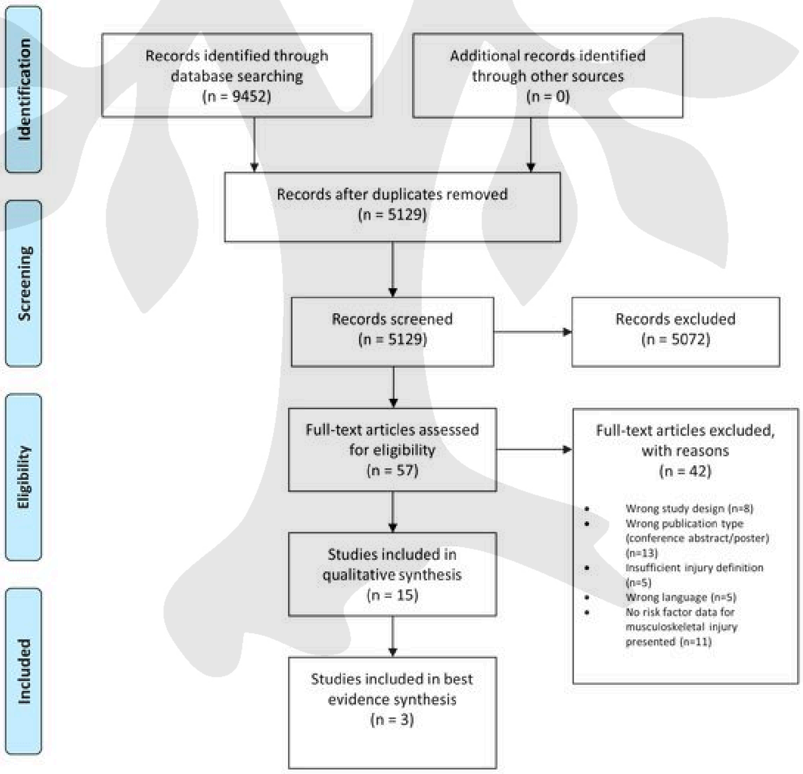
Risk factor	Details	Author	Year	n Subjects	Effect	Effect size, means, percentages, significance	Adjusted Effect size (confounders)
Beginners' program	Introduction classes (3 vs. 1 vs. 2 vs. none)	Larsen[$]	2020	166	=		
Variation in coaching	Always the same coach vs. coach with assistant vs. alternating 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[$]	2020	164	=		
	CrossFit exposure	Szeles	2020	406	=	OR: 0.9 (0.8-1.0 95%CI), not significant	Not available
Participation in other sports	Number of minutes reported for	Larsen[$]	2020	168	=		

	participation in other sports						
	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	=		


Non-modifiable athlete characteristics
Modifiable athlete characteristics
Coaching characteristics
Training characteristics
Strong Evidence
Number of weekly training days: =
Participation in other sports: =
Moderate Evidence
Limited Evidence
Athletic history & background: =
Bodyweight & BMI: =
Achieved recommended daily Physical activity & weekly alcohol use: =
Movement competency (FMS): =
Introduction classes: =
Variation in coaching & demonstration of proper form: =
Level of involvement & coaches presence: =
Increased duration of participation: ↓
Alternating Rx & Scaled training load: ↑
Number of open gym training days: =
Stretching or preventive exercise or protective equipment: =
Conflicting Evidence
Increased age: ↑/=
Sex (male participants): ↑/=
Previous injury: ↑/=


Identification
Screening
Eligibility
Included
Records identified through database searching (n = 9452)
Additional records identified through other sources (n = 0)
Records after duplicates removed (n = 5129)
Records screened (n = 5129)
Records excluded (n = 5072)
Full-text articles assessed for eligibility (n = 57)
Full-text articles excluded, with reasons (n = 42)
Wrong study design (n=8)
Wrong publication type (conference abstract/poster) (n=13)
Insufficient injury definition (n=5)
Wrong language (n=5)
No risk factor data for musculoskeletal injury presented (n=11)
Studies included in qualitative synthesis (n = 15)
Studies included in best evidence synthesis (n = 3)