Journal of Human Kinetics volume 73/2020, 251-265 DOI: 10.2478/hukin-2020-0006 251
Section IV – Medical Issues of Sport and Eercise

Prevalence of Injuries in Exercise Programs Based on Crossfit®, Cross Training and High-Intensity Functional Training Methodologies: A Systematic Review

by
Yaira Barranco-Ruiz[1], *Emilio Villa-González*[1], *Antonio Martínez-Amat*[2], *Marzo E. Da Silva-Grigoletto*[3]

Current literature shows studies that question the safety of the practices carried out in high-intensity training modalities such as CrossFit®, Cross Training or High-Intensity Functional Training, which may lead to a greater risk in the prevalence of injuries. The aim of this study was to analyze in detail the prevalence of injuries occurring in training based on the CrossFit®, Cross Training or High-Intensity Functional Training modalities, through a systematic review, as well as evaluating the methodological quality of the included studies. We used the recommendations of the PRISMA protocol. For the quality analysis of the studies, we applied the tool proposed by the National Institute of Health (United States). The areas that mainly present a higher risk of injury during CrossFit, Cross Training or High-Intensity Functional Training practices are shoulders, knees and back. Additionally, 11 of the 12 included studies displayed a poor methodological quality according to the quality tool used.

Key words: *training, high-intensity, sports injuries, gym, cross training.*

Introduction

Crossfit® is a global strength and fitness program, considered high-intensity, based on "global" movements, such as Olympic weightlifting, gymnastic skills and metabolic exercises (Drum et al., 2017). As previous studies show, this training program is open to changes in terms of the exercise progression and intensity, what allows a large population with different levels of physical conditioning to perform them safely and effectively (Dexheimer et al., 2019; Falk and Kennedy, 2019; Meyer et al., 2017; Montalvo et al., 2017). The popularity of such training program has grown exponentially over the past 10 years (Drum et al., 2017), and therefore the number of affiliated gyms across the world has increased to around 11,000 (Mehrab et al., 2017). Due to this increase in practitioners of this modality, there are several studies that display the different effects produced by this kind of training, such as physical conditioning and strength improvement, as well as other markers of health in very heterogeneous populations, such as adults and young people (Butcher et al., 2015a, 2015b; Chachula et al., 2016; Claudino et al., 2018; Meyer et al., 2017). On the other hand, there are doubts regarding the safety of practices that involve training considered high-intensity, which may lead to a higher risk in the prevalence of injuries (Elkin et al., 2019). Currently, within the existing literature, we find a limited number of studies that prove it, and the information they produce is not clear as to the rate of injuries that occur (Elkin et al., 2019; Minghelli and Vicente,

[1] - *Department of Physical and Sports Education, PROFITH "PROmoting FITness and Health through Physical Activity" Research Group, Sport and Health University Research Institute (iMUDS), Faculty of Education and Sport Sciences, University of Granada, 52005 Melilla, Spain.*
[2] - *Department of Health Sciences, Faculty of Health Sciences, University of Jaén, Jaén, Spain.*
[3] - *Functional Training Group (FTG), Federal University of Sergipe (UFS), Aracajú, SE.*

Authors submitted their contribution to the article to the editorial board.
Accepted for printing in the Journal of Human Kinetics vol. 73/2020 in July 2020.

2019). Some studies mention an injury rate per 1000 hours of training, similar or lower than that found in other sports such as soccer or rugby (Aune and Powers, 2017; Montalvo et al., 2017; Moran et al., 2017; Weisenthal et al., 2014), against other studies that report a very high injury rate of more than 40% of the population studied (Chachula et al., 2016; Mehrab et al., 2017), and a higher injury ratio than those reported by previous studies (Hak et al., 2013; Summitt et al., 2016). A recent systematic review that analyses the benefits and prejudices of the CrossFit® modality, concludes that this type of training can lead to various health improvements for those who practice it, but may also produce different associated injuries, although, as this review emphasizes, the injury ratio is similar to that presented in other forms of high-intensity training (Meyer et al., 2017). However, from our knowledge, no study has analyzed in depth what are the most reported injuries, the causes or factors related to them, as well as the methodological quality of research studies that include CrossFit® as practice or physical exercise.

By obtaining such information, we may know if the injuries that occur in CrossFit®, are due to training itself or, on the contrary, are due to other types of causes, such as poor progression of the volume load, limited training experience, etc. Therefore, the objective of this work was to analyze in detail the prevalence of injuries that occur in CrossFit® training through a systematic review of the literature, as well as to evaluate the methodological quality of the studies included. This information will allow to establish a series of recommendations for coaches, practitioners, athletes, as well as researchers from Sports Sciences, regarding the safety of this type of training and consequences for health and its application in the clinical field.

Although a systematic review study would not have such a hypothesis, we expect to observe through this systematic review that CrossFit training® is a safe modality, when practicing it appropriately, with a training program and supervised by fitness professionals. It is possible that the prevalence of injuries in CrossFit® training may be due to other types of uncontrolled factors, such as incorrect technical execution of exercises, high exercise intensity, a high number of training repetitions, or a degree of experience and training of the coaches, and not to the nature of CrossFit® training itself. We carried out this systematic review study in order to clarify these aspects.

Methods

Search strategy

The search strategy followed the recommendations set out in the PRISMA protocol (Moher et al., 2015). The "checklist" of the sections to include such review studies followed PRISMA recommendations is provided in **Supplementary file 1**.

Eligibility criteria

The inclusion criteria of the studies were as follows: 1) included CrossFit as a sports/intervention practice; 2) collected information on injuries; 3) reported injuries caused by practicing CrossFit® and no other disciplines. In addition, we excluded the literature review studies. All age ranges were valid and therefore this review included all ages. This review included studies that applied CrossFit® training programs, although on certain occasions this protocol or methodology was cited within the study under another name, such as "HIFT" (High Intensity Functional Training) or "HIPT" (High Intensity Power Training).

Search methods for study identification

We used four different databases for the search, such as PubMed, Web of Science (science citation index expanded), SPORTDiscus and Scopus, entering as keywords "CrossFit", "extreme conditioning program", Cross Training, "HIFT" (High Intensity Functional Training) and "HIPT" (High Intensity Power Training) using the corresponding Boolean operators (ex. OR). We included all publications without any language or type of publication restriction, between 2010 and 2018, since 2010 is the original year of the CrossFit® Method. The search appendix we used was "CrossFit OR Cross Training OR HIFT OR HIPT AND injuries OR pain OR disease". We describe the specific terms used for each database in **Supplementary File 2**.

In addition, we carried out manual searches with the aim of discovering any potential undetected studies with the electronic search of these databases. After the selection of studies reporting lesions on CrossFit®, we thoroughly analyzed them, extracted all the relevant information that would subsequently allow the comparison of the studies. Such information was related to characteristics such as descriptive information of the participants, the area of the reported injuries, the reasons, previous injuries, duration of these, the ratio of injuries reported, the athletes experience in this type of training, the presence or not of a qualified coach, as well as the main outcome of the study. The specification of all these variables extracted from each of the studies is in detail in **Table 1 (a to f)**.

Data detection and extraction

Screening

We carried out the eligibility process in two separate stages:

The authors (Y.B-R and E.V.G) independently selected the titles and summaries of all non-duplicate works, excluded those with exclusion criteria, and established a final list. The authors resolved discrepancies by consensus. When there was no consensus, a third lead author (ME.DS-G) acted as a mediator. If there was any doubt about inclusion, the article moved on to the next stage.

The articles that passed the evaluation were downloaded (full text) and evaluated for eligibility by two authors (Y.B-R and E.V-G) independently. Again, the authors resolved the discrepancies by consensus and, if necessary, a senior author (ME.DS-G) was consulted. Moreover, (A.M-A) acted as an arbitrator. Where necessary, the relevant authors of the selected studies were contacted to inquire about the study's eligibility (n = 1). We eliminated of this systematic review duplicates, non-intervention studies, non-English language studies and studies without analysis of the main element. The PRISMA flowchart shows the articles included in the revision **(Figure 1).**

Data extraction

Two researchers (Y.B-R and E.V-G) performed data extraction independently.

The authors resolved discrepancies by agreement. The data extracted were:

1. Publication details: year of publication.
2. Studies' design.
3. Study participants' details: sample, age range, training experience.
4. Reported injuries: cause of injury, duration, injury ratio, presence of the coach, previous injuries.
5. Results: main results of the study.

Evaluation of the quality of studies

We evaluated the quality of the studies using the quality assessment tools of the "National Institute of Health" (U.S. National Institute of Health) (U.S. Department of Health and Human Services, 2016). We assessed quality using two different tools: (1) quality assessment of observational and transverse cohort studies, and (2) quality assessment of case studies. These instruments assess the internal validity of a test, the extent to which reported effects could be strictly attributed to the intervention applied and possible errors in the methodology or implementation. Each tool contains specific questions to evaluate bias, confusion factors, etc. The answer to each question could be "yes", "no", "cannot be determined", "not reported" or "not applicable". We did not use the numeric scoring system. The evaluator had to consider the potential risk of bias in the study design for each "no" answer selected. Overall quality ratings classification were "good" (low risk of bias, valid results), "moderate" (certain risk of bias, does not invalidate results) or "poor" (significant risk of bias, can invalidate the results). If a study had a "fatal defect", the risk of bias was significant and the study had poor quality. All studies were independently evaluated by two reviewers (E.V-G), and two additional reviewers (ME.DS-G and A.M-A) who analyzed a sample of 50% (n = 6) to verify accuracy in the quality assessment.

Results

Selection of studies

In the first stage of the search strategy, we identified a total of 540 articles. In the second stage, after removing the duplicates (n = 122), where a total of 418 items were selected by the title/abstract. Subsequently, we excluded potentially relevant articles (n = 402) for reasons (details summarized in Figure 1). In the third stage, we reviewed 16 full-text articles in depth, and we excluded 4 studies for reasons (details summarized in Figure 1). Finally, we selected only 12 studies for the final analysis, which were studies that carried out CrossFit training protocols (n = 11) or extreme conditioning programs (n = 1) and which in turn reported some type of injury caused by practicing CrossFit / the Extreme Conditioning program, thus meeting both the inclusion and exclusion criteria. We should note that none of these occurred during training called Cross Training, HIFT or HIPT.

Characteristics of the studies included

The characteristics of the 12 studies included in this systematic review are in **Table 1 (a to c)**. In general, most of these studies (n = 8; 66.6%) are cross-sectional nature studies (Aune and Powers, 2017; Chachula et al., 2016; Hak et al., 2013; Mehrab et al., 2017; Montalvo et al., 2017; Moran et al., 2017; Summitt et al., 2016; Weisenthal et al., 2014; Williams et al., 2017), which collect information exclusively about the injuries reported by the athletes themselves and did not perform any specific intervention. In addition, we found three case studies (25%) (Friedman et al., 2015; Joondeph and Joondeph, 2013; Lu et al., 2015). Of all these studies, we can observe that the sample of participants we found was broad (from n = 1 to 449 subjects) and heterogeneous. The ages of individuals ranged from 17 to 69 years old, although, we can say that in the vast majority of studies (n = 11), we found no significant differences with respect to age in relation to reported injuries.

Analysis of the prevalence of injuries and associated factors

As we can see in **Table 1 (a to c)**, most reported injuries corresponded to upper limbs (shoulders, wrist, elbow, etc.). The structure with the most injury ratio was the shoulder joint, since 9/12 studies (75%) reported injuries in this region, and in the back and the knee area injuries were reported in 8/12 (66.6%) and 7/12 (58.8%) studies, respectively. In the studies, the reported causes for such injuries were mostly performance of Olympic weightlifting, and within them, the movements over the head (shoulder press, squat overhead, etc.). Similarly, it seems that the presence of previous injuries was a very important risk factor for new injuries to occur, as 6/12 studies (50%) confirmed this factor as the cause of the injury, while 4/12 (33.3%) did not report this information, and only 2/12 (16.6%) studies did not present previous injuries as a factor that could explain the occurrence of new injuries.

On the other hand, CrossFit® training experience collected in the studies analyzed was very heterogeneous, meeting novel athletes (less than one year) in 6/12 (50%) studies and experienced ones (more than one year) in 7/12 (58.3%), competitors (athletes who have competed in regional or CrossFit® Games) in 3/12 (25%) and non-competitors (more than two year training experience, but not running for competitions) in 3/12 (25%) studies.

Main results of the studies included

As for the results of the studies included, we also found a lot of heterogeneity, since each of the ten transversal/observational cohort studies included in this review reported different results (Aune and Powers, 2017; Chachula et al., 2016; Hak et al., 2013; Mehrab et al., 2017; Montalvo et al., 2017; Moran et al., 2017; Summitt et al., 2016; Weisenthal et al., 2014; Williams et al., 2017). Of the studies cited, four of them (Aune and Powers, 2017; Chachula et al., 2016; Montalvo et al., 2017; Moran et al., 2017) concluded that previous injuries increased the likelihood of injury during CrossFit® training. For example, the study of Chachula et al. (2016) observed that participants who had a previous injury were up to 3.75 times more likely to suffer an injury during CrossFit training®, compared to those who did not report it ($p = 0.04$). However, some other studies such as the one of Weisenthal et al. (2014) indicated that most participants did not report previous injuries (72/89; $p < .001$) or discomfort in the area (58/88; $P < .001$). Two of the studies included (Aune et al., 2017; Hak et al., 2013) focused on the ratio of injuries existing by the practice of the CrossFit® Method and compared it with other sports. In general, it seems that the rates of injuries produced in CrossFit® training are similar to those reported in the literature for sports such as Olympic weightlifting, weightlifting and gymnastics (Hak et al., 2013).

On the other hand, by including three case studies, we should reveal that these types of studies do not present results as such, but reflect and discuss on a topic in question, and therefore do not describe results that may give more data beyond the report of the injury itself (Friedman et al., 2015; Joondeph and Joondeph, 2013; Lu et al., 2015).

Methodological quality analysis of studies

The present study assessed the methodological quality of the studies using two tools: 1) quality assessment for observational and cross-sectional cohort studies and, on the other hand, 2) evaluation of case and control studies. In general, 11 of the 12 studies included in this review had a “fatal flag”, which corresponds to a fatal or serious failure that induces systematic bias, and therefore decreases the methodological quality of the study, thus evaluated with a “poor” quality. Only one study (Mehrab et al., 2017) of all those included in this review showed a “moderate” quality.

In relation to the different items that make up both tools, with regard to the observational and cross-sectional cohort studies, 6 of the 12 studies included in this review recruited a similar study population (Chachula et al., 2016; Mehrab et al., 2017; Montalvo et al., 2017; Moran et al., 2017; Weisenthal et al., 2014; Williams et al., 2017), applying the criteria of inclusion and exclusion to them uniformly. Regarding a sufficient period of time so that a reasonable association can be expected between the exposure and result variable, only 3 of the studies (Chachula et al., 2016; Mehrab et al., 2017; Williams et al., 2017) presented this item. Finally, none of the studies could be blinded to the evaluators of the results of the participants' exposure status, since these were not laboratory studies or with greater control, thus making blinding more difficult.

As for the three case studies included (Friedman et al., 2015; Joondeph and Joondeph, 2013; Lu et al., 2015) in the methodological quality analysis of this review, we can observe that all of them presented a “poor” methodological quality, always with more than one “fatal flag”, which corresponds to a serious failure, and therefore a negative assessment of the study. However, all of them clearly established the research question or main objective, and clearly detailed the population that made up the study. Based on the quality assessment of the tool used, none of the three studies fully included the inclusion and exclusion criteria, algorithms or processes used to identify or select valid, reliable cases, consistently implementing them on all study participants.

Discussion

The objective of this study was to analyze in detail the prevalence of injuries that occur in CrossFit® training. In addition, we analyzed the methodological quality of the studies included in this systematic review. In relation to the first objective, the area with the highest prevalence of injury within the studies analyzed is the shoulder joint. Furthermore, we can say that the injury rate or ratio, as shown by most studies included, depends on a wide variety of variables that we must take into consideration (previous injuries, protocol used, presence of qualified coaches, etc.). Finally, we have to emphasize that the majority of studies (11/12) had a low quality at the methodological level, presenting a final quality rating classified as “poor”.

We should highlight that the injury ratio reported by the studies included in this systematic review was similar, ranging from 2.1 per 1000 hours of training (Aune and Powers, 2017) to 3.1 (Hak et al., 2013), as well as the percentage of injured participants, who were between 19 (Weisenthal et al., 2014) and 73.5% (Hak et al., 2013). The comparison between CrossFit® with other sports such as sports gymnastics, powerlifting or team sports (soccer, rugby, etc.) should be done with caution, as they present a different working methodology and training protocols. However, the prevalence of injuries when comparing multiple sports with CrossFit® is similar, as discussed above. The reason for these injuries seems to have a common denominator, which we can well define by over-training, poor technique or training loads higher than the possibilities of athletes as shown by some previous studies (Aune and Powers, 2017; Chachula et al., 2016; Mehrab et al., 2017; Minghelli and Vicente., 2019). Similarly, the type of exercise that can cause this type of injury is also diverse, as shown by most of the studies included in this review, although we can highlighted the Olympic movements, especially those performed over the head (snatch, squat overhead, push press), like those which present a higher range of motion and predispose to a higher risk of injury. It is important to note that during performance of the WOD, in CrossFit® the series have a much larger number of repetitions per set, which implies fatigue. To exemplify the intensity of this type of the WOD, Maté-Muñoz et al. (2017, 2018) showed that there were concentrations greater than 10 mmol/l of lactate in a weightlifting-specific WOD, which can undoubtedly lead to significant remission of motor control. In addition, as mentioned above, one of the most important risk factors for injury in CrossFit® appears to be the presence of previous injuries, as research (Aune and Powers, 2017) indicates that those athletes with a previous injury are almost three times as likely to have a new injury compared to those who have not suffered any previous injuries. Additionally, that study states that they are up to five times more likely to suffer a new injury in the same injured area.

Table 1a. *Features of studies including CrossFit training programs, description of reported injuries, and quality assessment (n = 12).*

Study	Study design	Sample	Age	CrossFit experience	Injury zone	Injury reason	Duration	Injury ratio	Coach	Previous injury	Main result	Quality of the study
(Aune and Powers, 2017)	Cross-sectional	247 out of 1100 142 men 105 women	30-50 years old	12.7±9.4 months	1. Shoulder or upper limbs. 2. Knee or lower limbs. 3. Back, trunk, head	1. Olympic movements 2. Over-tiredness 46% 3. Bad technique 23% 4. Previous injury 14%	N/R	2.71/1000h	N/R	Yes, 62%	Participation in the exercise program led to a similar rate of injury to the one in weightlifting and most other recreational activities.	Poor
(Chachula et al., 2016)	Cross-sectional	54 military 40 men 14 women	17-50 (No differences by age)	4 Beginners 27 Intermediate 23 Expert	1. Back 27.5% 2. Shoulder 22.5%	1. Dead weight or swing KB (back). 2. Ring dips (shoulder).	N/R	44%	43 Yes 11 No	Yes. 3.75 times more likely of new injuries	Participants with a history of joint injury were 3.75 times more likely to have an injury during training CrossFit ($p = .04$; 95% confidence interval: 0.88,18.6).	Poor
(Friedman et al., 2015)	Case study	Man	43 years old	Intermediate	*Latissimus dorsi*	Muscle-up	3 months		N/R	Yes	This patient was treated conservatively and was able to resume active CrossFit training in 3 months. 6 months after the injury, he had only a slight residual functional deficit compared to his pre-injury level.	Poor
(Hak et al., 2013)	Observational	132 total 97 men 39 women	19-57	All levels	1. Shoulder 2. Low back 3. Elbow	1. Olympic movements over the head 2. Kipping 3. Metabolic	Not reported (9 operated)	3.1/1000h	N/R	Yes, 73.5%	Injury rates in CrossFit training are similar to those reported in the literature for sports such as: Olympic weightlifting, weightlifting and gymnastics and sports with less contact rather than competitive	Poor
(Joondeph and Joondeph, 2013)	Case study	Men	25 years old	N/R	Retina	Resistance band	4 months		N/R	Not reported	N/A	Poor
(Lu et al., 2015)	Case study	3 cases 2 men 1 woman	Not found	Initiated	Cervical internal carotid artery dissection	Quick head turns	Case 1: 4 months Case 2: more than 2 months Case 3: 6 months		N/R	N/R	N/A	Poor

Table 1b. *Features of studies including CrossFit training programs, description of reported injuries, and quality assessment (n = 12).*

Study	Study design	Sample	Age	CrossFit experience	Injury zone	Injury reason	Duration	Injury ratio	Coach	Previous injury	Main result	Quality of study
(Mehrab et al., 2017)	Descriptive	449 total 266 men 183 women	20-40	0-6 months 19.6% 6-12 m. 21.8% 12-24 m. 28.5% ≥24 m. 30.1%	1. Shoulder 2. Low back 3. Knee	- 39.7% WODs - 21.4% strength training - 9.1% technique - 4% metabolic - 16.7% unknown	N/R	56.1% of the simple, injured	Yes	N/R	The length of participation in CrossFit significantly affected the injury incidence rate (<6 months versus 24 months; odds ratio, 3.687 [IC 95%, 2.091 a 6.502]; *p* <.001)	Moderate
(Montalvo et al., 2017)	Retrospective	191 out of 255 94 men 97 women	20-40 years old	Competitors and non-competitors	1. Shoulder 22.5% 2. Knee 16.1% 3. Low back 12.9%	Movements over the head (improve technique, strength and flexibility)	54.8% acute 35.4% chronic	2.3/1000h 40% of competitors 19.05% of non- competitors	Yes (All the injured performed a warm-up)	Yes. 17.7% in already injured areas	Athletes who reported injuries also reported significantly higher values for the following risk factors: years of involvement (*p* = 0.001), weekly hours of athlete training (*p* = 0.020), athlete's weekly exhibitions (*p* = 0.003), height (*p* = 0.011), and body mass	Poor
(Moran et al., 2017)	Cohort prospective	117 (2 equal boxes) 66 men 51 women (More men injured)	25-45	N/R	1. Low back 33.3% 2. Knee 20% 3. Wrist 13.3%	1. Squats 86.6% 2. Dead weight 46.6% 3. Press over the head 20% 4. Asymmetries	N/R	2.1/1000h (15 injuries)	Yes	Yes (clear risk factor).	Men (rate ratio [RR]: 4.44 × / ÷ 3.30) with previous injuries (RR: 2.35 × / ÷ 2.37) had an increased risk of injury.	Poor
(Summitt et al., 2016)	Descriptive	187 out of 980	18-25 26-30 +31	83% more than 1 year 9% more than 6 months 8% less than 6 months	23.5% (it only studies shoulder injuries)	- 38% previous injuries - 25 out of 46 gymnastic - 26 de 46 Olympic	N/R	1.94/1000h (only shoulder)	Yes	N/R	The most common causes of injury were attributed to incorrect technique (33.3%) and exacerbation of a previous injury (33.3%)	Poor
(Weisental et al., 2014)	Descriptive	386 total 231 men 150 women	18-69 (no difference by age)	Athletes	1. Shoulder 2. Low back 3. Knee	1. Gymnastic (shoulder) 2. Powerlifting (back)	N/R	20% injured	Yes	No	(n=53) than women (n=21); P=0.03). Most participants did not report previous injuries (72/89; *p*<.001) or pain in the area (58/88; *p* <.001). Finally, the injury rate was	Poor

Table 1c. *Features of studies including CrossFit training programs, description of reported injuries, and quality assessment (n = 12).*

Study	Study design	Sample	Age	CrossFit experience	Injury zone	Injury reason	Duration	Injury ratio	Coach	Previous injury	Main result	Quality of study
(Williams,et al., 2017)	Prospective	6 total 3 men 3 women	22-30	Competing athletes	1. Knee 2. Low back 3. Wrist	Over-training	N N/R	Not reported	Yes	N/R	The risk of overuse problems increased substantially when a week was observed Ln rMSSD "low" combined with *"ACWR"* "high" (relative risk [RR]: 2.61, IC 90%: 1.38 - 4.93). In contrast, high "Acute to Chronic Workload Ranges" were well tolerated when *"Ln rMSSDweek"* remained "normal" or it was "high"	Poor

N/A: Not applicable. N/R: Not reported. ACWR: Acute-to-chronic workload ratios. Ln rMSSD$_{week}$: 7-day average of the natural logarithm of the square root of the mean sum of the squared differences between R–R intervals

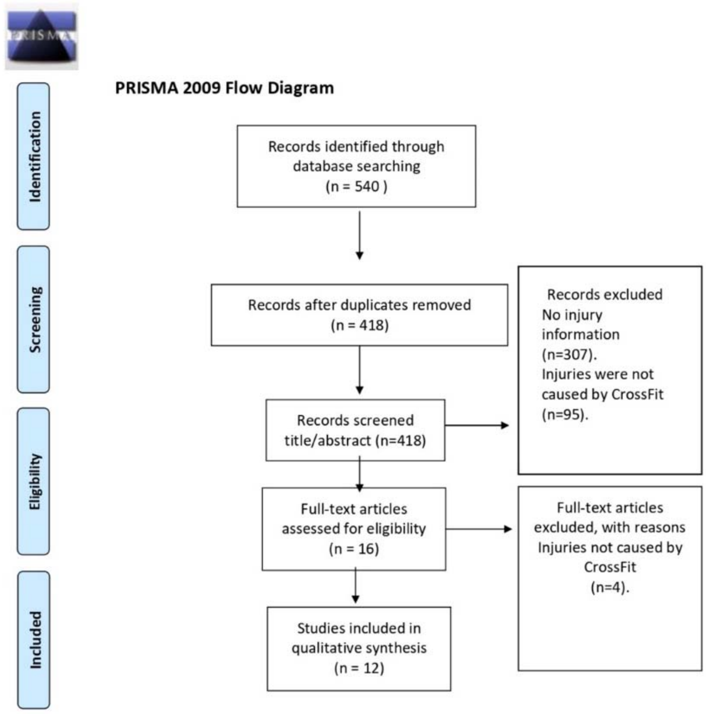

Figure 1. *Flow Diagram of the analyzed studies (n = 12)*

Supplementary table 1. PRISMA-P 2015 Checklist.
Title: *Prevalence of injuries in training programs based on CrossFit®: a systematic review*

Section/topic	#	Checklist item	Information reported: Yes	Information reported: No	Line number(s)
ADMINISTRATIVE INFORMATION					
Title					
Identification	1a	Identify the report as a protocol of a systematic review	☒	☐	3
Update	1b	If the protocol is for an update of a previous systematic review, identify as such	☐	☒	NA
Registration	2	If registered, provide the name of the registry (e.g., PROSPERO) and registration number in the Abstract	☐	☒	NA
Authors					
Contact	3a	Provide name, institutional affiliation, and e-mail address of all protocol authors; provide physical mailing address of corresponding author	☒	☐	1
Contributions	3b	Describe contributions of protocol authors and identify the guarantor of the review	☒	☐	NA
Amendments	4	If the protocol represents an amendment of a previously completed or published protocol, identify as such and list changes; otherwise, state plan for documenting important protocol amendments	☐	☒	NA
Support					
Sources	5a	Indicate sources of financial or other support for the review	☐	☐	NA
Sponsor	5b	Provide name for the review funder and/or sponsor	☐	☐	NA
Role of sponsor/funder	5c	Describe roles of funder(s), sponsor(s), and/or institution(s), if any, in developing the protocol	☐	☐	NA
INTRODUCTION					
Rationale	6	Describe the rationale for the review in the context of what is already known	☒	☐	3-4
Objectives	7	Provide an explicit statement of the question(s) the review will address with reference to participants, interventions, comparators, and outcomes (PICO)	☒	☐	3-4
METHODS					
Eligibility criteria	8	Specify the study characteristics (e.g., PICO, study design, setting, time frame) and report characteristics (e.g., years considered, language, publication status) to be used as criteria for eligibility for the review	☒	☐	7-9
Information sources	9	Describe all intended information sources (e.g., electronic databases, contact with study authors, trial registers, or other grey literature sources) with planned dates of coverage	☒	☐	7-9 and supplementary file 3.
Search strategy	10	Present draft of search strategy to be used for at least one electronic database, including planned limits, such that it could be repeated	☒	☐	7-9

NA: not applicable

Continuation of the Supplementary table 1. PRISMA-P 2015 Checklist.

Section/topic	#	Checklist item	Information reported		Line number(s)
			Yes	No	
STUDY RECORDS					
Data management	11a	Describe the mechanism(s) that will be used to manage records and data throughout the review	☒	☐	7-9
Selection process	11b	State the process that will be used for selecting studies (e.g., two independent reviewers) through each phase of the review (i.e., screening, eligibility, and inclusion in meta-analysis)	☒	☐	7-9
Data collection process	11c	Describe planned method of extracting data from reports (e.g., piloting forms, done independently, in duplicate), any processes for obtaining and confirming data from investigators	☒	☐	7-9
Data items	12	List and define all variables for which data will be sought (e.g., PICO items, funding sources), any pre-planned data assumptions and simplifications	☒	☐	7-9
Outcomes and prioritization	13	List and define all outcomes for which data will be sought, including prioritization of main and additional outcomes, with rationale	☒	☐	7-9
Risk of bias in individual studies	14	Describe anticipated methods for assessing risk of bias of individual studies, including whether this will be done at the outcome or study level, or both; state how this information will be used in data synthesis	☒	☐	7-9
DATA					
Synthesis	15a	Describe criteria under which study data will be quantitatively synthesized	☐	☐	NA
	15b	If data are appropriate for quantitative synthesis, describe planned summary measures, methods of handling data, and methods of combining data from studies, including any planned exploration of consistency (e.g., I^2, Kendall's tau)	☐	☐	NA
	15c	Describe any proposed additional analyses (e.g., sensitivity or subgroup analyses, meta-regression)	☐	☐	NA
	15d	If quantitative synthesis is not appropriate, describe the type of summary planned	☐	☐	NA
Meta-bias(es)	16	Specify any planned assessment of meta-bias(es) (e.g., publication bias across studies, selective reporting within studies)	☐	☐	NA
Confidence in cumulative evidence	17	Describe how the strength of the body of evidence will be assessed (e.g., GRADE)	☐	☐	NA

NA: not applicable

Supplementary table 2. *Quality assessment tool for observational and cross-sectional cohort studies.*

	(Aune and Powers, 2017)	(Chachula et al., 2016)	(Hak et al., 2013)	(Williams et al., 2017)	(Mehrab et al., 2017)	(Montalvo et al., 2017)	(Moran et al., 2017)	(Summitt et al., 2016)	(Weisenthatet al., 2014)
1. Was the research question or objective in this paper clearly stated?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2. Was the study population clearly specified and defined?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3. Was the participation rate of eligible persons at least 50%?	Yes	N/A	Yes	N/A	Yes	Yes	Yes	NA	Yes
4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?	No	Yes	N/A	Yes	Yes	Yes	Yes	No	Yes
5. Was a sample size justification, power description, or variance and effect estimates provided?	No	No	No	No	Yes	No	No	No	No
6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?	N/A	No	No	N/A	N/A	N/A	N/A	N/A	N/A
7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it existed?	No	Yes	No	Yes	Yes	No	No	No	No
8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?	No	No	No	N/A	N/A	N/A	N/A	No	No
9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	Yes	Yes	N/A	Yes	No	N/A	Yes	N/A	NA
10. Was the exposure(s) assessed more than once over time?	No	N/A	N/A	No	N/A	No	NA	NA	No
11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
12. Were the outcome assessors blinded to the exposure status of participants?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
13. Was loss to follow-up after baseline 20% or less?	N/R	N/R	N/R	N/R	Yes	Yes	No	Yes	N/R
14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?	Yes	No	No	Yes	Yes	No	No	Yes	Yes

NA not applicable, NR not reported.

Supplementary table 3. *Quality tool for the evaluation of case and control studies.*

	(Joondeph and Joondeph., 2013)	(Friedman et al., 2015)	(Lu et al., 2015)
1.Was the research question or objective in this paper clearly stated?	Yes	Yes	Yes
2. Was the study population clearly specified and defined?	Yes	Yes	Yes
3. Did the authors include a sample size justification?	Yes	Yes	Yes
4. Were controls selected or recruited from the same or similar population that gave rise to the cases (including the same timeframe)?	Yes	Yes	Yes
5. Were the definitions, inclusion and exclusion criteria, algorithms or processes used to identify or select cases and controls valid, reliable, and implemented consistently across all study participants?	No	No	No
6. Were the cases clearly defined and differentiated from controls?	N/A	N/A	N/A
7. If less than 100 percent of eligible cases and/or controls were selected for the study, were the cases and/or controls randomly selected from those eligible?	NA	NA	NA
8. Was there use of concurrent controls?	No	No	No
9. Were the investigators able to confirm that the exposure/risk occurred prior to the development of the condition or event that defined a participant as a case?	Yes	Yes	Yes
10. Were the measures of exposure/risk clearly defined, valid, reliable, and implemented consistently (including the same time period) across all study participants?	NA	NA	NA
11. Were the assessors of exposure/risk blinded to the case or control status of participants?	No	No	No
12. Were key potential confounding variables measured and adjusted statistically in the analyses? If matching was used, did the investigators account for matching during study analysis?	Yes	Yes	Yes

NA not applicable, *NR* not reported.

Supplementary archive 2. *Electronic search: databases and terminus included.*

The electronic search was carried out including dates from January 1, 2010 to December 31, 2018. The following terms were used;

a) Pubmed: (from 01-01-2010 to 2018)

Crossfit OR extreme conditioning program OR *Cross Training OR HIFT OR HIPT AND injuries OR pain OR disease* [Title/Abstract])

Additional filters: All database [builder term: Title/Abstract])

b) WOS: (from 2010 to 2018) main collection of Web of Science

TOPIC: (*Crossfit OR extreme conditioning program* OR *Cross Training OR HIFT OR HIPT*) *AND* TOPIC: (*injuries OR pain OR disease*)

Additional filters: main collection of Web of Science [builder term: Topic])

c) SportDiscus: (from 01/01/2010 to 31/12/2018)

ab(Crossfit OR extreme conditioning program OR *Cross Training OR HIFT OR HIPT) AND ab(injuries OR pain OR disease)*

Additional filters: [builder term: ab Abstract])

d) Scopus: (from January 2010 to Dec 2018)

AB (Crossfit OR extreme conditioning program OR *Cross Training OR HIFT OR HIPT) AND AB (injuries OR pain OR disease)*

Additional filters: [builder term: AB Abstract])

Within the different body structures, the areas of greatest risk are those belonging to the upper limbs, highlighting the shoulders, wrist or elbow. As mentioned above, 9 out of 12 studies (75%) reported injuries in that joint. Studies included in this review show lower prevalence of lesions in other areas, such as the back (8/12, 66.6%) or the knee (7/12, 58.8%). However, it is difficult to compare the various injuries from the different studies, since they present different etiology, include materials or not, present greater or lesser severity of the injury, even the appearance of discomfort that, with an accurate diagnosis, would not to be considered injury. For example, Joondeph and Joondeph (2013) reported a case of a retinal detachment after a resistance band broke during a CrossFit® workout. Therefore, more studies are necessary to bring together the different types of injury, severity and etiology, in order to learn more about the risk or the injury ratio associated with the practice of CrossFit®.

On the other hand, training experience associated with a higher or lower injury ratio during this type of training seems to be a confusing factor and requires further deepening. Some studies claim that it influences the onset of injuries when athletes are inexperienced or have been practicing a particular modality for less than 6 months (Aune and Powers, 2017; Chachula et al., 2016; Mehrab et al., 2017). However, other studies state that there are no significant differences in terms of time or years of sports experience (Weisenthal et al., 2014). Therefore, more studies need to clarify the relationship between the two variables. The study carried out by Weisenthal et al. (2014) found that in those gyms where the CrossFit® modality was implemented, and a period of adaptation with those athletes who had never done this type of training before was applied, the prevalence of lesions decreased to 18.5%. This fact underlines the importance of a proper progression to start these sports practices.

In relation to the quality of the studies, 11 of the 12 studies included in this systematic review exhibited a "poor" methodological quality. Only the study of Mehrab et al. (2017) had a "moderate" methodological quality. In general, the "poor" and "moderate" quality scores for most studies make it difficult to conclude consistently in future studies, mainly because the risk of bias in the design of the study critically decreases the confidence in the rationality of the results. It is possible that the use of the NIH quality tool could be more oriented to other types of studies, such as clinical trials. For example, the "blinding or shielding" item, not reported in any of the studies included, could be inapplicable because it is virtually impossible to blind participants receiving an intervention, in this case a program of CrossFit® training.

With all this information in mind, it is possible to give some recommendations for coaches and athletes, such as paying special attention to areas such as the shoulder and knee and evaluate their joint functions before applying any external load. Subsequently, it is important to previously or complementary work on stability and strengthening of these structures. Specifically for the shoulder joint, as our group recently suggested (de Souza et al., 2018), it is crucial to assess its mobility and only then work on its stability and strengthening. These behaviors will be of paramount importance in the technique of the exercises performed in CrossFit® and, consequently, in the appearance of injuries (Hak et al., 2013; Summitt et al., 2016). In addition, it would be interesting to have information about previous injuries of athletes to avoid or adapt certain exercises that may have a particular impact on these injured areas. Finally, it is important to follow the correct technical execution of the exercise before training sessions with a high number of repetitions and high intensity, since these two factors will implicitly involve a loss of technique that will increase the risk of injury.

To this end, it is essential to have a qualified coach who corrects appropriately and identifies errors in the different movements' execution. Therefore, future research should aim at further checking the prevalence of injuries with experimental studies, where a training protocol that participants follow is reported, and different factors involved are monitored.

This study has a main limitation, since we did not perform quantitative analysis (meta-analysis) due to the considerable conceptual heterogeneity in the studies included (systematic differences in the design of the study, populations studied, clinical heterogeneity, different duration of the study, the volume/frequency of training during the intervention and evaluation of results, etc.). In addition, considering that the studies were systematically different from each other, quantitative synthesis cannot be generalizable and applicable to clinical practice. In this context, we recognize and explain the heterogeneity in studies included in this review, particularly from a qualitative perspective, which is a general sense of what all studies say, and is crucial.

Conclusion

In conclusion, this systematic review shows that the area with the highest prevalence of injury within studies about the CrossFit®, Cross Training or High-Intensity Functional Training methodologies is the shoulder joint (9/12 studies). The rate or ratio of injury depends on a wide variety of variables to consider (previous injuries, protocol used, presence of qualified coaches, etc.). In addition, most of the studies included in this review (11/12) presented a low quality at the methodological level. Finally, it seems that CrossFit®, Cross Training or High-Intensity Functional Training methodologies involves a similar risk of injury to other sports.

An ideal recommendation for clinical practice and sports science in general would be to carry out an adaptation period with the aim of improving the technique, as well as continuous control of certain areas or structures that present an increased risk of injury, such as shoulders, knees and the lower back. In addition, at the research level, studies need to be more rigorous, so that it is possible to consider the results and extrapolate them into practice. To this end, we recommend that fitness professionals adequately plan training programs and are the ones who apply them, to be adapted to the characteristics of the clients or participants.

Acknowledgments

This study takes place thanks to funding from the University of Granada, Plan Propio de Investigación 2016, Excellence actions: Units of Excellence; Unit of Excellence on Exercise and Health (UCEES) from PROFITH group, University of Granada. The authors acknowledge the help of the student Jose María Morilla Jiménez, who participated in the first phase of the conception of this review.

References

Aune KT, Powers JM. Injuries in an extreme conditioning program. *Sports Health*, 2017; 9(1): 52-8

Butcher SJ, Judd TB, Benko CR, Horvey KJ, Pshyk AD. Relative intensity of two types of CrossFit exercise: Acute circuit and high-intensity interval exercise. *J Fit Res*, 2015a; 4(2): 3-15

Butcher SJ, Neyedly TJ, Horvey KJ, Benko CR. Do physiological measures predict selected CrossFit® benchmark performance? *Open access J Sport Med*, 2015b; 6: 241

Chachula LA, Cameron KL, Svoboda SJ. Association of prior injury with the report of new injuries sustained during CrossFit training. *Athl Train Sport Heal Care*, 2016; 8(1): 28-34

Claudino JG, Gabbett TJ, Bourgeois F, Souza HS, Miranda RC, Mezêncio B, Soncin R, Cardoso Filho CA, Bottaro M, Hernandez AJ, Amadio AC, Serrão JC. Crossfit overview: systematic review and meta-analysis. *Sport Med*, 2018; 4(1): 11

Dexheimer JD, Schroeder ET, Sawyer BJ, Pettitt RW, Aguinaldo AL, Torrence WA. Physiological Performance Measures as Indicators of CrossFit® Performance. *Sports*, 2019; 7(4): 93

Drum SN, Bellovary BN, Jensen RL, Moore MT, Donath L. Perceived demands and postexercise physical dysfunction in CrossFit® compared to an ACSM based training session. *J Sports Med Phys Fitness*, 2017; 57(5): 604-9

Elkin JL, Kammerman JS, Kunselman AR, Gallo RA. Likelihood of Injury and Medical Care Between CrossFit and Traditional Weightlifting Participants. *Orthop J Sport Med*, 2019; 7(5): 2325967119843348

Falk Neto JH, Kennedy MD. The Multimodal Nature of High-Intensity Functional Training: Potential Applications to Improve Sport Performance. *Sports*, 2019; 7(2): 33

Friedman MV, Stensby JD, Hillen TJ, Demertzis JL, Keener JD. Traumatic tear of the latissimus dorsi myotendinous junction: case report of a CrossFit-related injury. *Sports Health*, 2015; 7(6): 548-52

Hak PT, Hodzovic E, Hickey B. The nature and prevalence of injury during CrossFit training. *J Strength Cond Res* 2013 [Epub ahead of print]

Joondeph SA, Joondeph BC. Retinal detachment due to CrossFit training injury. Case *Rep Ophthalmol Med*, 2013; 2013: 189837. doi: 10.1155/2013/189837. Epub 2013 Sep 11

Lu A, Shen P, Lee P, Dahlin B, Waldau B, Nidecker AE, Nundkumar A, Bobinski M. CrossFit-related cervical internal carotid artery dissection. *Emerg Radiol*, 2015; 22(4): 449-52

Maté-Muñoz JL, Lougedo JH, Barba M, Cañuelo-Márquez AM, Guodemar-Pérez J, García-Fernández P, Lozano-Estevan MDC, Alonso-Melero R, Sánchez-Calabuig MA, Ruíz-López M, de Jesús F, Garnacho-Castaño MV. Cardiometabolic and Muscular Fatigue Responses to Different CrossFit® Workouts. *J Sports Sci Med*, 2018; 17(4): 668

Maté-Muñoz JL, Lougedo JH, Barba M, García-Fernández P, Garnacho-Castano MV, Dominguez R. Muscular fatigue in response to different modalities of CrossFit sessions. *PLoS One*, 2017; 12(7): e0181855

Mehrab M, de Vos R-J, Kraan GA, Mathijssen NMC. Injury incidence and patterns among Dutch CrossFit athletes. *Orthop J Sport Med*, 2017; 5(12): 2325967117745263

Meyer J, Morrison J, Zuniga J. The benefits and risks of CrossFit: a systematic review. *Workplace Health Saf*, 2017; 65(12): 612-8

Minghelli B, Vicente P. Musculoskeletal injuries in Portuguese CrossFit practitioners. J *Sports Med Phys Fitness* 2019 [Epub ahead of print]

Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, Shekelle P, Stewart LA. PRISMA-P Group. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst Rev*, 2015; 4(1): 1

Montalvo AM, Shaefer H, Rodriguez B, Li T, Epnere K, Myer GD. Retrospective injury epidemiology and risk factors for injury in CrossFit. *J Sports Sci Med*, 2017; 16(1): 53

Moran S, Booker H, Staines J, Williams S. Rates and risk factors of injury in CrossFit: a prospective cohort study. *J Sport Med Phys Fit*, 2017; 57(9): 1147-53

Summitt RJ, Cotton RA, Kays AC, Slaven EJ. Shoulder injuries in individuals who participate in CrossFit training. *Sports Health*, 2016; 8(6): 541-6

Weisenthal BM, Beck CA, Maloney MD, DeHaven KE, Giordano BD. Injury rate and patterns among CrossFit athletes. *Orthop J Sport Med*, 2014; 2(4): 2325967114531177

Williams S, Booton T, Watson M, Rowland D, Altini M. Heart rate variability is a moderating factor in the workload-injury relationship of competitive CrossFit™ athletes. *J Sports Sci Med*, 2017; 16(4): 443

Corresponding author:

Dr. Emilio Villa González
Department of Physical and Sports Education, PROFITH "PROmoting FITness and Health through Physical Activity" Research Group, Sport and Health University Research Institute (iMUDS), Faculty of Education and Sport Sciences, University of Granada, C/ Santander, 1, 52005 Melilla, Spain;
E-mail: evilla@ugr.es (E.V.-G.)