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REVIEW ARTICLE

The benefits and risks of the high-intensity CrossFit training

Elina A. Gianzina[1] · Olga A. Kassotaki[2]

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Abstract

Purpose The main aim of this study was to conduct a systematic review of the recent research output produced on CrossFit and to examine the benefits and risks of the high-intensity CrossFit training.

Methods Systematic search of PubMed, ScienceDirect, Scopus and Web of Science was conducted. Thematic analysis of the research output on CrossFit was performed and each of the included articles was assessed using the Delphi Scale for quality assessment of individual studies.

Results A total of 25 articles were included in this study. Based on our results, high-intensity CrossFit training incorporates both aerobic and anaerobic elements, which in turn improve cardiovascular fitness, anaerobic capacity, and body composition of individuals of all levels of fitness and of both genders. CrossFit has also positive psychological effects on athletes, such as exercise enjoyment, challenge, satisfaction, and goals achievement, which lead to high levels of retention and adherence of participants to CrossFit programs. On the other hand, high-intensity CrossFit training includes risks. These are musculoskeletal injuries occurring at different body parts, with most common being shoulder, lower back and knee injuries, and other more severe but less common injuries, such as exertional rhabdomyolysis.

Conclusions The findings of this study indicate that intense CrossFit training improves the six out of ten general physical skills of athletes, as proposed by CrossFit Inc., such as cardiovascular/respiratory endurance, stamina, strength, flexibility, power and balance. The other four physical skills, such as speed, coordination, agility, and accuracy, are yet to be verified.

Keywords Systematic review · CrossFit training · Benefits · Risks · Injuries

Introduction

Over the past years, CrossFit has gained popularity worldwide [1]. The first CrossFit gym opened in 2000 in California, USA, and since then more than 13,000 CrossFit gyms have been opened in at least 142 countries [2]. At present, more than 3.5 million athletes are training using CrossFit fitness programs [3]. In addition, CrossFit is replacing or augmenting traditional physical training methods to increase the physical fitness of lifeguards, fire fighters, police officers, and army soldiers and leaders [4, 5].

The CrossFit program is a high-intensity power-training (HIPT) program that is used to improve ten general physical skills, such as cardiovascular/respiratory endurance, stamina, strength, flexibility, power, speed, coordination, agility, balance and accuracy in athletes of both genders, as well as untrained individuals, through the appropriate mixture of diet, gymnastics, weightlifting, and multiple other aerobic and anaerobic exercises [2, 6]. In fact, it is useful for many individuals, as it requires minimal time commitment when compared with other traditional endurance training programs [6, 7]. The program incorporates exercises, such as Olympic weightlifting with jerks, squats, deadlifts, snatches, and overhead press, among others. It also uses traditional gymnastic exercises, which include the use of rings, handstands and parallel bars, and aerobic exercises, such as swimming,

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✉ Olga A. Kassotaki
o.gianzina-kassotaki@warwick.ac.uk

Elina A. Gianzina
elina.zina@hotmail.com

1 Department of Physical Education and Sport Sciences, Democritus University of Thrace, University Campus, 69100 Komotini, Greece

2 Strategy and International Business Group, Warwick Business School, University of Warwick, CV4 7AL Coventry, UK

running and rowing [5]. These exercises are often performed at a high intensity with little recovery time between exercises [8].

The CrossFit program uses a "workout of the day" or WOD, which is posted open access on the CrossFit website. The WOD incorporates both aerobic and anaerobic training styles in intervals to improve aerobic fitness and body composition of athletes. It is performed both as quickly as possible (for a best time), and for "as many rounds as possible" (AMRAP) [6]. In a typical CrossFit program, athletes conduct a warm-up, a skill or strength development segment, the WOD of the day, and a cool down [9, 10]. The WOD by design varies from day to day, but typically includes a mixture of high-intensity exercises of 5–20 min [4, 11].

The popularity of the CrossFit program, however, raises concerns about the benefits of the CrossFit training, and the possible risks and injuries that may occur from the participation in such a high-intensity fitness program. This study, therefore, uses the recent research output on CrossFit produced by scholars to examine the benefits and risks of CrossFit, and discusses the varying effects of the CrossFit training on individuals. A detailed analysis of our review strategy follows in the next section.

Methods

Search strategy and inclusion criteria

This systematic review conforms to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [12]. When identifying the articles, the following electronic databases were used: PubMed, ScienceDirect, Scopus, and Web of Science. The search term of this study was «CrossFit». All CrossFit articles included in this review were peer reviewed, written in English and not limited to specific years or country, while we excluded any review articles from the main body of our review, as well as articles that had no full text.

Study selection and quality assessment

One independent researcher evaluated the articles and extracted the data, which was later evaluated by a second researcher. Any disparities on data extraction were resolved by discussion. More specifically, after the first screening process of the articles, duplicate articles and studies with irrelevant titles and abstracts were removed. All articles were written in English, except for one, as it had important practical applications for athletes and, therefore, included in this work. In addition, one review article on injuries in CrossFit was also included, as it was considered to have important theoretical applications on CrossFit research. After the second screening, we excluded further studies, which had no full text, or due to insufficient data for analyses, if they had non-exercise interventions or with results that had no relation to our themes.

Each of the included articles was assessed using a Delphi Scale for quality assessment of individual studies (see Table S1) [13, 14]. This is a scale with nine items to assess the methodological quality, such as internal validity, external validity, and statistical considerations of randomized clinical trials. In this scale, it is not described a calculation of score and all items have three response options: yes, no, or do not know. Two independent researchers analyzed the studies and provided a rating. The discrepancies between the reviewers were resolved through discussion. In Fig. 1 below, we provide the search flow diagram for studies related to CrossFit.

Results

The search strategy found 215 articles in total (81 articles from PubMed, 33 articles from ScienceDirect, 50 articles from Scopus, and 51 articles from Web of Science). After the inclusion/exclusion criteria were implemented, 25 articles were included in this study, whereas 190 articles were excluded due to unfit title, abstract or full text.

To perform our review on CrossFit research, we carefully read the research output produced on CrossFit to become familiar with the data, and then created two major themes and then sub-themes [15]. When constructing the main themes of this review, we were interested in including the most important elements of the CrossFit training that have important theoretical and practical applications for a great number of sport scientists, coaches and athletes. These include: (1) the benefits of the high-intensity CrossFit training, which were divided into two sub-themes (1.1) physical and physiological benefits, and (1.2) psychological and motivational benefits, (2) the risks and injuries observed during the high-intensity CrossFit training, which were also divided into two sub-themes (2.1) musculoskeletal injuries, and (2.2) other injuries (see Table S2).

Discussion

Benefits of the high-intensity CrossFit training

Scholars have emphasized on the benefits of CrossFit on individuals in multiple studies [2, 5]. The most common positive effects of CrossFit include physical and physiological benefits that improve the physical capability of athletes, and psychological and motivational benefits, which have positive impact on the psychology of athletes. In general, physical capability, including aerobic and anaerobic capacity, as well

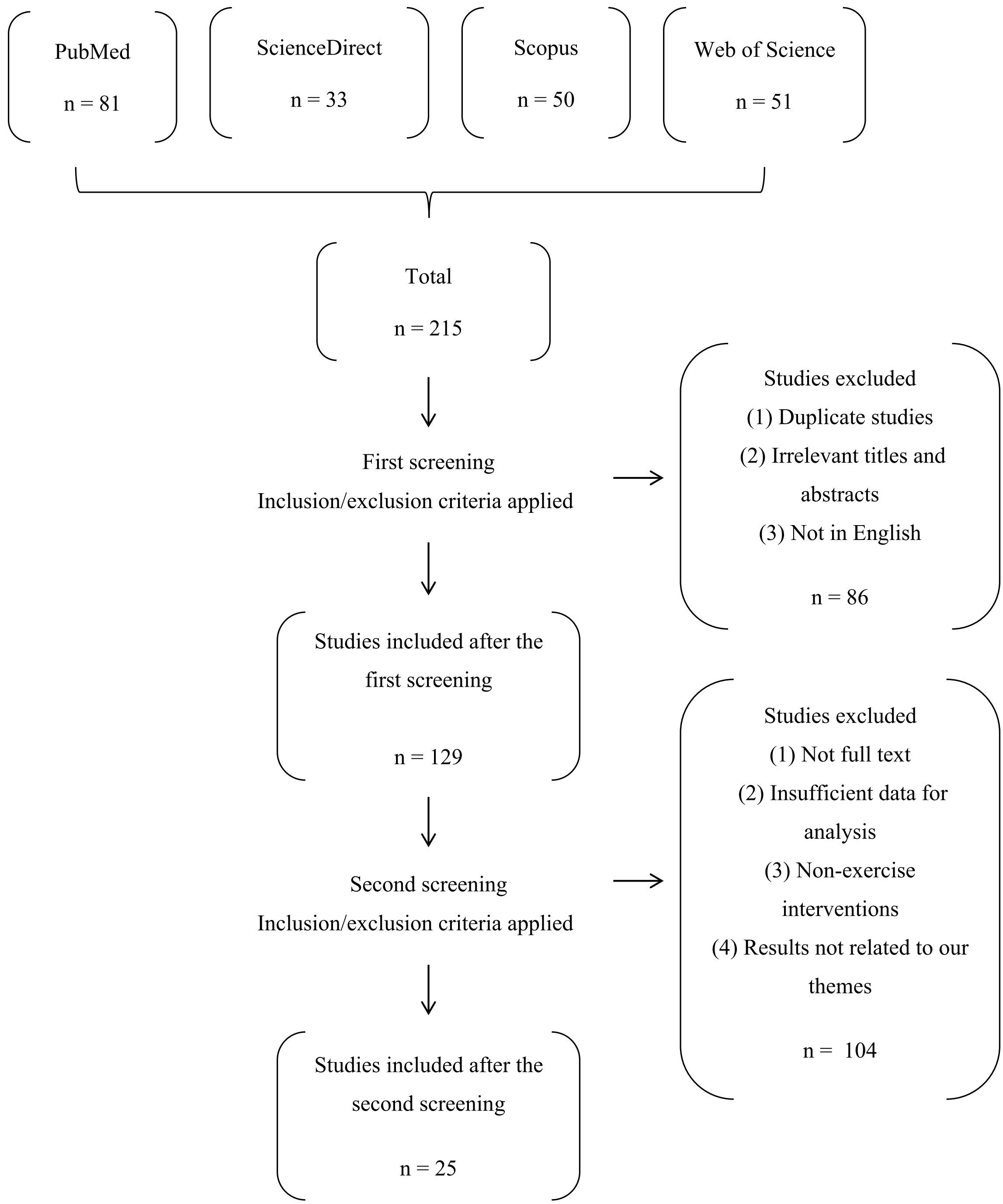

Fig. 1 Search flow diagram for studies related to CrossFit

as anaerobic power of athletes, is an important factor that ensures success in athletic endeavors [16]. Anaerobic power has to do with the ability of individuals to optimize muscular power output (P_{max}), which is fundamental for the successful performance of many athletes [17]. It refers to the rate of anaerobic energy production, whereas anaerobic capacity refers the total amount of anaerobic energy produced. Aerobic capacity is also an important component of athletic success, which refers to the maximum amount of oxygen consumed by the body during intense exercise, in a given time frame [18].

CrossFit training incorporates both aerobic and anaerobic elements, which in turn improve cardiovascular fitness, anaerobic capacity, and body mass and composition (e.g., reduction in body fat, BMI, waist circumference) of individuals of all levels of fitness [9, 10, 16, 19, 20]. CrossFit exercises are considered to be of moderate to high intensity [21, 22], which lead to moderate to high HR_{max} scores (53.5–95%) [19, 21, 22], high RPE scores (7.3/10–19/20) [11, 19, 22], increased blood lactate (mean values 1.2 to > 10 $mmol^{-1}$) [21, 23], and increased $\%VO_{2max}$ (mean values 56.7–66.2%) [9, 22]. Some CrossFit workouts (e.g., 10-min AMRAP of 3 burpees, 4 push-ups, 5 squats) have a moderate-intensity impact on individuals [21], while other WODs, such as Fran (for time reps of 21-15-9 thrusters and pull-ups) or Murph (for time reps of 100 pull-ups, 200 push-ups, 300 unweighted squats) are considered to be high-intensity protocols [11, 19, 22]. Finally, CrossFit training has also psychological and motivational benefits on athletes, such as exercise enjoyment, challenge, satisfaction, and goals achievement, which lead to high levels of retention and adherence of participants to CrossFit programs [2, 10, 24].

Physical and physiological benefits

In relation to the physiological benefits of CrossFit, when comparing different fitness levels, Bellar et al. [16] tested in their study the maximum aerobic capacity (VO_{2max}) and the anaerobic power (Wingate test) of 32 adult males in two representative CrossFit workouts, who were either naïve (11 healthy young men), or have competed in the CrossFit competitions (21 trained men). Linear regression was undertaken to predict performance on the first workout (time) with age, group (experienced or naïve), VO_{2max}, and anaerobic power, which were all significant predictors in the model. Accordingly, in the second workout (repetitions), only CrossFit experience was a significant predictor. The results of this study showed that a history in participation in CrossFit competition is a key component of performance in CrossFit workouts, and that in at least one of these workouts, aerobic capacity and anaerobic power are associated with success.

Accordingly, Butcher et al. [19] examined in their study 57 participants (38 female), comprised of novice ($n = 35$) and experienced individuals ($n = 22$) who completed circuit (using resistance exercises) and high-intensity interval sessions. They found that for the whole study population, mean heart rate (HR) responses during interval sessions (76 ± 7%predmax) were significantly lower than during circuit sessions (88 ± 6%predmax) despite similar perceived exertion (RPE) scores (17 ± 2 vs. 18 ± 1/20, respectively), while experienced participants had higher overall HR than the novice group during both sessions with greater indices of work performance but no differences in RPE. Rate of perceived exertion is used to measure the exercise intensity, which in this study was recorded at the end of each interval using the Borg category (6–20 scale). The researchers concluded that both continuous circuit and high-intensity interval CrossFit sessions can be used to elicit a significant HR response during exercise and are likely appropriate training methods for achieving recommended target intensities for both novice and experienced athletes.

When observing young CrossFit participants, Eather et al. [10] noticed in a study on 51 physically active, 15-year-old adolescents, improvements in body mass and composition (waist circumference, BMI, BMI–*Z* score), cardiorespiratory fitness (measured by the shuttle run test), muscle run fitness (measured by the standing jump test), and flexibility (measured by the sit and reach test). The findings of this study demonstrate that CrossFit Teens is a feasible and efficacious program for improving health-related fitness in adolescents.

In a similar study, Shaw et al. [21] examined the physical and physiological demands of 12 sedentary college-aged males taking part in a 10-min single bout of the CrossFit triplet training session. They observed increased heart rate (53.5% of aged-perceived maximal HR), increased blood lactate (5.95 ± 3.24 $mmol\ l^{-1}$), and lack of increase in blood glucose in individuals following the CrossFit training, which indicate that the exercise was performed at a moderate to high intensity. In addition, CrossFit training was found to cause no significant changes in systolic and diastolic blood pressure, total cholesterol, and pulse and arterial pressure in individuals. These findings support the safety for the inclusion of this type of training as a form of physical exercise and also as a competitive fitness sport.

In addition, Fernandez–Fernandez et al. [22] in their study examined the physiological (heart rate, oxygen uptake (VO_2), blood lactate), and perceptual responses (ratings of RPE) of ten trained individuals during two CrossFit workouts and if the physical demands of CrossFit met the American College of Sports Medicine (ACSM) criteria of cardiovascular fitness in healthy adults. The ACSM recommends engaging in moderate-intensity aerobic activity for a minimum of 30 min per day, 5 days per week (i.e., 40–60% of VO_{2max}; 60–75% of HR_{max}) or vigorous-intensity aerobic activity for a minimum of 20 min per day, 3 days per week (i.e., 60% of VO_{2max}; 75% of HR_{max}) to promote and maintain health in adults. The researchers observed fitness and health improvements from CrossFit exercises that met the ACSM criteria for energy expenditure and exercise intensity in healthy adults. They also noticed that CrossFit exercises are high-intensity workouts (90–95% of HR_{max}; LA values > 10 $mmol^{-1}$; RPE values > 8/10) that lead to maximal physiological and perceptual responses.

Moreover, Murawska-Cialowicz et al. [9] examined if CrossFit training can change brain-derived neurotrophic factor (BDNF) and irisin levels at rest and if it can improve aerobic capacity and body composition of 12 young, physically active individuals. The BDNF is a protein that affects the nervous system of individuals in the brain, is released from skeletal muscles during exercise and can facilitate the proper communication between the nervous and muscular systems. Irisin is an exercise hormone that is also released from skeletal muscles and is involved in the oxidation processes in the organism, while increasing the energy expenditure. In their study, the researchers used two consecutive 10–15-min CrossFit workouts with a 5-min break. They observed, after a 3-month CrossFit training program and after Wingate and progressive tests, improvement in the cardiovascular fitness and anaerobic capacity of individuals, improvement in body composition and increase in BDNF (irisin levels showed no change) showing very high application value, especially in a therapeutic process leading to improving an individual's wellbeing.

Finally, Tibana et al. [23] investigated in their study the effects of CrossFit training designed to enhance work capacity through cardiovascular and muscular exercises on cytokines, muscle power, blood lactate and glucose in nine trained men. Two experimental protocols (WODs) of 10–12 min were used to evaluate the above variables. Cytokines are proteins secreted by various cell types. When pro-inflammatory cytokines are administered to humans, they produce fever, inflammation, and tissues destruction, while anti-inflammatory cytokines resolve inflammation and promote healing. Muscle power is the ability to exert a maximal force in as short a time as possible, which in this study was measured by a linear position transducer. Previous research has shown that high-intensity training with short rest protocol elicits a significant increase in muscle damage, inflammation, and produced hyper-reactions in metabolic and adrenal function in men and women with experience in resistance training. The results of this study showed an increase in blood lactate and glucose concentration, as well as increase in pro/anti-inflammatory cytokines of individuals after CrossFit training without any impairment in their muscle power.

Psychological and motivational benefits

With respect to motivational benefits, Partridge et al. [7] explored the impact of gender and membership time on perceived motivational climate and goals of 144 experienced CrossFit participants (88 females, 66 males). In their study, they state that people may set goals related to self-improvement (mastery) or performance improvement (performance) in comparison with other individuals. Motivational climate refers to an individual's perception of being encouraged to focus on either mastery or performance goals. The results of their study showed that motivational climate and goals in CrossFit may vary based on demographic variables. In that respect, females mostly focus on mastery goals, whereas males mostly focus on performance goals. In addition, participants in their study who were exercising in CrossFit gyms for less than 6 months reported higher levels of mastery and performance goals than those who were members for more than 6 months.

Finally, in a study on 23 physically inactive, overweight and obese participants, Heinrich et al. [24] observed that they spent significantly less time on high-intensity CrossFit training per week, yet they were able to maintain exercise enjoyment, while also intending to continue. In addition, participants were able to maintain their body composition or even lose weight. Drop out rates in this study were 25% for high-intensity training participants, which were lower than the average 45% for other exercise interventions. Accordingly, in a study with 51 physically active CrossFit teens, Eather et al. [10] observed high levels of retention (82.3%) and high levels of satisfaction (scores ranged from 4.2 to 4.6 out of 5) in adolescents after CrossFit training. Table 1 below presents studies, which describe the benefits of the high-intensity CrossFit training.

Risks and injures observed in CrossFit training

Despite the benefits of the CrossFit training, scholars have also observed multiple injuries occurring in different body parts from CrossFit, with most common being shoulder, lower back and knee injuries [2, 8, 20, 25–28]. The most common injury types include musculoskeletal injuries, whereas there are also other more severe but less common injuries, such as exertional rhabdomyolysis [28, 29]. A small number of CrossFit athletes has also cardiopulmonary complaints and other neurologic complaints, such as headaches, migraines, weakness, and paresthesia [28].

However, as the definition of an injury is different in multiple studies, the comparison of injury incident rates among studies is difficult. For example, Hak et al. [27] defined an injury as "any injury sustained during training that prevented the participant from training, working or competing in any way and for any period of time", with sports medicine physicians to report that 1 week is the time needed to differentiate the discomfort as soreness or injury [8, 30]. On the other hand, Weisenthal et al. [8] defined an injury as "any new musculoskeletal pain, feeling, or traumatic event that results from a CrossFit workout and leads to one or more of the following options: total removal from CrossFit training and other outside routine physical activities for more than 1 week; modification of normal training activities in duration, intensity, or mode for more than 2 weeks; or any physical complaint severe enough to make the individual seek a health care professional to diagnose or treat the injury".

Another issue that occurs when comparing studies is the method of how the data are collected. For example, Mehrab et al. [30] in their study collected data on injuries directly from athletes, while other researchers use data that come from physicians or physical therapists [8, 28]. Therefore, to eliminate some of the disparity observed when comparing injury incidence rates in studies on CrossFit, a common definition of injury is needed, while also the source (athletes

Table 1 The benefits of the high-intensity CrossFit training

Authors	Date	Sample size	Research design	Method of analysis	Key findings—benefits	Type of benefit
Heinrich et al.	2014	23 physically inactive, overweight and obese participants	Stratified, randomized two-group pre-test post-test intervention	8 Weeks of CrossFit training	Positive effects on overweight and obese participants—no significant changes in BMI or body composition High-intensity training led to maintaining enjoyment and adherence to training 18 participants adhered (ART = 9, 81.8%; HIFT = 9, 75%), HIFT dropouts ($p = 0.012$) and ART participants ($p = 0.009$) reported lower baseline exercise enjoyment than HIFT participants, although ART participants improved enjoyment at post-test ($p = 0.005$). More HIFT participants planned to continue the same exercise than ART participants ($p = 0.002$)	Psychological and motivational reasons
Partridge et al.	2014	144 trained individuals (88 females 66 males)	Descriptive study	By electronic questionnaire with CrossFit participants	Examination of the impact of membership time and gender on goals and motivational climate of CrossFit participants Males focus on performance goals, females focus on mastery goals Participants who were CrossFit members for less than 6 months had higher levels of mastery and performance goals than other participants	Psychological and motivational reasons
Bellar et al.	2015	32 adult males (11 naïve, 21 trained)	Correlational study	Two representative CrossFit workouts: (1) 12 min in duration, (2) total time to complete the prescribed exercise	Aerobic capacity and anaerobic power were associated with increased performance in CrossFit workouts	Physical fitness and performance
Butcher et al.	2015	57 trained participants	Correlational study	4 different CrossFit workouts: "Grace", "Fran", "Cindy", and "CrossFit total"	Improvement of cardiovascular fitness of all levels of fitness Experienced athletes demonstrated evidence of increased workloads and greater ability to sustain higher heart rates than the novice participants, suggesting greater work capacity	Physiological
Fernandez-Fernandez et al.	2015	10 trained individuals	Study of acute physiological and perceptual responses	Incremental treadmill test and two CrossFit workouts: "Fran" and "Cindy"	Significant differences were found for average VO_2 (34.4 ± 3.5 vs. 29.1 ± 1.1 ml·kg-1·min-1), %VO_{2max} (66.2 ± 4.8 vs, 56.7 ± 6.2%) and energy expenditure (318.2 ± 32.5 vs. 121.0 ± 38.5 kcal·min-1; $p < 0.001$; ES = 3.8) with "Cindy" workout showing higher values, while "Fran" resulted in significantly time spent above 1 (76.0 ± 29.7 vs. 47.7 ± 21.4%; $p < 0.05$; ES = 0.7) CrossFit exercises met the ACSM criteria for energy expenditure and exercise intensity in healthy adults	Physiological and perceptual responses, and physical demands

Table 1 (continued)

Authors	Date	Sample size	Research design	Method of analysis	Key findings—benefits	Type of benefit
Murawska-Cialowicz et al.	2015	12 young, physically active individuals	Correlational study	3-Month CrossFit training program	Improvement in the aerobic capacity, increase in VO_{2max}, reduction in adipose tissue percentage in women and an increase in LBM in all the participants After 3 months of CrossFit training the level of BDNF increased in all the participants, and also was higher in men than in women Irisin levels showed no change Improvement of body composition in all the participants	Physical fitness
Shaw et al.	2015	12 sedentary males	Study of physical and physiological demands	Single bout of CrossFit training	CrossFit training can be considered moderate to high intensity, with sufficient intensity and safety A single boot of CrossFit training significantly increased HR (79.17 ± 21.96 to 108.00 ± 23.71 bpm; $p = 0.002$), RPP (8995.00 ± 3434.33 to 11808.60 ± 6191.09; $p = 0.028$) and blood lactate (2.20 ± 1.35 to 5.95 ± 3.24 mmol l^{-1}; $p = 0.003$), while decreasing forced expiratory volume in 1-s (FEV_1) (3.71 ± 0.37 to 3.53 ± 0.42 l; $p = 0.034$) No effect on systolic blood pressure ($p = 0.450$), diastolic blood pressure ($p = 0.844$), pulse pressure ($p = 0.168$), mean arterial pressure ($p = 0.638$), forced vital capacity (FVC) ($p = 0.054$), FEV_1/FVC (%) ($p = 0.308$), total cholesterol ($p = 0.195$) and blood glucose ($p = 0.609$)	Physical and physiological
Eather et al.	2016	51 physically active teens	Assessor-blinded randomized controlled trial	8-Week CrossFit training program (60 min twice per week)	Significant group-by-time intervention effects were found for waist circumference [− 3.1 cm, $p < 0.001$], BMI [− 1.38 kg m(−)(2), $p < 0.001$], BMI-Z [− 0.5 z scores, $p < 0.001$], sit and reach [+ 3.0 cm, $p < 0.001$], standing jump [+ 0.1 m, $p = 0.021$] and shuttle run [+ 10.3 laps, $p = 0.019$] Retention rate was 82.3%, and high levels of satisfaction with scores ranging from 4.2 to 4.6 out of 5	Physical and psychological benefits
Tibana et al.	2016	9 trained men	Study of effects of two CrossFit training sessions	Two experimental protocols with 24 h apart, each with: (1) strength and power exercises, (2) gymnastic movements, and (3) metabolic conditioning. The exercises included double-unders, rowing, power snatches and target burpees	Increase in pro/anti-inflammatory cytokines without any impairment in muscle power Significant increase in blood lactate (1.20 ± 0.41 to 11.84 ± 1.34 vs. 0.94 ± 0.34 to 9.05 ± 2.56 mmol l^{-1}) and glucose concentration (81.59 ± 10.27 to 114.99 ± 12.52 vs. 69.47 ± 6.97 to 89.95 ± 19.26) Significant changes ($p \leq 0.05$) in IL-6, IL-10 and osteoprotegerin concentration over time mg/dL	Physical fitness

Table 2 The risks and injuries observed in CrossFit training

Authors	Date	Sample size	Research design	Method of analysis	Key findings—risks and injuries
Grier et al.	2013	1393 solders	Surveys	Collection of personal characteristics, tobacco use, personal physical fitness training, Army physical fitness test results, and self-reported injuries	Categorization of injuries—overuse injuries, traumatic injuries, and overall injury
Hak et al.	2013	132 responses of trained individuals	Descriptive study	By electronic questionnaire distributed amongst international CrossFit online forums	Musculoskeletal injuries Most common shoulder and spine injuries 73.5% injured in total with 7% requiring surgical intervention Injury rate of 3.1 per 1000 h trained No incidents of rhabdomyolysis Injury rates similar to sports, such as Olympic weight lifting, power lifting, and gymnastics and lower than sports, such as rugby union and rugby league
Weisenthal et al.	2014	386 trained participants	Descriptive study	By online survey with CrossFit gyms	Overall injury rate 19.4% from CrossFit training (75/386) Mostly observed musculoskeletal injuries—shoulder (21/84), low back (12/84) and knee injuries (11/84) Men more frequently injured (53/231) than women (21/150; $p=0.03$) Shoulder injured during gymnastic movements, while lower back injured during power lifting movements The injury rate was decreased with the trainer involvement ($p=0.028$)
Chachula et al.	2016	54 trained individuals (40 males, 14 females)	Correlation study	By survey with CrossFit participants	Individuals with a joint injury were 3.75 times as likely to sustain an injury during CrossFit training Patients with prior injuries may be more susceptible to injury during CrossFit workouts
Lichtenstein & Jensen	2016	603 trained individuals	Descriptive study	By online survey using Facebook groups	5% of individuals experience exercise addiction in CrossFit Young athletes and men are more prone to exercise addiction Significant positive associations between exercise addiction and the tendency to exercise in spite of injury, feelings of guilt when unable to exercise, passion turning into obsession and taking medication to be able to exercise
Sprey et al.	2016	622 trained individuals	Descriptive epidemiological study	By questionnaire with CrossFit athletes	Overall injury incidence of approximately 31% in CrossFit participants CrossFit injury rates are comparable to those of other recreational or competitive sports Injuries show profiles similar to weight lifting, power lifting, weight training, Olympic gymnastics, and running More injuries compared to CrossFit were observed in soccer The injury rate was decreased with the trainer involvement

Table 2 (continued)

Authors	Date	Sample size	Research design	Method of analysis	Key findings—risks and injuries
Summitt et al.	2016	187 trained individuals	Descriptive survey study	By electronic survey with CrossFit individuals	Shoulder injury as the most frequently injured body region 23.5% were injured in the shoulder over the previous 6 months 38.6% of those who reported injury, stated this injury was an exacerbation of a previous injury sustained before CrossFit The most commonly attributed causes of injury were improper form (33.3%) and exacerbation of a previous injury (33.3%) 64.1% of those who experienced injury reported 1 month or less of training reduction due to injury
Drum et al.	2017	101 trained individuals	Descriptive study	By questionnaire with CrossFit and ACSM participants	Only one incident of exertional rhabdomyolysis (ER) Significant RPE levels of 7.3 ± 1.7 and 5.5 ± 1.4 ($p \leq 0.001$) and amounts of hard days per week of 4.0 ± 1.1 and 3.5 ± 1.4 ($p = 0.04$) The five most frequent and hardest ECP workouts of the day (WODs) were Fran (47), Murph (27), Fight Gone Bad (10), Helen (9) and Filthy 50 (9) Presence of severe post-exercise symptoms was notably higher in CrossFit for excessive fatigue (42 vs. 8; $p < 0.001$), muscle soreness (96 vs. 48; $p = 0.04$), muscle swelling (19 vs. 4; $p = 0.048$), shortness of breath (13 vs. 1; $p = 0.02$), muscle pain to touch (31 vs. 4; $p = 0.001$), and limited muscle movement during workout (37 vs. 9; $p = 0.007$)
Fisker et al.	2017	34 trained participants	Study of the effects of acute overload on tendon thickness	Observation of healthy participants with ultrasonography	Significant increases were observed in patella tendon thickness before ($M = 4.5$, SD = 0.6) and after ($M = 5.0$, SD = 0.7) highly intense strenuous exercise, with an estimated mean differences of 0.47 mm (95% CI: 0.35–0.59 mm; $p < 0.0001$) Significant increases in Achilles tendon thickness before ($M = 4.4$, SD = 0.4) and after ($M = 4.5$, SD = 0.5) workout, with an estimated difference of 0.17 mm (95% CI: 0.04–0.29 mm; $p < 0.01$)
Hopkings et al.	2017	498 patients	Study of exercise-related injuries	Treatment of patients at the major academic center	20.9% were spine injuries, the most common injuries identified, with 6.7% requiring surgical intervention Among spine injuries, the most common location of injury was the lumbar spine (83.1%) Average symptom duration was 6.4 months $\pm$ 15.1, and radicular complaints were the most common symptom (53%) A total of 30 (32%) patients had positive findings on neurologic examination

Table 2 (continued)

Authors	Date	Sample size	Research design	Method of analysis	Key findings—risks and injuries
Mehrab et al.	2017	449 trained participants	Descriptive epidemiological study	By questionnaire distributed to CrossFit gyms and Facebook groups	Most injured shoulder ($n=87$, 28.7%), lower back ($n=48$, 15.8%) and knee injuries ($n=25$, 8.3%) The majority of injuries were caused by overuse ($n=148$, 58.7%) The duration of participation in CrossFit significantly affected the injury incidence rates (<6 months vs. ≥24 months; odds ratio, 3.687 [95% CI, 2.091–6.502]; $p < 0.001$) Coaches' involvement is important for the decreased risk of injuries who can determine the correct volume, complexity and intensity of the workouts
Montalvo et al.	2017	191 trained individuals	Descriptive study	By survey with CrossFit gyms	50 out of 191 athletes sustained injuries in 6 months—26.1% injury rate Shoulder, knee and lower back were the most frequently reported locations of injury Taller and heavier athletes were more likely to experience injury Increased exposure to training in the form of greater weekly athlete training hours and weekly participations may contribute to injury Competitors were more likely to be injured (40% vs. 19%, $p=0.002$) and had greater weekly athlete training hours (7.3 ± 7.0 vs. 4.9 ± 2.9, $p<0.001$) than non-competitors Injury incidence in CrossFit was similar to related sports, such as Olympic weightlifting, gymnastics and power lifting High risk factors for: years of participation (2.7 ± 1.8 vs. 1.8 ± 1.5, $p=0.001$), weekly athlete training hours (7.3 ± 3.8 vs. 4.9 ± 2.1, $p=0.020$), weekly athlete exposures (6.4 ± 3.8 vs. 4.7 ± 2.1, $p=0.003$), height (1.72 ± 0.09 m vs. 1.68 ± 0.01 m, $p=0.011$), and body mass (78.24 ± 16.86 kg v 72.91 ± 14.77 kg, $p=0.037$)
Moran et al.	2017	117 trained individuals	Correlational study	12 Weeks of CrossFit training	A multivariate Poisson regression model identified males (rate ratio, RR: 4.44 ×/÷ 3.30, very likely harmful) and those with previous injuries (RR: 2.35 ×/÷ 2.37, likely harmful) as having a higher injury risk Injury rates associated with CrossFit training were low and comparable to those observed in other sports
Klimek et al.	2018	3 studies	Literature review	Comparison of studies conducted on injuries in CrossFit	The reported incidences of injuries associated with CrossFit were comparable or lower than rates of injury in Olympic weightlifting, distance running, track and field, rugby, or gymnastics The injury rate was decreased with the trainer involvement Shoulder injuries were the most common injuries

or physicians) and the time frame (e.g., last 6 or 12 months) must be clearly defined. In that respect, there should be a differentiation between new injury caused by CrossFit and exacerbation of a previous injury sustained prior to starting CrossFit.

Finally, according to researchers, injury rates in CrossFit are similar with those observed in sports such as Olympic weightlifting, power lifting, weight training, running and gymnastics and lower than those observed in sports such as soccer, ice hockey, rugby union and rugby league [25–27, 31–33]. In addition, men are more frequently injured than women, and injuries are more prevalent during training, where supervision is not always available to athletes, so that the exercises are correctly executed [8, 25, 30–32, 34]. Finally, researchers observed an increased risk of injury from CrossFit training in the area that has been injured before [5, 32, 34, 35]. For example, Chachula et al. [34] observed that 54 trained individuals (40 males, 14 females) in their research with a history of joint injury (i.e., ankle sprains, etc.) were 3.75 times as likely to sustain an exacerbation of a previous injury during CrossFit training.

Musculoskeletal injuries

In relation to musculoskeletal injuries, Grier et al. [33] in their study on extreme conditioning programs, such as CrossFit, distinguished injuries as overuse injuries, traumatic injuries, and overall injury. Overuse injuries include injuries such as stress fractures and reaction, tendinitis, shin splits, and general musculoskeletal pain. Traumatic injuries are those that result from a sudden force or forces applied to the body. Overall injury is defined as the total number of injuries occurring to the body [25].

Under this view, Weisenthal et al. [8] in a study with 386 trained participants observed a 19.4% overall injury rate from the high-intensity CrossFit training. Shoulder was the most commonly injured area during gymnastic movements, while lower back was mostly injured during power lifting movements. In the same vein, Montalvo et al. [26] observed a 26.1% injury rate (calculated as the number of injuries/1000 training hours in the preceding 6 months) in their study of 191 trained individuals, with taller and heavier athletes, and those participating in competitions being more likely to experience injury, while Sprey et al. [31] referred an overall injury incidence rate of 31% in 622 trained CrossFit participants in their research.

Much higher injury incident rates were found in the studies of Mehrab et al. [30], where 56.1% of 449 trained participants sustained an injury in the preceding 12 months, and Hak et al. [27], where 73.5% of 132 trained participants sustained an injury during CrossFit training, with 7% requiring surgical intervention. Differences in sample size and response bias may explain some of the disparity observed in all the above studies [25].

In a more specialized study, Summitt et al. [32] reported that 23.5% of the 187 trained individuals in their research experienced a shoulder injury over the previous 6 months, of whom 38.6% stated that this injury was an exacerbation of a previous injury sustained prior to starting CrossFit. The most commonly stated reasons for the shoulder injury, which was the most frequently injured body region, were improper form of movement and exacerbation of a previous injury. Most of the athletes stated that they needed 1 month or less of training reduction due to injury to return to their previous healthy state. Accordingly, Montalvo et al. [26] observed in their research with 191 trained individuals that depending on the severity of injury, in acute cases, athletes stated that after being injured, they either stop performing an exercise or cease activity completely, while in more severe cases they seek medical attention for their injury.

In a study with exercise-related injuries, Hopkings et al. [28] examined 498 patients (all fitness levels) who presented to the main hospital at a major academic center due to CrossFit-related injury between 2010 and 2016. In their study, injuries were classified by the anatomical location. The researchers observed that 20.9% of the patients presented spine injuries, which were the most common injuries identified, with 6.7% requiring surgical intervention. Of the spine injuries, 83.1% were lumbar spine injuries. The average symptom duration for all the injuries in their study was approximately 6 months.

In a recent study, Fisker et al. [36] observed the acute tendon changes in intense CrossFit workouts in 34 trained participants. Previous research has shown that chronically overloaded tendons thicken, a fact that can increase the risk of tendinopathy. However, it remains unknown if acute overload caused by high-intensity exercise leads to changes in tendons and if these changes can be detected through ultrasonography. The researchers observed in their study using ultrasonography that indeed high-intensity CrossFit training leads to a significant increase in the thickness of tendons (patellar and Achilles), which in turn may cause tendinopathy.

Finally, Lichtenstein and Jensen [37] observed that 5% of 603 trained individuals in their study were addicted to exercise; an addiction which was more prevalent in young athletes and in males. Due to this addiction, they tended to exercise despite injury, as they were feeling guilty when unable to exercise, while also taking medication to continue training.

Other injuries

Other more severe but less common injuries observed in CrossFit are rhabdomyolysis, ocular dysfunction, abdominal pain, pulmonary symptoms, scrotal inflammation, proteinuria, and dehydration [28]. With respect to rhabdomyolysis, it is the result of the muscular tissue damage that leads to the release of different cell contents into the bloodstream. These cell contents disrupt homeostasis that is important for the stable state of an organism and of its internal environment. The most important factors related to rhabdomyolysis include heat stress, dehydration, dietary supplements or the use of medication, and intense training. Rhabdomyolysis occurring from exercise is called exertional rhabdomyolysis (ER). Research has shown that even though the presence of severe post-exercise symptoms was high in the CrossFit program for excessive fatigue, muscle soreness, muscle swelling, shortness of breath, muscle pain to touch and limited muscle movement during workouts, still scholars have observed only two incidents of ER in three studies, while examining 1, 132, and 157 trained individuals, respectively [11, 27, 38]. Table 2 below presents studies, which describe the risks and injuries that may occur from the high-intensity CrossFit training.

Limitations and future directions

This study is not without limitations. As the thematic analysis is an inherently interpretive technique, which includes judgments and biases, it may have affected the reliability of our data presentation. In addition, generalizations of some of the results on CrossFit were difficult. For example, when comparing injury incident rates of CrossFit with other exercise interventions, some studies presented mixed results about which sports have higher or lower injury rates than CrossFit. In addition, studies with larger samples, which include in their methods training sessions (e.g., single efforts, couplets and triplets) with different exercise intensities and duration in exercise execution, are still needed to better investigate the benefits of CrossFit and draw more reliable conclusions, while also reducing the risk of bias. More studies are also needed with respect to the proper coaching of CrossFit athletes or the cooperation with other sport experts (e.g., weightlifting coaches, etc.) to avoid injuries, as well as research on the different training methods is needed that include intense interval exercises (e.g., Tabata protocol, EMOM protocol, etc.). More research is necessary on ER and how it is compared with other intense exercise interventions (e.g., running, etc.), and finally more studies are required on the elite level about how severe are the effects of the intense training of CrossFit on athletes that take part in competitions.

Conclusion and practical applications

This review reveals that high-intensity CrossFit training has physiological impact on athletes, as it incorporates both aerobic and anaerobic elements, which in turn improve cardiovascular fitness, anaerobic capacity and body composition of individuals of all levels of fitness and of both genders. Accordingly, high-intensity CrossFit training has also psychological effects on athletes, as it contributes to exercise enjoyment, challenge, satisfaction, and goals achievement, which in turn leads to high levels of retention and adherence of participants to CrossFit programs. The findings of our study show, therefore, that CrossFit training improves the six out of ten general physical skills of athletes, which are cardiovascular/respiratory endurance, stamina, strength, flexibility, power and balance, whereas the other four physical skills, such as speed, coordination, agility, and accuracy, are yet to be verified. Finally, CrossFit training also includes risks and may cause injuries to athletes. Our review reveals that CrossFit may lead to multiple musculoskeletal injuries occurring in different body parts, with most common being shoulder, lower back and knee injuries, as well as other more severe but less common injuries, such as exertional rhabdomyolysis.

In practice, CrossFit athletes and especially novice, untrained individuals should be in close cooperation with experienced coaches, so that the exercises are correctly executed, the movements are controlled, the load is low, and thus the risks of injuries are diminished, as some of the exercises demand not only the appropriate technique, but also considerable skill, balance, and strength (e.g., kettlebells, suspended rings, or hand-stand push-ups). Accordingly, elite athletes should adhere to individualized training methods with clearly defined objectives, periodicity in training with rest periods, while hydrating at regular intervals and implementing a proper nutrition protocol to avoid severe homeostatic imbalances. Finally, the improvement of the exercise technique is also an important factor in the reduction of injury risk. In that respect, in many CrossFit gyms, at least one session per week is used to increase the exercise technique, which improves the efficacy of movements and reduces the risk of injuries. Using such guidelines, therefore, sport experts will help elite CrossFit athletes, as well as novice individuals to ensure optimal, safe, and progressive development of physical and functional readiness.

Compliance with ethical standards

Conflict of interest The authors declare they have no conflict of interest.

Ethical approval This review article does not contain any participation of human subjects or animals.

Informed consent For this type of study, informed consent is not required.

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