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Review article

CrossFit® Training Strategies from the Perspective of Concurrent Training: A Systematic Review

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Abstract

In the basic principles of CrossFit®, the goal is to improve fitness, related to the simultaneous development of strength and endurance. This is also the main idea of concurrent training, which has been researched since the 1980s. This article aimed to analyze the acute and chronic effects of CrossFit® and to assess the relevance of using the concurrent training methodology. The findings show that CrossFit® is an intense form of exercise that affects the function of the endocrine, immune, and central nervous systems. It also has potential in the development of strength and endurance parameters. These conclusions were compared with relevant concurrent training studies. Although the CrossFit® interventions (workouts of the day) have much in common with concurrent training, methodological recommendations can only be partially transferred. The approach for training and athlete development must be based on the originality of this sport.

Key words: Performance, high intensity, concurrent exercise, training load.

Introduction

CrossFit® has developed into a popular sport, there are more than 11,481 affiliated gyms worldwide (Official CrossFit® Affiliate Map, 2020), which have an extensive base of athletes. The first CrossFit® Games were held in 2007, which can be described as the birth of the CrossFit® competitive form. Performance and competition have become part of this sport, as evidenced by the number of participants in the CrossFit® Games Open from 26000 in 2011 to more than 400,000 (Aucher, 2014; Mangine et al., 2020) as well as a significant number of international and local competitions. Many competitions are not officially organized by CrossFit® HQ, however, their concept is similar.

Every sport needs to find effective methods to increase athlete performance. The purpose of CrossFit® is to develop a wide range of abilities that also require maximum strength, long endurance, or mixed modal performance. In performance-oriented and competitive form, the goal is to test athletes in a variety of fitness aspects (Serafini et al., 2018; Tibana et al., 2019a). These fitness tasks are very diverse and require comprehensive readiness. An important attribute of most competitions is the non-publication of workout of the day (WOD), announced just before or even during the competition. The athlete must, therefore, be prepared to complete a variety of workouts.

Not only training preparation, but also the performances themselves are connected with the principles of concurrent training. Training sessions are often applied that contain strength and endurance components (Schlegel et al., 2020). During training cycles, the combination of different types of strength and endurance is essential for CrossFit® performance. Therefore, it is essential to optimize the training process to be as efficient as potential and to avoid possible interference (adverse effect on adaptation mechanisms in the development of strength or endurance during concurrent training) of these modals (Berryman et al., 2019). One of original goals of CrossFit® is to develop ten physical skills (Cosgrove et al., 2019), but this paper focuses mainly on strength and endurance.

This article aims to analyze the short-term and long-term effects of CrossFit® and evaluate training strategies in conjunction with concurrent training.

Methods

The author performed a systematic literature review of available human studies on the research topic describing CrossFit®, high-intensity functional training, and concurrent training. CrossFit® is seen in the context of this article primarily as a sport. There are terms such as Functional fitness, Sport of fitness, or Extreme conditioning programs, which are not identical to the concept of sports performance or competition design. Some authors use the term High-intensity functional training; however, it is not yet in full agreement with other scientists and athletes or the community. The research studies were selected based on research topics such as acute response, strength, endurance, training, interference effect, chronic adaptation, CrossFit, high-intensity functional training, high-intensity interval training, weightlifting, concurrent training found in four databases Web of Science, PubMed, Springer, and Scopus. The terms used were searched using AND to combine the keywords listed and using OR to remove search duplication where possible. The search period ended in April 2020. Altogether 9,632 articles were identified across the databases. After removing duplicates and titles/abstracts unrelated to the research topic, 320 studies remained. Of these, only 66 articles were relevant to the research topic – CrossFit® and concurrent training strategies. These research studies were classified according to their relevancy (Figure 1). The information found in the selected studies on CrossFit®, long- and short-term effects, and concurrent training are described and discussed in the following sections. Studies on acute effects and interventions involving CrossFit® (a total of 25) are described in the tables and commented in the text.

The inclusion criteria were as follows: the publica-

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tion period of the article was limited to March 2020; only reviewed full-text studies in scientific journals in English were included; the subjects had to be: adult healthy population and athletes, without age restriction. The exclusion criteria involved: specific target groups - children, seniors, and people with disabilities. Figure 1 below, then illustrates the selection procedure.

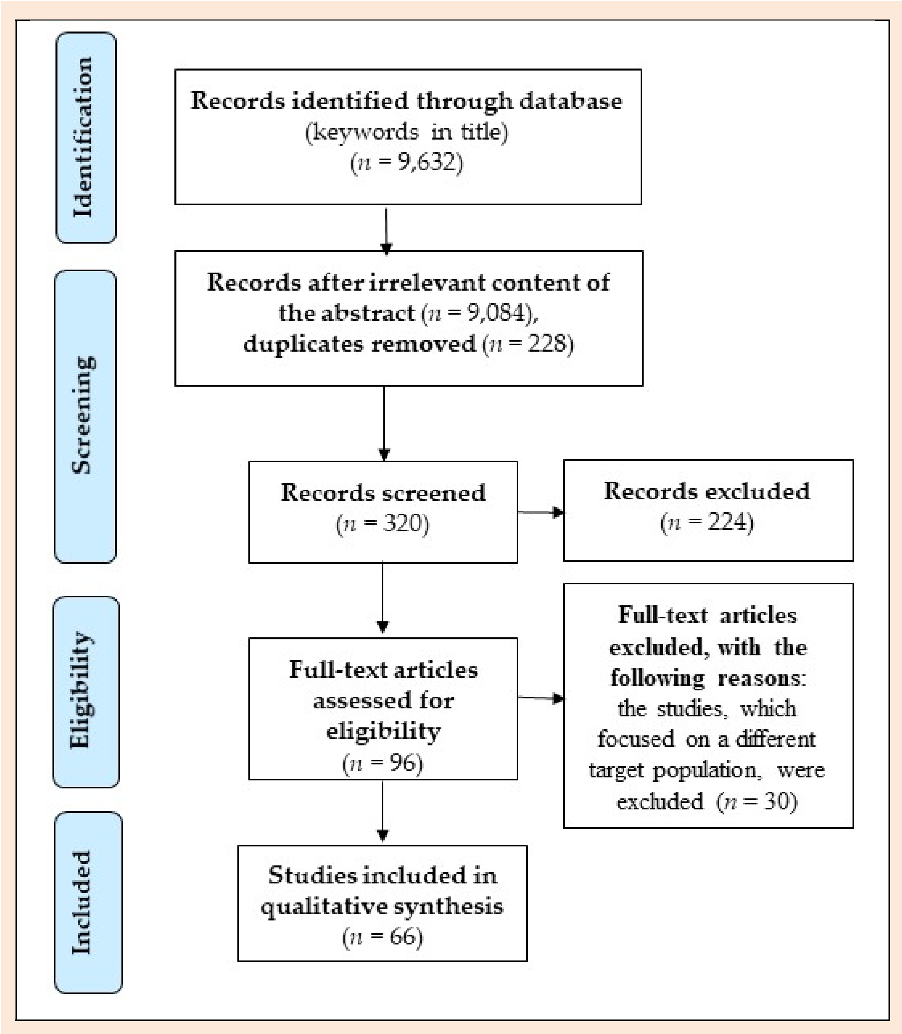

Figure 1. An overview of the selection procedure.

Results

Training session

The basic principle of the CrossFit® training session is based on the uniform application of the modalities weightlifting (W), gymnastics (G), metabolic conditioning (M) (Crawford et al., 2018b). The aim is to select such methods that will be efficient for the development of partial parts and will also have a transfer to the overall development of fitness. These three domains are used either separately or in combination. Weightlifting and gymnastics are a type of resistance exercise using external load, respectively person's bodyweight designed to develop absolute and relative strength. Metabolic conditioning means (monostructural) cardio or an/aerobic training, which aims at progression in endurance performance. Original CrossFit® template programming, is also used for research purposes (Barfield and Anderson, 2014; Poderoso et al., 2019; Cosgrove et al., 2019 et al.), all modalities alternate evenly, regularly and in predetermined combinations. All combinations are used in a closed interval of 2-3 weeks (G-W-M model: W, GW, GM, WGM, G, WG, M).

The original assembly of the CrossFit® session represents warm up, preparation, and WOD. Over time, the content of the training session began to expand, and more parts were added, which aim to develop a specific modality or technical aspects. Brisebois et al. (2018) report resistance exercise (weightlifting, powerlifting) and metabolic conditioning in each training session, in addition, to warm up and cool down. The combination of strength and cardio parts is also reported by Feito et al. (2018b). The example showed Tibana et al. (2016): in a workout of the day 1, subjects completed: (a) five sets of one repetition of snatch from the block at 80% of one-repetition maximum (1RM) with 2–5 min of rest intervals; (b) 3 sets of 5 Touch & Go Snatches (full) at 75% of 5RM with 90 s of rest between sets; (c) 3 sets of 60 s of weighted plank hold with 90 s of rest; After the third set of the exercises mentioned above, 5 min of rest was allowed, and then endurance conditioning was performed with 10 min of as many rounds as possible (AMRAP) 30 double-unders and 15 power snatches (34 kg).

The unique form of the training sessions (not following CrossFit® programming) was chosen by Murawska-Cialowicz et al. (2015). Each contained two different WODs (triplets); there was no part focused directly on strength. However, this was specific programming that is not generally used (cf. Drake et al., 2017; Poderoso et al., 2019).

Workout of the Day (WOD)

Workout of the Day (WOD) is usually the main or only part of a training session. The nature of the WOD can be very different; the content can be conditioning, strength, or mixed, and they constantly vary also in duration (Crawford et al., 2018a). Thanks to this, the physiological response to the load and the subsequent adaptation potential also differ.

Mixed WOD content means a composition of several exercises and modalities. Kliszczewicz et al. (2018) chose to test 15 min of work where participants repeated the following sequence for as many rounds as possible (AMRAP): 250m row, 20 kettlebell swings, 15 dumbbell thrusters. It is a continuous diverse load, where one endurance exercise and two strength-endurance exercises alternate. Tibana et al. (2018) used "Fran": 21-15-9 reps of thrusters (42.5kg) and pull-ups. Another example is Maté-Muñoz et al. (2018) when "Cindy" was selected, an AMRAP in 20 minutes of: 5 pull-ups, 10 push-ups, 15 squats. Butcher et al. (2015) tested "Grace": 30 Clean & Jerks (60kg) for time. From the above, it is clear that the time or content of WOD can vary dramatically, and thus the physiological response to exercise also varies.

The originality of CrossFit® lies, among other things, in the combination of fitness development through strength exercises. Heavens et al. (2014) used the “for time” scheme for WOD: 10-9-8… 2-1 repetitions for the back squat, bench press, deadlift exercises (for all 75% of 1 repetition maximum - RM). Although these are purely strength exercises, there will be significant involvement of muscle endurance in the process. The mean duration of the protocol was 34 minutes for women and 39 minutes for men. High levels of lactate (14.2 and 9.1 mmol/ L) demonstrate a significant effect of aerobic and anaerobic components and demonstrate high exercise intensity.

Participants’ physiological responses to the CrossFit® type of training are shown in Table 1. In the studies, different WODs were used, which had different compositions and lengths. Some WODs lasted on average between 4 and 6 minutes (Maté-Muñoz et al., 2018; Tibana et al., 2018), but most did not last longer than 20 minutes (Kliszczewicz et al., 2015). Benchmark workouts (bearing female names such as "Grace", "Fran", or "Cindy"), which are notorious in the CrossFit® community, were selected several times (Fernandez-Fernandez et al., 2015; Kliszczewicz et al., 2015; Tibana et al., 2018). It can be seen that during exercise, athletes achieve high heart rates that exceed 170 beats per minute on average (Tibana et al., 2018; 2019a). Another common feature is high blood lactate values, ranging from 10.4-18.4 mmol/ L (Perciavalle et al., 2016; Maté-Muñoz et al., 2018; Timón et al., 2019). These data are in synergy with the rate of perceived exertion (RPE), which did not fall below 7. In the studies of Heavens et al. (2014), Mangine et al. (2018b), and Tibana et al. (2019a), increased elevated testosterone levels were found. Similarly, the cortisol level was monitored, which also reached elevated values after training (Szivak et al., 2013; Mangine et al., 2018b). High training intensity was also reflected in pro/anti-inflammatory reactions by increasing interleukin-6/10 activity (Heavens et al., 2014; Tibana et al., 2016).

Adaptation to CrossFit®

The adaptation of the organism to CrossFit® has only appeared in research in recent years. Table 2 describes the CrossFit® intervention programs. In some cases (e.g., Cosgrove et al., 2019), the term "High-Intensity Functional Training" was used, but the content and principle fully resonate with other research. The duration of interventions ranges from 4 weeks to 6 months. The authors used official CrossFit® template programming more often, which means that a template was used that determines the concept and number of training sessions (G-W-M model). Specific content (workouts) has always been prepared directly by the authors. In other cases, a custom template was created (Murawska-Cialowicz et al., 2015; Brisebois et al., 2018).

Maximum strength was often chosen as the test criterion. Brisebois et al. (2018) and Cosgrove et al. (2019) noted a significant improvement in back squat or deadlift. Similarly, an improvement was noted in 5 RM front squats (Feito et al., 2018b). However, no significant effect on the 1 RM back squat was observed by Kephart et al. (2018), which could be due to the ketogenic diet used. The impact on upper body strength performance (1 RM bench press, 1 RM strict shoulder press, maximum repetition of pull-ups) was tested by Brisebois et al. (2018), Crawford et al. (2018a) and Cosgrove et al. (2019), in all cases with a positive result.

Effects on the development of endurance parameters were also confirmed, such as VO2max testing (Barfield and Anderson, 2014; Crawford et al., 2018a; Brisebois et al., 2018) and the positive effect was not confirmed by Drake et al. (2017) or only partially by Cosgrove et al. (2019). The studies of Kephart et al. (2018) and Durkalec-Michalski et al. (2019) have mixed conclusions, however, the training program was not specified, and it was connected with a specific diet. Only Murawska-Cialowicz et al. (2015) tested anaerobic fitness using the Wingate test and found significant improvement.

The CrossFit® program has also been shown to be effective in improving body composition - an increase in lean body mass (Brisebois et al., 2018) and a decrease in body fat (Murawska-Cialowicz et al. 2015; Feito et al. 2018b). Only Drake et al. (2017) did not show any effects on body composition.

Training experience

The main distinction in the research literature is between general athletes, regular gym visitors, and competition-oriented athletes. Mangine et al. (2020) state that in addition to the lower fat percentage and higher lean body mass, advanced Crossfitters also have a different muscle morphological characteristic compared to the gym visitors. The difference was also found in aerobic and anaerobic performance (14-18%); on the contrary, no difference was found in terms of hormone levels between groups (Mangine et al., 2020). The relationship between groups with different CrossFit® experience levels was tested using two WODs (Bellar et al., 2015). Here, CrossFit® experience (more than 12 months) proved to be the strongest predictor of performance. Other essential variables for predicting workout performance were aerobic capacity and aerobic power.

Table 1. Acute physiological effects of CrossFit®

Study	N (M/F)	Participants	WOD	Main outcome
Szivak et al. (2013)	9/9	resistance-trained	for time: 10-9-8-7…3-2-1 Back squats, bench presses, deadlifts (75% 1 RM)	lactate 14.2/9.1 mmol/L; elevated cortisol level; no significant sex differences
Heavens et al. (2014)	9/9	resistance-trained	for time: 10-9-8-7…3-2-1 Back squats, bench presses, deadlifts (75% 1 RM)	increased myoglobin - 10.0 nmol/L; elevated testosterone level; increased interleukin-6 3.5 pg/mL
Fernandez-Fernandez et al. (2015)	10/0	12+ months experience with CrossFit®	1. "Fran", for time: 21-15-9 of thrusters (42,5kg), pull-ups 2. "Cindy", 20 minutes AMRAP: 5 pulls-ups, 10 push-ups, 15 squats	1. HRavg 179 bpm; RPE 8.4; lactate 14.0 mmol/L 2. HRavg 182.2 bmp; RPE 8; lactate 14.5 mmol/L
Kliszczewicz et al. (2015)	10/0	3+ month experience with CrossFit®	"Cindy", 20 minutes AMRAP: 5 pull-ups, 10 push-ups, 15 squats	increased acute blood oxidative stress (comparable with high-intensity running)
Tibana et al. (2016)	9/0	6+ month experience with CrossFit	2 days/ 2 mixed training sessions; 1. strength, gymnastics, metabolic conditioning; 10 minutes AMRAP: 30 double-unders, 15 power snatches (34kg) 2. strength, gymnastics, metabolic conditioning; 12 minutes AMRAP: 250m row, 25 target burpees	1. lactate 11.8 mmol/L; glucose concentration 115 mg/dL 2. lactate 9.1 mmol/L; glucose concentration 89.9 mg/dL after both increased interleukin-6; increased interleukin-10 after 2.
Perciavalle et al. (2016)	15/0	advanced CrossFitters	for time: 27-21-15-9 of row (calories), thrusters (43kg)	lactate 13.8 mmol/L; worsening of attentional performance
Drum et al. (2016)	101	CrossFitters	questionnaire	average RPE 7.3; high muscle soreness; shortness of breath
Maté-Muñoz et al. (2018)	32/0	6+ month experience with strength training	1. "Cindy", 20 minutes AMRAP: 5 pull-ups, 10 push-ups, 15 squats 2. 8 rounds: 20 s work : 10 s rest of double-unders 3. 5 minutes AMRAP: power cleans (40% 1 RM)	1. HRavg 178 bpm; RPE 17; lactate 12.2 mmol/L 2. HRavg 178 bpm; RPE 16; lactate 10.4 mmol/L 3. HRavg 171 bpm; RPE 15.6; lactate 11.5 mmol/L
Mangine et al. (2018b)	5/5	CrossFitters	CrossFit OPEN 2016 (5 weeks, 5 workouts)	elevated testosterone level in workouts 2.-5., in 1. unchanged elevated cortisol level after each workout
Kliszczewicz et al. (2018)	10/0	3+ month experience with CrossFit®	1. "Grace": 30 clean and jerks (60kg) 2. 15 minutes AMRAP: 250m row, 20 kettlebell swings (16kg), 15 dumbbell thrusters (15kg)	1. HRavg 170 bpm; lactate 14.3 mmol/L 2. HRavg 172 bpm; lactate 13.7 mmol/L both workouts same effect on autonomic nervous system
Tibana et al. (2018)	23/0	CrossFitters	1. "Fight gone bad": 3 rounds: 1 minute wall balls, 1 minute sumo deadlift high-pulls (35kg), 1 minute box jumps (60cm), 1 minute push presses (35kg), 1 minute row (for calories), 1 minute rest 2. "Fran": for time: 21-15-9 of thrusters (42,5kg), pull-ups	1. HRmax 184 bpm; lactate 17.2 mmol/L; RPE 8.5 2. HRmax 182 bpm; lactate 17.8 mmol/L; RPE 9.5
Tibana et al. (2019a)	9/0	6+ month experience with CrossFit®	3 consecutive competition days, 5 workouts	elevated testosterone level (24 hours after) cortisol level unchanged elevated immunoglobulin A-IgA (24-72 hours after)
Timón et al. (2019)	12/0	CrossFitters	1. 5 minutes AMRAP: 1-2-3-4… of burpees and toes to bar 2. 3 rounds: 20 wall balls, 20 power cleans (40% 1 RM)	1. HRavg 127 bpm; lactate 13.3 mmol/L; RPE 7.2 2. HRavg 160 bpm; lactate 18.4 mmol/L; RPE 8.2 creatine kinase and hepatic transaminase at normal level after 48 hours in both workouts

WOD - Workout of the Day; HRavg- average heart rate; HRmax - maximal heart rate; RPE - rated perceived exertion; AMRAP - as many repetitions as possible; RM - repetition maximum

Tabel 2. CrossFit® intervention studies.

Study	N (M/F)	Participants	Duration	Program	Main outcome
Barfield and Anderson (2014)	25/0	active	12 weeks	CrossFit® template program (5 d/w)	↑ aerobic capacity (6%); muscle endurance (22%)
Murawska-Cialowicz et al. (2015)	15/15	active	3 months	2d/w; 2 mixed WOD every day	↑lean body mass; Wingate test; VO_2max (just women); brain-derived neurotrophic factor ↓ body fat (in women)
Drake et al. (2017)	6/0	active	4 weeks	CrossFit® template program (5 d/w)	↑ inflammatory status ↓ mood state performance no significant changes in strength, endurance, body composition
Brisebois et al. (2018)	4/10	active	8 weeks	3d/w; unique program, mixed training sessions	↑ VO2max; lean body mass; strength 1 RM (bench press, leg press)
Crawford et al. (2018a)	13/12	untrained	6 weeks	CrossFit® template program (5 d/w)	↑ 1 RM back squat, strict press, deadlift; VO_2max
Feito et al. (2018b)	9/17	3+ months experience with CrossFit®	16 weeks	2d/w; unique program; 51% strength workouts, 49% metabolic conditioning	↑ 3 mixed WOD; 5 RM front squat; lean body mass; bone mineral content improvements (greater in women) ↓ body fat
Kephart et al. (2018)	9/3	6+ months experience with CrossFit®, on ketodiet	3 months	not described	↑ push-up test ↓ body fat no changes in 1 RM back squat, 400m run, VO_2peak
Crawford et al. (2018b)	13/12	untrained	6 weeks	CrossFit® template program (5 d/w)	no relationship between RPE and heart rate variability
Tibana et al. (2019b)	0/1	elite CrossFitter	6 months	5d/w competition CrossFit program	acute chronic workload ratio (ACWR): 50% of weeks outside the "safe zone"; no relationship between RPE, heart rate variability, ACWR; no influence on well-being status
Poderoso et al. (2019)	17/12	6+ months experience with CrossFit®	6 months	CrossFit® template program (5 d/w)	elevated testosterone level (greater changes in men); lower cortisol level (greater changes in women); no changes in lymphocytes
Cosgrove et al. (2019)	22/23	0-6 and 7+ months experience with CrossFit®	6 months	CrossFit® template program (5 d/w)	↑ 1 RM back squat, bench press, deadlift, pull-up test; 1,5 km run (women with less experience)
Durkalce-Michalski et al. (2019)	11/10	CrossFitters on ketodiet	4 weeks	not described	↑ utilization of fat under aerobic load (just men)

↓↑ - significant changes; WOD - Workout of the Day; M - male; F - female; w- week; d- day; RPE - rated perceived exertion

Schlegel et al. (2020) discussed the identification of the relationship between performance parameters, including strength and endurance elements, with the placement in the CrossFit® Open. The correlation showed the strongest association in placement with the maximum performance in Olympic weightlifting (snatch, clean & jerk). On the other hand, the weakest relationship was shown with bodyweight exercises (pull-up, handstand push-up). A similar comparison was made by Martínez-Gómez et al. (2019), where squat performance proved to be a determining factor for success in CrossFit® Open workouts. It should be noted that Olympic weightlifting was not tested in this study, but only strength performances. A certain specificity of the CrossFit® Open must be emphasized: 5 days to complete a workout, adapted to the conditions of a regular gym in terms of space and equipment, workouts must be able to distinguish thousands of athletes with a similar performance level, etc. It is not identical to CrossFit® Games, sanctioned or CrossFit-style competitions.

Studies by Butcher et al. (2015) and Dexheimer et al. (2019) tested the relationship between benchmark WODs ("Fran", "Nancy", "Cindy", "CrossFit Total") and selected performance parameters. In both cases, participants were advanced CrossFitters. The measurements show that it is impossible to determine precisely the mean aspect of fitness that would be most important concerning all WODs. Depending on the nature of the WOD, VO2max (for "Nancy", "Cindy"), anaerobic power, and strength performance (for "CrossFit Total") proved to be essential for better workout results. The importance of high performance in anaerobic power (Wingate test) and VO2max relative to results of the 12-minute WOD is demonstrated by Bellar et al. (2015). Similarly, Feito et al. (2019) note the positive relationship between results of repeated Wingate tests and performance in the original (has never been used before) WOD (15 minutes).

Best competitive CrossFitters (n = 1,500) were compared according to their performance, the sample was divided into groups, and a clear difference was shown between the quantiles generated (Serafini et al., 2018). With increasing overall performance, strength performances (back squat, deadlift, strict press) and Olympic weightlifting (snatch, clean & jerk) increased significantly. Almost no development was shown in aerobic (5km run) or (mainly) anaerobic performance (400 m run).

On a large sample (more than 130,000 athletes), Mangine et al. (2018a) tried to create standards for self-reported performance in benchmark workouts ("Grace", "Fran", "Helen", "Fight gone bad", Filthy 50 "). From the created deciles, a specific athlete can be assigned to a performance group. For example, for "Grace" (30 clean and jerks for time), a range of 64-296 seconds was set for men.

Discussion

Acute physiological reactions and the long-term effects of CrossFit® are essential for determining the training plan and selecting the optimal training methods (Bellar et al., 2015; Tibana et al., 2018; Serafini et al., 2018). It is a new topic which, due to the growing popularity of performance-oriented CrossFit®, deserves its attention. Thanks to similar elements with concurrent training, it is possible to compare these concepts and possibly use some conclusions for CrossFit® training.

The CrossFit® training session has one central part (WOD) in its original form (see G-W-M model). In this case, there is no need to select the intra-session exercise sequence. Usually, however, a multi-part model is used (Brisebois et al., 2018). Traditionally, the strength part is preferred to the endurance-oriented part, which would correspond to the recommendations of concurrent training (Doma et al., 2017). However, the assembly of a CrossFit® session is not absolute and can take various forms. The preference of the strength part does not have to be absolute. Positive effects are also demonstrated from the opposite combination: development of endurance at the beginning, and then strength-oriented part (Berryman et al., 2019). It is crucial to determine the main goal of the training session and its desired effect (development of absolute strength, power, muscle hypertrophy, an/aerobic endurance, etc.). It is possible (under certain conditions) to choose any exercise combination according to a specific goal.

Methods of resistance and endurance training are applied in one training session. This combination can lead to degraded performance (Bishop et al., 2019). If resistance training (followed by endurance) is preferred in the training session, it should be beneficial for lower limb strength, and at the same time, it should not negatively affect aerobic capacity (Murlasits et al., 2018). Otherwise, if endurance training is followed by resistance training, deterioration may occur (Karavirta et al., 2011; Jones et al., 2017). It must be taken into account that after strength training, muscle glycogen is lost by up to 39% (Jensen et al., 2011). This effect can limit the following endurance performance in the order of hours (Doma et al., 2017). Another factor, along with muscle glycogen depletion, is nervous system fatigue, which occurs after both types of exercise (Doma and Deakin, 2013). It can subsequently affect strength and coordination skills (movement economics) or modify the internal training load and intensity (Maté-Muñoz et al., 2017). Regardless of the nature of the training load, it is necessary to prioritize the modality that is more important in a given training session (Methenits, 2018). Therefore, it is necessary to carefully choose the combination of individual components, the set intensity (RPE, %RM, or % heart rate) for the first part of the session will be decisive. In the case of advanced CrossFitters, where it is necessary to maximally support all performance parameters' progress, it will be appropriate to separate these components on the basis of multiphase training (Bishop et al., 2019; Schlegel et al., 2020).

The concept of concurrent training often works with the application of continuous endurance activities. In the study of Berrymann et al. (2019), for example, cycling is shown to better results than running in the context of interference. Similarly, a positive outcome of a combination of rowing and resistance training has been demonstrated (Gallagher et al., 2010). High-intensity interval training (HIIT) has also been shown to be very efficient in short-term interventions (Petré et al., 2018; Sabag et al., 2018). One of the probable causes is the use of glycolytic muscle fibers, which are important for developing strength or hypertrophy. (Doma et al., 2017). Along with positive effects on VO2max, maximal aerobic power has been demonstrated in HIIT. But in some regards, it is challenging to replace long continuous training with HIIT (Laursen and Buchheit, 2019). In CrossFit® programming, it is possible to use a wide range of endurance activities (running, rowing, swimming, etc.), including methods (continuous, interval, fartlek); there are no restrictions. In the case of a combination of monostructural cardio and a strength part in one session, it will, therefore, be more appropriate to apply HIIT.

CrossFit® includes strength and endurance development of the upper and lower part of the body. Skattebo et al. (2016) prove that the application of strength training to the upper half of the body for cross-country skiers is beneficial and can improve their double-poling performance. On the other hand, Doncaster and Twist (2012) demonstrated a reduction in maximal endurance performance (arm cranking) after bench press. Therefore, it seems that the muscles of the upper half of the body will react similarly to the training load as the lower limbs in concurrent training. Endurance activities, such as cross-country skiing or swimming, which are dominant for the upper half of the body, are not generally used to such an extent in CrossFit® (Feito et al., 2018a). It is more common to combine an upper body strength load along with endurance running or rowing. There is a theory that if in one training session there are strength loads of specific muscles and at the same time endurance loads of others (for example bench press and running), the effects should not interfere. Unfortunately, no valid study is available for such confirmation.

The concept of concurrent training works with a combination of strength exercises and classic endurance activities (running, cycling, rowing). CrossFit® develops endurance both with these tools and with the help of bodyweight or free weight exercises. This model proves to be efficient for the current development of strength and endurance components (Crawford et al., 2018a). When combining the strength part and WOD containing, for example, weightlifting exercises (see "Grace"), there is strength endurance activity, which is also demanding in terms of (aerobic, anaerobic) endurance. By involving not only slow fibers, interference may not occur, but there is excellent synergistic potential (Berryman et al., 2019). However, it is crucial to consider the metabolic effect on a given muscle, which may not respond to the necessary strength-oriented adaptation in case of significant exhaustion. Very little information is available in this regard; classical concurrent training does not deal with this combination (Methenitis, 2018).

In endurance sports, the term energy cost of locomotion is used to evaluate movement technique (di Prampero, 1986). The aim is to make the activity as economical as possible in terms of energy consumption. This factor can be influenced by concurrent training (training sessions) (Berryman et al., 2019). By working with resistance exercises under metabolic stress in CrossFit®, the economics of movement are essential as well. Especially for dynamic exercises like the snatch and clean & jerk, which are characterized by high speed, and therefore high energy consumption is important at the workout to find the optimal technical skill that will be effective and also energy efficient. In training, it would be appropriate to include similar strength or dynamic exercises before the WOD, which do not exhaust the muscle and help with the optimal technique. The principle of post-activation potentiation (short-term improvement in performance as a result of using conditioning exercise) also manifests itself here (Docherty and Hodgson, 2007).

Strength or strength-hypertrophic training causes acute changes in hormone levels, such as testosterone, growth hormone, or cortisol. These changes affect proteosynthesis and associated regeneration, muscle growth, and strength gains (Tremblay et al., 2004). After endurance exercise, similar hormonal changes are observed, but rather the overall catabolic effect concerning to muscle growth predominates (Kindermann et al., 1982). After a mixed load caused by resistance and endurance training, fluctuations of these hormone levels are also monitored (Taipale et al., 2014). The acute physiological effects after CrossFit® (Table 1) show the potential to change hormone levels. Mixed WODs, including resistance exercises, appear to increase testosterone levels (Heavens et al., 2014; Mangine et al., 2018b; Tibana et al., 2019a). It is a different effect compared to concurrent training, wherein one session, the strength part was applied and then the endurance block (Taipale and Häkkinen, 2013), and a decrease was noted even after 48 hours. The original nature of CrossFit® sessions can lead to an increase in testosterone levels, which is a difference compared to the effect of concurrent training (cf. Schumann et al., 2013). Measurements after completing a WOD also showed an increase in cortisol levels (Szivak et al., 2013; Mangine et al., 2018b), identical to the responses after concurrent training. However, in the study of Tibana et al. (2019a), the level didn't change. Despite the inconsistent findings, an increase in cortisol levels can be expected due to the high intensity of exercise. The hormonal response after concurrent training (also due to different methodologies) is not uniform. The relationship between acute hormonal response and long-term adaptation has not been confirmed (Taipale et al., 2010; Cadore et al., 2012). Although a similar result can be expected with CrossFit®, the exact conclusion cannot yet be made.

After the application of concurrent training, a decrease in muscle glycogen, an increase in lactate levels, heart rate, and central nervous system fatigue are observed (Methenitis, 2018). Measured blood lactate values, heart rate, or RPE in CrossFit® also indicate a high load associated with high stress in the body. Such an exercise disrupts the homeostasis of the autonomic nervous system (Kliszczewicz et al., 2018). This stress is also manifested by changes in the immune system (Tibana et al., 2016). Such an effect can affect the organism's condition and performance for several days (Bishop et al., 2019). It is important to emphasize that in the mentioned studies (Table 1), the participants were motivated to maximum effort. Although high intensity is a feature of CrossFit® (Drum et al., 2016), a distinction should be made between training and competition performance because of different effort, motivation, etc. Then we can expect a difference in physiological biomarkers.

The ratio of individual components is essential for optimal simultaneous development of strength and endurance parameters. To induce positive changes, it is necessary to complete at least 2-3 training sessions per week containing exercises to develop the ability (Bishop et al., 2019). In the case of excessive predominance, one of them, interference may occur (Wilson et al., 2012). CrossFit® interventions (Table 2) show that they can to develop both strength performance and endurance parameters (Crawford et al., 2018a; Feito et al., 2018b). Due to the varied nature of the WOD content, it is difficult to determine the strength/ endurance ratio in such a program. Although WODs usually do not focus directly on the development of strength or endurance, both factors are included (Barfield and Anderson, 2014). Although the conclusions are not unambiguous (Kephart et al., 2018), the intervention was not precisely described in this study, i.e. it was impossible to analyze the cause of such results. It is necessary to take into account that the specific content of training sessions may significantly differ, which is related to the effects. Although the positive effects of concurrent training on the development of strength or endurance have been demonstrated (Methenitis, 2018), there are too many methodological differences in study designs to compare the results in more detail.

To reduce the risk of interference, it is recommended to separate the training session's single modalities because the interaction can occur even after 24-72 hours (Wilson et al., 2012). This guideline to separate modalities is based on studies using hypertrophic training and continuous endurance activity, or maximum effort performance until exhaustion (Doma et al., 2017). The original CrossFit® programming uses five sessions per week (5 training days – 2 days rest or 3 training days – 1-day rest), and most have mixed content (Poderoso et al., 2019). Because of the application of HIIT methods and WOD involving strength exercises, separating modalities rule does not seem to apply (Tibana et al., 2019a). However, it is crucial to consider the recovery time after high-intensity training, which can adversely affect adaptation mechanisms.

To assess the acute response or long-term adaptation of the organism, it is important to consider the group's training experience. Training experience usually means the total time that an individual engages in a particular activity. Researchers made a distinction between a "trained" individual with at least 3-9 months of experience with a given physical activity (Fyfe and Loenneke, 2017). Otherwise, the improvement can be attributed to a new stimulus, to which the organism responds more willingly. Beginners with no previous experience with CrossFit® were included in multiple studies (Barfield and Anderson, 2014; Murawska-Cialowicz et al., 2015; Drake et al., 2017; Brisebois et al., 2018; Crawford et al., 2018a). And it has been confirmed that a CrossFit® program is effective in physically active individuals for the development of maximum strength or V02max (Barfield and Anderson, 2014; Murawska-Cialowicz et al., 2015; Brisebois et al., 2018).

In advanced athletes, it is essential to specifically develop the abilities, which has also been confirmed (Cosgrove et al., 2019). It is necessary to take into account the total training time, the number of training sessions, or also the performance level of the athlete (Buckner et al., 2017). Determining important performance parameters or morphological variables by testing is key to identifying optimal training methods (Dexheimer et al., 2019; Butcher et al., 2015). Only one intervention study (Tibana et al., 2019b) deals with an elite Crossfitter; in other cases, the research sample was untrained or moderately advanced athletes. Elite CrossFit® athletes have been shown to have excellent performance especially in Olympic weightlifting and fundamental strength exercises (Martínez-Gómez et al., 2019; Schlegel et al., 2020), furthermore, by above-average VO2max results (> 50ml/ kg) or strong anaerobic capacity (Feito et al., 2019). Unfortunately, there are no concurrent training studies that address the development of Olympic weightlifting performance and endurance parameters.

The elite athletes and competitors need to have an excellent level of a wide range of strength and endurance abilities. Due to the tasks that are usually in the competition, the "CrossFit® performance" includes maximum strength (especially Olympic weightlifting, free weight), strength endurance (bodyweight, external load), aerobic capacity (using different domains), maximum aerobic power (different domains), anaerobic capacity (different domains) or a combination of each other (Serafini et al., 2018; Martínez-Gómez et al., 2019; Tibana et al., 2019b). Performance-oriented CrossFitters, therefore, need a specific composition of the training program, which has not yet been the subject of research.

Practical applications

- In the "mixed training session", it is appropriate to give priority to strength training.
- In the "mixed training session", the first part should not be too exhausting (RPE, %RM, HR) concerning muscle glycogen, the central nervous system, so as not to affect the upcoming exercise.
- When choosing exercises and methods for one training session, consider the local load, and combine the the upper and lower half of the body (gymnastics – running; squat – ski erg).
- When applying pure endurance exercise combined with the strength part, it is advisable to choose HIIT methods, or rowing, cycling.
- Single modality training sessions should be separated as much as possible (> 48 hours), especially for continuous endurance and hypertrophy-oriented exercises.
- For advanced athletes, it is appropriate to divide pure strength and endurance exercises into separate training sessions.
- Before WOD, it is possible to choose a higher load for previous exercises to improve the economic cost of locomotion (clean and jerk – "Grace"; front squat – wall balls).
- When organizing training, consider the intensity of exercise, which can significantly impact the endocrine or immune system for up to several days.
- The original CrossFit® template program is functional for the development of strength and endurance parameters for beginners.
- "Barbell conditioning" could be beneficial for the development of strength and endurance.
- Strength : endurance ratio is applicable in CrossFit®

Conclusion

CrossFit® is a young sports discipline that falls by nature partly into the category of concurrent training. The findings show that CrossFit® training can influence the function of the endocrine, immune, central nervous systems and also has a potential in the development of strength and endurance parameters. For training, it is necessary to identify optimal procedures for the ideal development of strength, endurance, power, speed, accuracy, and other specific (CrossFit®) performances. In certain aspects, it is possible to involve the training methodology of concurrent training. However, it is confirmed that in many ways, CrossFit® is a sport that requires unique training methods, for which the amount of information is limited. Further research is needed to verify some of the conclusions.

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Key points

- CrossFit® training is efficient in the development of strength and endurance in short-term and long-term programs.
- Some concurrent training strategies are suitable for CrossFit® (application of HIIT and strength exercise; a combination of strength exercise with rowing, cycling or cross-country skiing; a ratio of strength and endurance exercise in the training program).
- CrossFit® is sports discipline with unique training principles (using barbell conditioning; preparation for any combination of strength and endurance in one workout; a combination of Olympic weightlifting with other exercises; energy cost of locomotion in bodyweight and free weight exercises).

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