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REVIEW

Aerobic and Anaerobic Effect of CrossFit Training: A Narrative Review

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Abstract

CrossFit is recognized as one of the fastest growing modes of high-intensity functional training. This strength and conditioning program is used to optimize physical competence in ten fitness domains: (1) cardiovascular/respiratory endurance, (2) stamina, (3) strength, (4) flexibility, (5) power, (6) speed, (7) coordination, (8) agility, (9) balance, and (10) accuracy. The aim of this review is to provide an overview related to Crossfit and its implication in aerobic and anaerobic parameters. Specifically, in this work, we will discuss the impact that this type of physical activity can have on a physiological level. Furthermore, the tools will be provided to understand how, by modulating the intensity, one can have benefits at an aerobic and anaerobic level. We will also review studies using CF as a resistance training methodology and finally discuss the findings of the various studies and provide recommendations for future studies.

Keywords: *CrossFit, Functional fitness, aerobic training, anaerobic training, workouts programs*

Introduction

Functional fitness is a type of exercise designed to emulate activities from everyday life. Functional fitness likely grew out of an older concept called general physical preparedness (GPP) that has similarly experienced a recent renaissance (Gamble, 2006). The evidence of the growth and expansion of GPP and functional fitness training can be seen in the emergences of CrossFit (CF) across the world. The CF is one of the new modality of HIFT that have emerged in the last few years. A typical CF training is organized into daily sessions called "workouts of the day" (WOD), including metabolic exercises (running, rowing), gymnastic movements (pull-up, push-ups, air squats, burpees), and weightlifting (snatch, clean, and jerk) and performed at an intensity close to 95% of the maximum heart rate (HRmax) (Maté-Muñoz et al., 2018). WODs are organized as circuits with little or no rest periods, performed "as many repetitions as possible" (AMRAP) during a given time domain (Katz et al., 2016) or as quickly as possible over periods of 10 to 20 min ("CrossFit-based High Intensity Power Training Improves Maximal Aerobic Fitness and Body Composition: Retraction" 2017).

Variety is one of the main appeals for CF program participants as workouts are short, intense, and constantly varied. The intense nature of this form of training is congruent with CF training. The CF is a type training regimen based upon a multidimensional view of fitness (D'alpino et al., 2022). The CF model suggests that fitness is best measured via performance in a variety of tasks in relation to other competitors (Glassman, 2002). This multifaceted description of fitness has been offered before, by two authors (Kilgore & Rippetoe, 2007) and by the American College of Sports Medicine (American College of Sports Medicine, 2014). The CF adds a layer of competition to the attainment of multidimensional fitness, which may explain the recent rise in popularity and number of affiliates nationwide. The CF is a form of high-intensity functional training that combines resistance exercises, gymnastics, and traditional

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aerobic modalities (e.g., cycling, rowing, running) into single workouts that vary by day to elicit general physical preparedness (Glassman, 2016). This training form is enjoyed recreationally by participants of varying levels of fitness, training experience, age, and lifestyles (Thompson, 2017) and also exists as its own sport. The primary CF competition is the Reebok CrossFit Games™ (the Games) which awards individual winners the title of "Fittest on Earth". Historically, this competition has consisted of several stages designed to narrow the initial participant pool down to the top athletes. Although the competition's structure has changed over time, the presence of an initial online qualifying round (e.g., the CrossFit OpenTM) has remained. This round typically involves multiple workout challenges that are completed over the course of several weeks. Competitors who complete all workouts and rank high enough will progress to the next stage of the competition. Regardless of which stage, it is expected that each workout will consist of a set of challenges that will require some combination of strength, power, endurance, and/or sport-specific skill (Glassman, 2016). However, little is known about which physiological characteristics of competitors who progress beyond the opening round of the competition.

The CF Games have matured from an informal athletic meeting to a worldwide sponsored competition with prize money (CrossFit Games, 2016). In concert with this worldwide competition, local CF affiliates routinely host fitness contests. With the rise in popularity of CF and CF competition, an opportunity exists to evaluate the capacities of these athletes from a laboratory perspective. Physical capability, including the aerobic and anaerobic capacity of athletes, is an important element leading to success in athletic endeavors (Moscatelli et al., 2020). Traditional methods of assessing physical capacity are power and aerobic capacity. The ability to optimize muscular power output is considered fundamental to the successful performance of many athletic and sporting activities (Cronin & Sleivert, 2005). Aerobic capacity has also been accepted as a major component of athletic success (Ranković et al., 2010). Although the CF training model incorporates both aerobic and anaerobic capabilities, to date very little research has been conducted to understand the impact of CF training, or the abilities required to be successful (attaining greater ranking in competitions local, regional or national) in CF competitions. Results released from a 2010 study funded by the U.S. Army suggest that CF training can improve the functional capacity of soldiers (Paine & Uptgraft, 2010). This study and one other represents the only existing research that examined actual CF model training schemes and the effects on fitness (Smith et al., 2013). Reviews of research that use similar functional fitness schemes such as sandbag training (Sell et al., 2011; Moscatelli et al., 2021) and functional fitness training for Judo athletes (Henry, 2011) suggest that these functional schemes have been associated with increases in fitness capability. However, to date there is no existing research on the components of fitness associated with the sport aspect of CF, thus the aim of this review was to provided an overview on the CF and its effects on the aerobic and anaerobic parameters.

Physiological aspect of CrossFit

It is important to understand how anaerobic and aerobic metabolism relate to this innovative activity in order to better comprehend CrossFit performance. Authors (Dodd, 2007) ran an experiment to determine the kind of training that would help a sportsperson's lower body power. Results showed that when compared to conventional heavy resistance and high-velocity approaches, complex training, which combines plyometrics and heavy resistance training simultaneously, produced larger increases in lower body speed and power. The idea that anaerobic performance would probably be related to CrossFit performance is backed by the fact that the event frequently consists of both weight training and runs up to 800 meters. A recent investigation (Farrar, 2010) who showed that kettlebell swings posed an aerobic challenge that could impact VO2 max supports the existence of a reasonable link between aerobic fitness. The enormous volume of repetitive weightlifting motion used in CrossFit training, which is comparable to the continuous kettlebell swings in the Farrar, Mayhew, and Koch (2010) study, makes this work extremely pertinent.

Body mass (Butcher et al., 2015), strength and anaerobic power (Moscatelli, 2015; Martínez-Gómez et al., 2019), aerobic capacity (Bellar et al., 2015), sport-specific skill (Barbieri et al., 2020), and experience (Serafini et al., 2018) have all been associated with either CF workout performance or competitive ranking. Collectively, these data imply that athletes must train to be proficient in each to perform well in competition. However, several limitations exist among these studies that prevent making such a conclusion. For instance, Serafini et al. (2018) reported that higher ranking competitors of the 2016 Open were stronger, more powerful, and more proficient at short-duration, sprint-type CF workouts. Among regional competitors, final ranking was positively related to 400-m sprint time and time-to-completion in longer, benchmark workouts (i.e., Filthy-50) (r=0.69–0.77), and negatively related to maximal weight lifted in the Olympic lifts (r=-0.39 to -0.42) (Barbieri et al., 2020). Although these studies involved participants who have successful competitive records, the measures used to distinguish rank were all self-reported. As such, the authenticity and actual data of measurement (self-reported data were obtained from an online resource) cannot be verified. In contrast, others have measured a variety of physical parameters and related them to CF-style workouts performed in a controlled, laboratory setting (Martínez-Gómez et al., 2019). While these studies have also included successful CF athletes, laboratory workouts do not adequately emulate the competitive setting and may influence the physiological response to CF training (Mangine et al., 2019). Thus, questions remain about the distinguishing characteristics of successful CF athletes.

In more traditional sports (e.g., football, baseball, basketball, etc.), identifying the key physiological and athletic characteristics that distinguish performance is common (Mangine et al., 2014). The practice enables strength and conditioning professionals to develop sport-specific training programs that are more effective in translating adaptations to in-game performance. However, CF is unique in that typical training session workouts mirror those that appear in competition. Moreover and consistent with its primary purpose (Feito et al., 2018), chronic participation in CF training has been documented to improve a variety of fitness parameters (Feito et al., 2019). Though it might be assumed that CF training represents an ideal training strategy for developing the physiological characteristics present in successful competitors, such a conclusion would be premature based on the available data.

CrossFit and resistance training

Amongst a variety of training regimens for increasing performance, resistance training (RT) is essential, as it enhances muscular strength and power (Suchomel et al., 2016). Typically, RT aims at increasing skeletal muscle strength by working against a weight or force. Recently, high-intensity functional training (HIFT) has received growing popularity and is alleged to improve overall physical conditions. The HIFT relies on basic elements of "every day" movements derived from both aerobic and resistance efforts, performed at high intensities. The efficiency of exercise training depends not only to the training load, but also on the athlete's capability to sustain it. One way to gauge exercise-induced internal environmental stress fluctuations is through the evaluation of the hormonal responses, and through the monitoring of biomarkers of inflammation and oxidative stress. Improving overall performance or accounting for residual training effects might rely on reproducible indicators of reactions to training (Rankovic et al., 2011). Along this line, any effort made to quantify the fine balance between training practice and athlete's tolerance may help to optimize training programs (Powers & Jackson, 2008). In fact, the CF is a style of exercise that takes a multifaceted approach to fitness. According to the CF concept, the best way to gauge fitness is by competitors' performance in a variety of tasks (Glassman, 2002). The American College of Sports Medicine (2000) and Kilgore and Kilgore (2007) have both previously provided this comprehensive definition of fitness. The recent increase in popularity and the number of affiliates countrywide may be attributed to the fact that CF adds a level of competitiveness to the pursuit of holistic health.

The undoubted beneficial effects of exercise have been underlined in a number of studies. Nevertheless, exercise is a stress situation that challenges homeostasis (Powers & Jackson, 2008), and the body must find a new dynamic equilibrium, that requires, among others, adaptive responses of the hormonal, metabolic, and immune systems. As concerns the outcomes of HIFT programs, CF has been demonstrated to improve body composition and physical fitness (Ahmad et al., 2018), also eliciting metabolic (Ramires et al., 2016), inflammatory (Heavens et al., 2014), and hormonal responses (Mangine et al., 2018). Furthermore, CF training has been shown to induce an immunosuppressive effect (Jin et al., 2015) and acute oxidative stress responses, affecting the immune system (Kliszczewicz et al., 2015). Particularly, it has been shown that a HIFT with short rest protocol carried out in men and women with no experience in resistance training elicits significant increases in inflammation and induced hyperreactions in metabolic and adrenal (cortisol) functions. Another study showed that two consecutive HIFT sessions increase pro/anti-inflammatory cytokines with no interference on muscle performance in the recovery period (Ramires et al., 2016). On the whole, a recent review (Ramires et al., 2018) analyzed the prevalence and incidence of physiological responses and chronic adaptations to HIFT programs, which resulted in increased acute oxidative, metabolic, cardiovascular, and hormonal stress, depending on the protocol adopted, as for intensity, duration, and training status of the subjects. Interestingly, the authors reported that an insufficient rest between HIFT sessions resulted in unfavorable cytokine responses, with a decrease in anti-inflammatory and increase in proinflammatory cytokines. We can assume that advanced-level technique during maximal timed exercise repetitions, without suitable rest intervals between sets and shifts, as well as an inadequate recovery time between high-volume loads and training sessions (such as CF) may produce premature fatigue and additional oxidative stress level in athletes (Claudino et al., 2018). The immune and endocrine systems are closely intertwined in modulating an appropriate response to physiological and psychological stress factors (Elenkov, 2008; Moscatelli et al., 2022). Moreover, biochemical monitoring is useful in sports contexts to assess and manage workload and fatigue of athletes at all levels (McCall et al., 2015). With regard to exercise, cortisol plays an important regulatory role in metabolic responses to stressor events through the activation of energy proteolysis and lipolysis (Kraemer & Ratamess, 2005; Ruberto et al., 2021). Lastly, the regulation of protein turnover during recovery from physical exercise, involving also contractile myofibrils adaptation to training, is closely linked to appropriate glucocorticoid actions (Viru & Viru, 2004). Studies have shown significant elevations in acute cortisol secretion as no change (Ahtiainen et al., 2003) or reductions (Harizi et al., 2014). Elevations of cortisol levels have been reported during normal strength and power training (Häkkinen & Pakarinen, 1991), while in CF training a greater acute cortisol response (Mangine et al., 2018) and a lower chronic response were obtained compared to strength and power training (Poderoso et al., 2019).

According to Kraemer and Ratamess (Kraemer, 2005), regimens including high volume, high intensity, and little rest tend to result in larger hormonal increases. Mangine et al. (2018) recently documented an increase in testosterone in CrossFit® training participants, which may be the result of temporary increases in muscle force production. Depending on the mix of the many training variables (exercise type and modality, volume, and load) throughout time, it's possible that CrossFit periodization ®'s has an impact. These increases may be caused by training overload and the recruitment of motor units during the various exercises used in Olympic weightlifting and powerlifting. The relationship between cortisol and testosterone levels was inverse. According to França et al. (2006), testosterone and cortisol levels vary depending on the volume and length of exercise. A persistent adaptation to exercise can be a drop in cortisol levels, particularly in men. Recreationally active people, according to Mangine et al. (2018), undergo adaptive organic processes to safeguard the muscles and other tissues susceptible to glucocorticoids and prevent negative effects.

Exercise performance is significantly impacted by persistent cortisol increases in the skeletal muscles. Assessing adrenal function activation is relevant as exacerbated cortisol concentrations may lead to reiterative stress over subsequent training sessions, contributing to a non-functional overreaching or even to overtraining. Yet, it is well established that training can alter host defense, leading to changes in disease susceptibility and severity (Collao et al., 2020). Both aerobic and RT have been explored to understand their inflammatory mediators and the parameters of the reaction to exercise (Monteiro et al., 2017). For instance, as to exercise-induced changes in interleukin-1 (IL-1) circulating levels, long-distance runners showed chronically elevated plasma IL-1 without an acute increase 3 h after an eccentric exercise bout, whereas their untrained controls had lower baseline IL-1 levels along with acute spurs 3 h post-exercise (Evans et al., 1986). In line with this, a two-fold increase in plasma IL-1 beta β (IL-1β) concentrations were found 30 min after 45-min cycling exercise at 70% of VO2max in non-athlete subjects (Vassilakopoulos et al., 2003). In another work, plasma IL-1 levels were undetectable after exercise (Northoff & Berg, 1991).

Exercise regulates a number of bodily processes, and more recently, it has come to light that skeletal muscle is a metabolically active organ, which has heightened the need to research how training regimens affect the generation of myokines (Pedersen, 2012). Myokines are chemicals generated by the contraction of skeletal muscles that serve a variety of purposes inside the body and can act locally or in other tissues (Pedersen. 2008). Typically, endurance training mediates anti-inflammatory actions that lead to fat loss and improvement of aerobic capacity. However, research recently demonstrated that high-intensity intermittent exercise cause anti-inflammatory responses similarly to moderate-intensity continuous exercise (Zwetsloot 2014; Cabral-Santos 2015; Lira 2015).

Finally, the antioxidant defense is activated by exercise, preferably via low molecular weight non-enzymatic antioxidants, i.e., uric acid (Sacheck & Blumberg, 2001). It is known that plasma urate levels increase with exercise, possibly as a physiological coping mechanism to increased oxidative stress. Recently it has been shown that anaerobic trainings (Wiecek et al., 2018), as well as a CF program (Kliszczewicz et al., 2015), induce oxidative stress immediately after the exercise, and also during the early period of recovery. However, the mechanisms controlling training load are not fully known, and stress responses are key determinants to that purpose. Given the complexity of these HIFT programs and the increasingly high number of its participants, studies are required to investigate the effects of these trainings and whether a tailored training optimization could be obtained.

Discussion

A study comparing CF training with a training approach based on ACSM recommendations reported CrossFit training as more strenuous and considered a "very hard" activity by participants (Drum et al., 2017). CrossFit participants also reported greater fatigue, greater muscle pain and swelling, and limb movement difficulties during or within 48 h after the workout (Drum et al., 2017). In an acute study, the WOD "CF triplet" (i.e., three burpees, four push-ups, and five squats) was associated with significant changes in physiological responses (Shaw et al., 2015). Participants achieved approximately 12,000 mmHg for rate pressure product, 6 mmol/L for blood lactate, and 54% of HRmax (Shaw et al., 2015). According to the authors, "CF triplet" was of moderate to high intensity and thus considered a viable interval training option that provides sufficient intensity in a safe manner (Shaw et al., 2015). In the correlation studies, whole-body strength, power, endurance, and experience seemed to be important measures associated with performance in CrossFit (Butcher et al., 2015). Others authors found VO2max and anaerobic power to be significant predictors of performance after one CrossFit training session (Bellar et al., 2015). The authors also divided 32 young healthy men into two groups and found CrossFit experience, or CrossFit training history, was also a predictor of performance during a WOD (Monda et al., 2017a; 2017b). Nonetheless, more research is required as the present literature is inconclusive regarding predictors of CrossFit performance.

Based on the systematic review, in general, WODs present highly varied psycho-physiological demands: heart rate between 54 and 98% of HRmax, blood lactate levels between 6 and 15 mmol/L, %VO2max between 57 and 66%, RPE between 8 and 9 (out of 10), and rate pressure product around 12,000 mmHg. Some WODs (e.g., "Fran," "Cindy," and "15.5") can be identified as high-intensity level whereas others (e.g., "CrossFit triplet") can be considered moderate. Until now, current CrossFit scientific literature has been based on studies that investigated the effects of CrossFit on body composition, psycho-physiological parameters, musculoskeletal injury risk, life and health aspects, and psycho-social behavior. Meta-analysis did not find a significant effect of CrossFit training changes in body mass index, relative body fat, fat mass, lean body mass, and waist circumference. Unfortunately, the number of studies investigating CrossFit with high level of evidence at low risk of bias is sparse. As a result, these findings neither firmly establish the benefits or risks of CrossFit, nor provide definitive practical recommendations concerning CrossFit training. Despite this disparity, there is the existence of initial evidence of higher levels of sense of community, satisfaction, and motivation among CrossFit participants.

Our study, despite dealing with a recent and highly topical topic, has some limitations. Initially, few studies have been conducted on this modality of physical exercise practice, and therefore, it would be necessary to increase the number of subjects undergoing CF to more accurately evaluate the impact of this new discipline. Furthermore, the training loads should be accurately evaluated and how they are modular in the different age groups. Therefore we believe that many studies can be carried out in the future which will be able to provide useful indications for the development of this recent discipline in order to obtain excellent results in terms of efficacy and also reduce the risk of injuries.

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Conflict of Interest
The author declares that there is no conflict of interest.

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