Original Article

Metabolic profile of a crossfit training bout

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ABSTRACT

CrossFit is a physically and metabolically-demanding training mode increasing in popularity among recreational athletes. Presently, however, scarce evidence is available documenting its energetic profile. This study investigated the metabolic characteristics of a CrossFit training bout as measured by expired gases and blood lactate. Eleven females and 7 males completed a 12-minute CrossFit bout on two occasions separated by three days. During both experimental sessions (Pt1, Pt2), subjects performed as many rounds as possible (AMRAP) within the timed workout which consisted of consisted of 12 box jumps (30" for males, 20" for females), 6 thrusters (24 kg for males, 16 kg for females), and 6 bar-facing burpees in sequence. Oxygen consumption (VO2), respiratory exchange ratio (RER), blood lactate (BL), and repetitions completed were measured during both experimental sessions. The average VO2 and RER of both bouts (Pt1 and Pt2) was 37.0 ± 4.8 ml/kg/min and 1.04 ± 0.1, respectively. Average BL significantly increased above pre-exercise concentrations (3.0 ± 1.3 mmol/L) at 4 min (10.1 ± 3.2 mmol/L; $p < 0.01$), 8 min (12.3 ± 3.5 mmol/L; $p < 0.01$), and immediately post at 12 min (12.6 ± 3.9 mmol/L; $p < 0.01$). Repetitions completed in Pt2 (140.2 ± 25.9) were significantly different to repetitions completed in Pt1 (131.2 ± 27.2) ($p = 0.023$). Average repetitions completed in Pt1 and Pt 2 was 135.7 ± 26.6. These data suggest that CrossFit is a metabolically-demanding conditioning method that relies heavily on both aerobic and anaerobic energy production and may represent an alternative to traditional methods of exercise to improve fitness and longevity. **Key words:** ANAEROBIC EXERCISE; HIGH-INTENSITY; LACTATE; METABOLISM.

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INTRODUCTION

CrossFit is a physically and metabolically demanding conditioning method that has become increasingly popular as a mode of exercise as well as a competitive sport. The ultimate training goal of CrossFit training is to maximize and sustain power output in each bout (Smith, Sommer, Starkoff, & Devor, 2013). This conditioning program is characterized by the use of gymnastics, strength training (including Olympic lifts), anaerobic training, and high power cardiorespiratory activities performed in varying combinations, loads, and volumes. Within a given workout, trainees may encounter several distinct and sometimes unconventional training stresses. For example, a CrossFit bout may involve light to moderate-loaded weight lifting performed at high-volumes or near 1RM loads performed at low-volumes followed by multiple sets of rope climbs. Some workouts may call for high-volumes of heavy loaded lifts accompanied by intense cardiorespiratory conditioning such as 1 mile run and/or row. These bouts vary in duration as well, ranging from 5 minutes or less to 30-45 min, and in rare cases, longer.

Similar to other strength/power performances, the aim of CrossFit bouts is to produce high power outputs, derived via anaerobic metabolism. However, whereas other high intensity performances are intermittent in nature with established periods of activity and rest, CrossFit is unique in that bouts are sustained. Most workouts lack prescribed rest periods, thereby making performance dependent on the individuals' ability to maintain a high power output. Individual training bouts are scored based on the athlete's ability to complete a set amount of work as fast as possible or to complete as much work as possible within a given time period (Smith et al., 2013). Thus, it is likely the energetic demands supporting CrossFit performance are derived from both aerobic and anaerobic means. The high-intensity nature of this training mode was illustrated by Babiash et al. (Babiash, Porcari, Steffen, Doberstein, & Foster, 2013) who collected descriptive data of the metabolic demands of two CrossFit workouts. During each of the two workouts corresponding VO_2 were 44.8 (± 7.75) and 44.2 (± 8.85) ml/kg/min, respectively (males) and 36.6 (± 9.14) and 32.4 (± 5.31) ml/kg/min (females). The achieved VO_2 scores reported by Babiash et al. represented oxygen uptakes above the subjects' anaerobic threshold. In addition, substantial blood lactate (BL) changes were also noted; + 11.6 (± 2.96) and + 11.0 (± 4.41) mmol/L in males and + 10.2 (± 3.20) and + 8.46 (± 1.88) mmol/L in females indicating high glycogenolytic flux (Greenhaff et al., 1994). It is worth noting that expired gases were not collected during the experimental sessions, and VO_2 was calculated using a regression equation for each subject based on heart rate data. Another study by Shaw et al. (Shaw, Dullabh, Forbes, Brandkamp, & Shaw, 2015) noted significant increases in heart rate and blood lactate levels as well. At present, no data exits documenting VO_2 collected during CrossFit performance.

CrossFit is practiced by a variety of populations including novice trainees seeking improved health and fitness as well as highly-trained athletes. Therefore, data describing the metabolic characteristics of this mode of training are necessary to develop an understanding of the specific stresses and thus anticipate the subsequent adaptations imposed by such training stresses. To date there is scarce literature pertaining to CrossFit and as far as the authors are concerned, presently, there is no published evidence addressing the metabolic profile or nutrient blend supporting CrossFit conditioning as measured by expired gases during a training bout. Such inquiry will enhance the ability of practitioners to not only make programming and periodizing training adjustments, but also tailor nutrient intake for these trainees. Thus, the purpose of this study is to investigate the metabolic profile of CrossFit training as measured by expired gases and BL during a 12 minute workout. Results will provide information regarding the metabolic and physiological demands and responses elicited by this novel training method. Additionally, establishing the metabolic profile of CrossFit training may aid in making nutritional recommendations for such performance. It was hypothesized that this CrossFit bout would result in a high, mean oxygen consumption (VO_2), as well as respiratory exchange ratio (RER) and blood lactate (BL) scores that would reflect significant and sustained glycolytic energy production.

MATERIAL AND METHODS

Participants

Eighteen recreationally-trained individuals (eleven females, mean age: 22.9 ± 2.8 yrs; mean body mass 61.1 ± 5.5 kg; mean height: 164.5 ± 5.4 cm; 7 males, mean age: 26.1 ± 10.2 yrs; mean body mass 77.2 ± 8.8 kg; mean height: 178.7 ± 8.1 cm) with a strength and conditioning experience of ≥ 3 days per week for a minimum of one year participated in the study (Table 1). Given the broad spectrum of training adaptations that is present with the CrossFit community (due to the variety in programming and periodization), it is difficult to establish a common athletic "profile" with all CrossFit trainees. Thus, we believe our criteria for subject selection introduced a valid representative sample of those who practice CrossFit. In addition, potential subjects must have been familiar with the movements of the exercise protocol and were capable of meeting the demands of the associated stresses. To ensure the latter, a video illustrating the expected exercise mechanics was shown and a questionnaire was administered to further validate the criteria for inclusion. Subjects completed a three day dietary record using the MyFitnessPal mobile application within a seven day period. Mean CHO intake of subjects was 3.55 g/kg/day (± 1.22). This was done to control variance in CHO intake among subjects given the well-established effect of CHO on intense exercise (Lambert & Flynn, 2002; Maughan et al., 1997). Eligible participants were also required to complete a Physical Activity Readiness Questionnaire (PAR-Q) to ensure a reasonable good health standing and physical preparedness. The participants were informed of the risks and benefits involved, and signed a written informed consent prior to participation. The protocol for this investigation conformed to the California State University, Fresno (CSUF) policy on the use of human subjects.

Table 1. Mean and standard deviation for age, body mass, and height of subjects. (n = 18).

	Female (n = 11)	Male (n = 7)
Age (yrs)	22.9 ± 2.8	26.1 ±10.2
Body Mass (kg)	61.1 ± 5.5	77.2 ± 8.8
Height (cm)	164.5 ± 5.4	178.7 ± 8.1

yrs= years, kg = kilograms, cm = centimeters

Procedures

Subjects completed the first of two performance tests (Pt1) in the Human Performance Laboratory (HPL) at CSUF, Department of Kinesiology. Pt1 was followed by three days of complete rest. The next day subjects again reported to the HPL and executed the second performance test (Pt2; Figure 1). Pt2 was intended to evaluate the consistency of the dependent variables measured during Pt1.

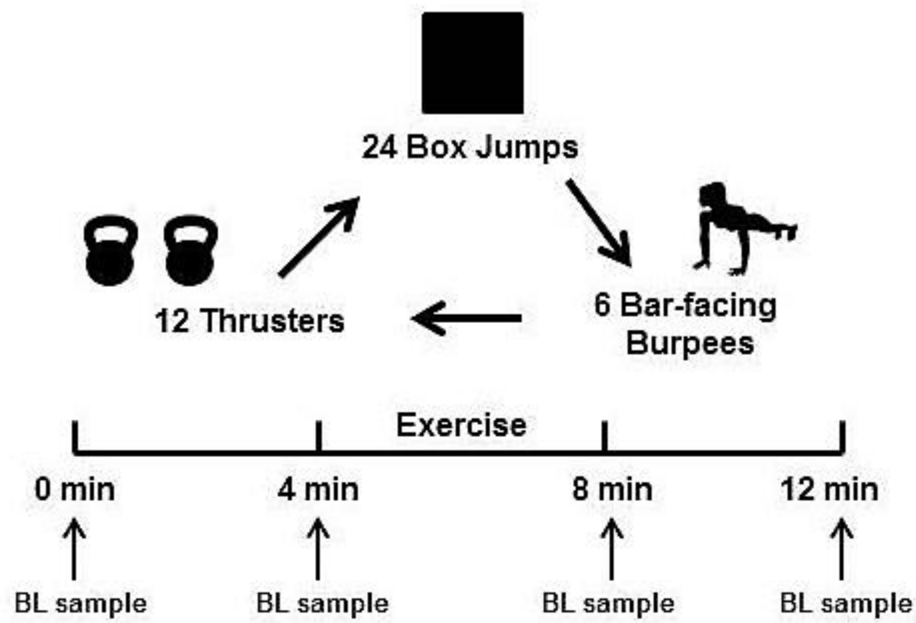

Figure 1. Depiction of exercise protocol and blood lactate (BL) sampling time points.

Performance Test

During both performance tests , VO_2 and RER were measured (15 second average) using the ParvoMedics' True One 2400 Metabolic Measurement System (Sandy, Utah, USA) connected via a hose to a 2-way Hans-Rudolph Valve (Shawnee, Kansas, USA. In addition, BL was assessed with a Scout lactate analyzer (Leipzig, Germany) according to procedures described by the manufacturer. In both experimental sessions (Pt1, Pt2), subjects were required to perform as many rounds as possible (AMRAP) of a popular 12-minute CrossFit workout (Rahoi). Consistent with the CrossFit training method all loads were fixed for each sex and consisted of twelve 30" (20" for females) box jumps, six 24 kg (16 kg for females) thrusters, and 6 bar-facing burpees in sequence. Also consistent with CrossFit training, there were no rest periods during both 12-minute bouts. Thus, our subjects were allowed to take self-selected rest periods of varying frequency and duration. This workout was selected to minimize a skill bias as the included movements are not highly technical or skill-dependent. In addition, such movements were expected to be familiar to most subjects. In order to collect expired gases during these non-traditional and more dynamic exercise bouts, two 9' gas collection hoses were connected with a cardboard mouthpiece (used for spirometry) and athletic tape. The hose extending from the Hans Rudolph valve was taped to the right side of the headgear and run down the back of the subject. The hose was held in place using a large resistance band, which was wrapped around the torso. This setup required that the thrusters be performed with kettlebells as the Hans Rudolph valve would interfere with the path of the barbell.

Statistical Analyses

The dependent variables in the study corresponded to those measured during the experimental exercise sessions (Pt1, Pt2). The dependent variables were: mean VO_2 (ml/kg/min), mean RER, BL (mmol/L) (pre, 4 min, 8 min, immediately post [12 min]), and repetitions completed. For all dependent measures, descriptive statistics (means and standard deviations) were calculated. A paired samples t-test was done to probe for differences between Pt1 and Pt2. A Pearson's correlation coefficient was done for dependent variables for

Pt1 and Pt2. A univariate analysis of variance (ANOVA) was done for BL at pre-exercise, 4 min, 8 min, and 12 min. For all statistical tests, a significance of $p < 0.05$ was set *priori*. All analyses were done with the Statistical Package for the Social Sciences (V.21; SPSS Inc., Chicago IL).

RESULTS

No statistically significant differences were found between Pt 1 and Pt 2 at any of the measured time-points for the dependent variables: mean VO_2, mean RER, and BL at pre, 4 min, 8 min, and immediately post at 12 min ($p < 0.05$). As seen in Table 2 the average VO_2 from both bouts (Pt1 and Pt2) was 37.0 ± 4.8 ml/kg/min. Pearson correlation coefficient of Pt 1 and Pt 2 for mean VO_2 was r = .679. Average RER for Pt 1 and Pt 2 was 1.04 ± 0.1 (Pearson correlation coefficient: r = .788). BL significantly increased above pre-exercise concentrations (3.0 ± 1.3 mmol/L) at 4 min (10.1 ± 3.2 mmol/L; $p < 0.01$), 8 min (12.3 ± 3.5 mmol/L; $p < 0.01$), and immediately post at 12 min (12.6 ± 3.9 mmol/L; $p < 0.01$) in Pt1 and Pt2. Pearson correlation coefficients were r = .643, .313, .489, .310, respectively. As indicated in Table 1, the repetitions completed in Pt2 (140.2 ± 25.9) were significantly different to repetitions completed in Pt1 (131.2 ± 27.2) ($p = 0.023$). Average repetitions completed in Pt1 and Pt 2 was 135.7 ± 26.6. Pearson correlation coefficient of the exercise bouts for repetitions completed was r = .837.

Table 2. Mean oxygen consumption (VO_2; ml/kg/min), mean respiratory exchange ratio (RER), blood lactate (BL; mmol/L) at pre-exercise, 4 min, 8 min, and immediately post (12 min), and repetitions completed. (n = 18). *significantly different from pre-exercise ($p < 0.05$).

	VO_2 (ml/kg/min)	RER	BL Pre (mmol/L)	BL 4 min (mmol/L) *	BL 8 min (mmol/L) *	BL 12 min (mmol/L)*	Repetitions completed
Mean of Pt1 + Pt2	37.0 ± 4.8	1.04 ± .06	3.0 ± 1.3	10.1 ± 3.2	12.3 ± 3.5	12.6 ± 3.9	135.7 ± 26.6

DISCUSSION

The purpose of this study was to investigate the metabolic characteristics of a CrossFit training bout. Both 12-minute workouts resulted in a mean VO_2, mean RER, and BL scores indicative of high metabolic cost and anaerobic energy contribution. High and sustained VO_2 was noted (average of 37.0 ml/kg/m ± 26.6 between Pt 1 and Pt 2). The corresponding RER average was 1.04 ± 0.1. RER scores above 1.0 may imply the inclusion of nonmetabolic CO_2 in expired gas formed from the buffering of free H^+ ions within the bloodstream as a result of from rapid ATP hydrolysis (Goedecke et al., 2000), however, given the non-steady state nature of this exercise, the use of expired gasses to make inferences on substrate use (i.e. CHO metabolism) should be withheld. Nonetheless, these measures demonstrate that CrossFit training is that of intense nature. This is confirmed by the substantial increases in BL concentration observed throughout the bout at 4 min, 8 min, and 12 min (Figure 2): 10.1, 12.3, and 12.6 mmol/L, respectively. Peak concentrations sampled from the exercise sessions were 22.1 mmol/L, 21.4 mmol/L, and 19.4 mmol/L. The observed BL response elicited from the present training bout is similar to that noted in repeated Wingate performance (Wahl et al., 2013). Repetitions completed were significantly difference between Pt 1 and Pt2: 131.2 vs. 140.2, respectively. This is likely due to a learning effect between performances resulting in more strategic pacing and timely selection of rest intervals to combat fatigue.

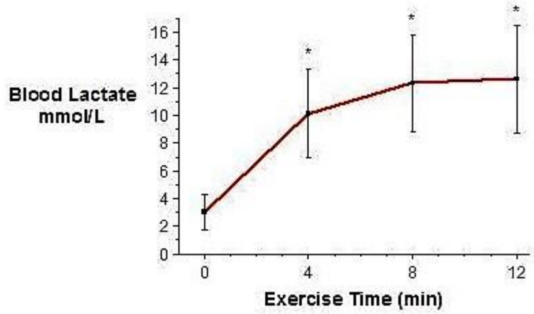

Figure 2. Blood lactate (BL; mmol/L) at pre-exercise, 4 min, 8 min, and immediately post (12 min). *significantly different from pre-exercise ($p < 0.05$).

Given the intense nature of CrossFit training as demonstrated by the present study, CrossFit may serve as an effective mode for metabolic conditioning. The metabolic responses, including VO_2 and BL, observed in the present study are similar to those elicited from other high-intensity interval-based training (Fortner, Salgado, Holmstrup, & Holmstrup, 2014) which has been shown to enhance measures of aerobic and anaerobic capacity (Ogita, Hara, & Tabata, 1996; Tabata et al., 1996). Of the few studies available, Smith et al.(Smith et al., 2013) reported that 10 weeks of CrossFit-based power training improved VO_2max in a mixed sample of trained and untrained males (43.10 ± 1.40 to 48.96 ± 1.42 ml/kg/min) and females (35.98 ± 1.60 to 40.22 ± 1.62 ml/kg/min). Improvements in body fat percentage were also noted; males incurred an average decrease of 4.2% while females experienced a 3.4% decrease. This finding is similar to investigations of other forms of high-intensity interval-type training and resistance exercise-based circuit training that have resulted in improved measures of fitness (Laursen & Jenkins, 2002). Franch et al. (Franch, Madsen, Djurhuus, & Pedersen, 1998) showed that 6 weeks of intense interval training using 4 to 6 sets of 4 minute intervals resulted in a 6% improvement in VO_2max and a greater increase in time to exhaustion at 85% VO_2max compared to 6 weeks of continuous running (+93% vs. +67%, respectively). Similarly, Tabata et al. (Tabata et al., 1996) reported a 7 ml/kg/min increase in VO_2max in addition to a 28% increase in anaerobic capacity following 6 weeks of 7 to 8 sets of 20 second cycling at ~170% VO_2max with a 10 second rest period between bouts while 6 weeks of sustained moderate-intensity exercise resulted in a 5 ml/kg/min increase in VO_2max, but no increase in anaerobic capacity. Additionally, 24 weeks of low-volume and high-volume resistance exercise-based circuit training is capable of improving measures of muscular strength, power, and endurance, including 1RM bench press and leg press, vertical jump power, and bench press and leg press repetitions to failure at 80% 1RM(Marx et al., 2001). Given that CrossFit incorporates elements of metabolic conditioning including both aerobic and anaerobic, as well as resistance-based training in combination, it is likely that chronic training would lead to similar improvements in aerobic power, anaerobic capacity, and muscular fitness as seen by Tabata et al (Tabata et al., 1996) and Franch et al.(Franch et al., 1998). In addition, CrossFit may lead to improved markers of metabolic health, given that shorter and intense exercise bouts similar in nature to CrossFit training have been shown to elicit positive effects on symptoms associated with cardiometabolic diseases such as coronary heart disease (Gibala, Little, Macdonald, & Hawley, 2012; Warburton et al., 2005), obesity (Gibala et al., 2012; Whyte, Gill, & Cathcart, 2010) and insulin resistance (Gibala et al., 2012; Hood, Little, Tarnopolsky, Myslik, & Gibala, 2011; Little et al., 2011).

CONCLUSION

CrossFit is a metabolically-demanding conditioning method that relies heavily on both aerobic and anaerobic energy production. Regular training may lead to enhancements of aerobic and anaerobic capacity as well as improved metabolic health. Thus, the CrossFit training methodology appears to represent a novel alternative to traditional methods of exercise and conditioning that likely results in positive outcomes of fitness and longevity. Future inquiry is warranted to further characterize the metabolic profile of CrossFit training and elucidate the long-term adaptations and benefits to this mode of training.

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