The relationship of aerobic capacity, anaerobic peak power and experience to performance in CrossFit exercise

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ABSTRACT: CrossFit is becoming increasingly popular as a method to increase fitness and as a competitive sport in both the Unites States and Europe. However, little research on this mode of exercise has been performed to date. The purpose of the present investigation involving experienced CrossFit athletes and naïve healthy young men was to investigate the relationship of aerobic capacity and anaerobic power to performance in two representative CrossFit workouts: the first workout was 12 minutes in duration, and the second was based on the total time to complete the prescribed exercise. The participants were 32 healthy adult males, who were either naïve to CrossFit exercise or had competed in CrossFit competitions. Linear regression was undertaken to predict performance on the first workout (time) with age, group (naïve or CrossFit athlete), VO_2max and anaerobic power, which were all significant predictors ($p < 0.05$) in the model. The second workout (repetitions), when examined similarly using regression, only resulted in CrossFit experience as a significant predictor ($p < 0.05$). The results of the study suggest that a history of participation in CrossFit competition is a key component of performance in CrossFit workouts which are representative of those performed in CrossFit, and that, in at least one these workouts, aerobic capacity and anaerobic power are associated with success.

INTRODUCTION

CrossFit and high intensity training have become increasingly popular within the fitness community of the United States and Europe. Though some slightly elevated risks for injury have been noted in CrossFit training [1,2], a recent study reported data related to the motivational climate within CrossFit training centers suggesting positive impact for the types of goal established during training [3]. The expansion of CrossFit provides an opportunity for studies that can demonstrate a greater depth of understanding of this type of training from both a psychological and physiological perspective.

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 [4]. The evidence of the growth and expansion of GPP and functional fitness training can be seen in the emergences of CrossFit.com and CrossFit affiliates across the world. Variety is one of the main appeals for CrossFit program participants as workouts are short, intense, and constantly varied. The intense nature of this form of training is congruent with CrossFit training. The arrival of CrossFit as a legitimate sport was heralded in 2011 by a sponsorship from Reebok [5] and coverage by ESPN 2 of the culminating competition, The CrossFit Games.

CrossFit is a type training regimen based upon a multidimensional view of fitness. The CrossFit model suggests that fitness is best measured via performance in a variety of tasks in relation to other competitors [6]. This multifaceted description of fitness has been offered before, both by Kilgore and Rippitoe [7] and by the American College of Sports Medicine [8]. CrossFit 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 CrossFit Games have matured from an informal athletic meeting to a worldwide sponsored competition with prize money [9]. In concert with this worldwide competition, local CrossFit affiliates routinely host fitness contests. With the rise in popularity of CrossFit and CrossFit 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 [10]. 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 [11]. Aerobic capacity has also been accepted as a major component of athletic success [10].

Although the CrossFit training model incorporates both aerobic and anaerobic capabilities, to date very little research has been conducted to understand the impact of CrossFit training, or the abilities required to be successful (attaining greater ranking in competitions local, regional or national) in CrossFit competitions. Results released from a 2010 study funded by the U.S. Army suggest that CrossFit training can improve the functional capacity of soldiers [12]. This study and one other represents the only existing research that examined actual CrossFit model training schemes and the effects on fitness [12,20]. Reviews of research that use similar functional fitness schemes such as sandbag training [13] and functional fitness training for Judo athletes [14] 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 CrossFit.

In order to better understand CrossFit performance, it is necessary to determine the relationship of anaerobic and aerobic metabolism to this novel sport. Dodd and Alvar [15] performed an experiment to see what type of exercise would help improve an athlete's lower body power. Results demonstrated that complex training, which is the simultaneous combination of heavy resistance training and plyometrics, showed greater increases in lower body speed and power when compared to traditional heavy resistance and high-velocity methods. The hypothesis that anaerobic performance would likely be related to CrossFit performance is supported by the fact that runs of up to 800m are often included in the event as well as weight training. A plausible connection with aerobic fitness exists as evidenced by the recent work by Farrar, Mayhew and Koch [16] who demonstrated that kettlebell swings presented an aerobic challenge that could influence VO_2 max. This work is very relevant as CrossFit training includes high volumes of repetitive weightlifting motion, similar to the continuous kettlebell swings in the Farrar, Mayhew and Koch [16] study.

As little descriptive information is thus far known about CrossFit exercise, the present investigation was undertaken to provide some descriptive information about the relationships between anaerobic power, aerobic fitness, experience level, and performance in CrossFit workouts. The primary research question was to evaluate the relationship between anaerobic power, maximum aerobic capacity and CrossFit exercise, with a secondary question seeking to evaluate which relationship demonstrated the greatest strength. The research hypothesis was that higher levels of aerobic and anaerobic fitness would be associated with greater performance on CrossFit style workouts and that experience may influence this relationship.

MATERIALS AND METHODS

Experimental Approach. The institutional review board at the local University approved the present study and all participants gave written informed consent prior to participating. CrossFit workouts generally involve a mixture of different movements ranging from a medicine ball throw to a snatch. It is difficult to encapsulate CrossFit by using only one representative workout due to the variety from one workout to the next. Therefore in the present investigation two different CrossFit workouts to test performance were sought from a CrossFit certified trainer (Level 1, greater than 2 years experience with training) that represented the scope and breadth of this exercise genre.

It was also determined that people experienced with CrossFit and people who were CrossFit naïve would both be examined. The groups completed the two CrossFit performance testing sessions after a short dynamic warm up and underwent testing to determine maximum aerobic capacity (VO_2max) and anaerobic power (Wingate) within the course of a three-week period. All participants had a minimum of 72 hours between sessions.

Participants

The participants in the present investigation all gave written informed consent prior to any data collection. The group of experienced CrossFit athletes consisted of 21 males (Age: 26.7±4.3 yrs, Height: 177.8±7.3 cm, Weight: 83.8±11.8 kg). The experienced CrossFit athlete cohort included one athlete who had competed at the CrossFit Games, four athletes who had made it to the CrossFit regionals, and 17 more athletes who competed in multiple local competitions held by CrossFit affiliates and had trained for at least 12 months. The CrossFit naïve group consisted of 11 males (Age: 22.3±1.9 yrs, Height: 179.3±5.6 cm, Weight: 83.5±12.2 kg). Complete descriptive information can be seen in Table 1.

CrossFit Performance Testing

First CrossFit session

The first session (AMRAP workout) was a 12 minute long workout that consisted of rounds of 12 throws of a 9.07 kg medicine ball at

TABLE I. Participant Characteristics

Variable	HIT Experienced (n=21)	HIT Naïve (n=11)	Difference
Age (yrs)	26.7±4.3	22.3±1.9	p=0.004
Height (cm)	177.8±7.3	179.3±5.6	p=0.565
Weight (kg)	83.8±11.7	83.5±12.2	p=0.938
VO_2max (ml·kg^{-1}·min^{-1})	52.5±4.6	52.0±4.3	p=0.788
Peak Power (WaNT) (Watts)	864.8±154.8	806.5±129.4	p=0.295

Note: Participant characteristics are given as Means±SD. Differences (alpha levels) are the result of one-way Anova by group (HIT experiences vs naïve).

a 3.05 meter target, 12 swings of a 16.38 kg kettlebell, and 12 burpee pullups. The participants completed the exercises in sequence (medicine ball throw then kettlebell swing then burpee pullups) for the prescribed number of repetitions, then started over again in an attempt to complete as many repetitions of exercise as possible within the allotted 12 minutes of time. The performance in this session was based upon the total number of repetitions that the participant was able to complete within the allotted 12 minutes.

Second CrossFit session

The second session (21-15-9 workout) consisted of the following exercises: a sumo deadlift high pull, a 0.5 meter box jump, and a 40-meter farmer's walk gripping two 20 kg bumper plates. The participants completed 21 repetitions of the sumo deadlift high pull and box jump in round one, 15 repetitions in round two, and 9 repetitions in round three. Each round was ended with the completion of one 40-meter farmers walk. The participants were scored based upon the total time needed to complete all the exercises.

Anaerobic testing (Wingate)

A Monark Peak Bike (Ergomedic 894E Peak Bike, Monark Sports and Medical, Sweden) with computerized data acquisition was utilized for all Wingate (WAnT) testing. Prior to the initiation of testing, the seat and handlebars were adjusted to the frame of the participant. The subject was allowed to pedal against zero resistance to become accustomed to the bike and to warm-up for 2 minutes prior to the start of the testing. The resistance on the ergometer was adjusted to allow for seven percent of the subject's kilogram weight to be added to the flywheel at the start of the 30-second assessment. The subject was instructed prior to the start of the test not to ,pace' the effort. Following the acceleration of the flywheel to maximum cadence (RPM), the weight basket loaded with the appropriate resistance was released and the subject worked maximally against the load for 30 seconds. The computer program reported the participant's peak, mean and minimum power in watts at the conclusion of the test.

Maximum aerobic capacity

Participants in the study all were tested the same graded exercise test format on the same equipment. The subjects ran on a Trak Master TMX 425 treadmill (Full Vision Inc., Newton, KS.) during the assessment. Participants' expired air was sampled and analyzed with a ParvoMedic TrueOne 2400 metabolic measurement system (ParvoMedics, Sandy, UT.) The system utilizes a mixing chamber and was set to sample every 20 seconds. The system was calibrated prior to each test according to the manufacturer's specifications. Listed accuracy for the gas sensors in the unit are: paramagnetic O_2 analyzer $\pm0.1\%$, infrared CO_2 analyzer $\pm0.1\%$. pneumotach $\pm 2\%$. After each assessment drift within the sensors was checked for, but determined to be negligible.

For the assessment a custom ramp protocol was used that had been developed previously and pilot tested on a similar group of athletes [17,18,19]. This protocol included a 30-second initial familiarization stage at 5.6 kilometers per hour, and then a two-minute first stage at 5.6 kilometers per hour and a 2.0% grade. After the initial stage the speed and grade were increased every 2 minutes by 1.6 kilometres per hour and 1.5% respectively until the conclusion of the test. The test was concluded when the oxygen consumption was determined to have reached a plateau (<100 ml·min^{-1}) and the respiratory exchange ratio (RER) had reached 1.15. Heart rate during the test was determined through a Polar Wear Link heart rate sensor (Polar Electro Inc., Lake Success, NY.) that was linked to a receptor on the metabolic measurement system.

Statistical Analysis

Difference in performance by group were examined with one way ANOVA. In order to investigate the relationship of maximum aerobic capacity and anaerobic peak power to CrossFit exercise performance for the AMRAP and 21-15-9 workouts were used as the outcome variable in a two multiple linear regression model (one for each CrossFit session). Age was included as a control variable. A separate bivariate correlation was used to examine the relationship of aerobic fitness to exercise performance by group. Statistical significance was set *a priori* at alpha<0.05, and a modern computerized statistical software package was used to perform all analyses (SPSS ver 20.0).

RESULTS

Performance Results. The CrossFit experienced group performed significantly (F= 35.72, p≤0.001) more repetitions on the AMRAP workout (209.7±6.1 vs. 147.6±8.4) compared to the naïve group. Similarly when time was examined on the 21-15-9 workout the experienced group took significantly (F=30.93, p≤0.001) less time to complete the workout (221.4±8.1 s vs. 300.8±11.7 s).
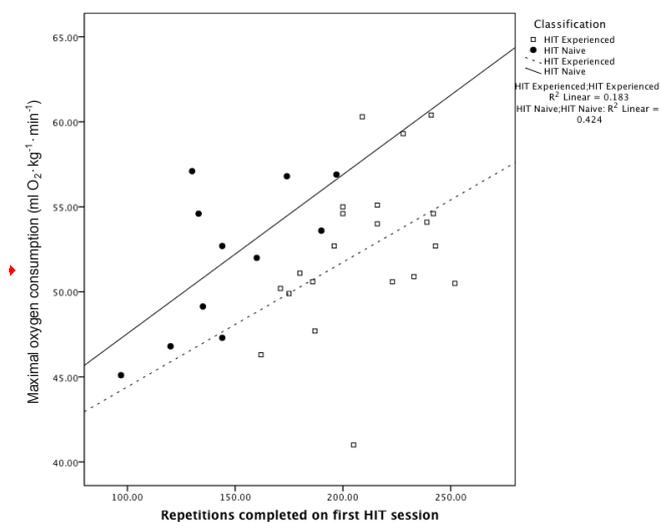

FIG. I. Scatterplot of maximum aerobic capacity (ml $O_2 \cdot$ kg$^{-1} \cdot$ min^{-1}) versus repetitions on WOD 1 by CrossFit Experience
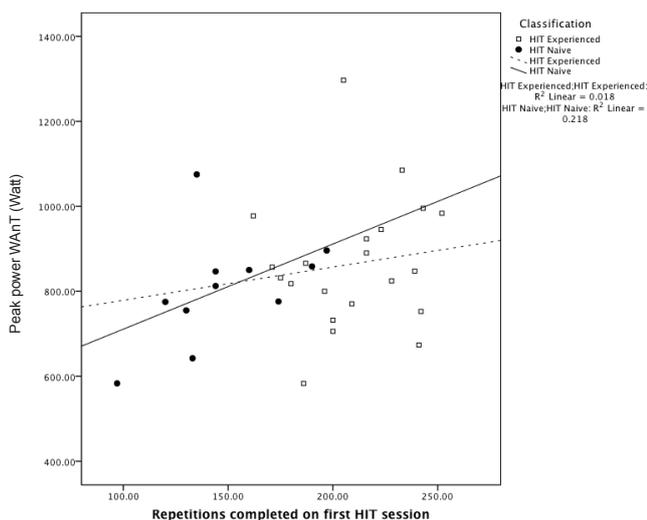
FIG. 2. Scatterplot of peak power (Watts) versus repetitions on WOD 1 by CrossFit Experience.

Multiple linear regression

Results of similar multiple linear regression for the repetitions completed on the first AMRAP workout resulted in a significant model (R^2=0.804, p≤0.001). All predictors in the model were significant with group (naïve group or athlete group) having the greatest influence on the model (Beta= 0.737, p≤0.001) followed by maximum aerobic capacity (Beta=0.503, p≤0.001), WaNT peak power (Beta=0.417, p≤0.001) and Age (Beta=0.208, p=0.049). Greater aerobic capacity, greater peak power and younger age were associated with higher numbers of repetitions. A scatterplot of the aerobic capacity and peak power versus performance on session 1 can be seen respectively in Figures 1 and Figure 2.
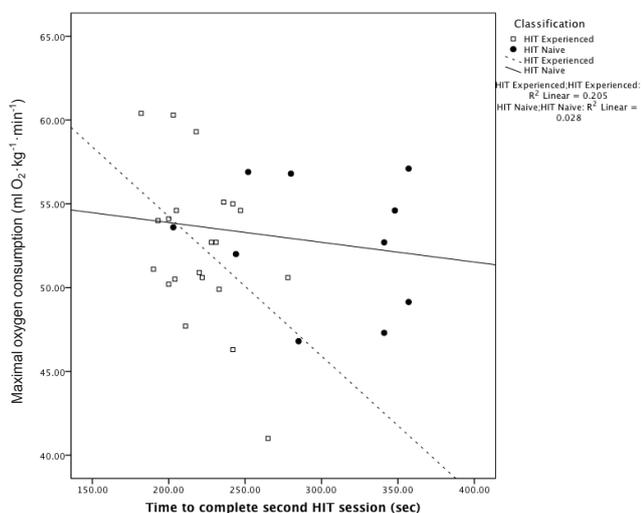
The final multiple linear regression analysis was undertaken to predict the time to complete the 21-15-9 workout (R^2=0.593, p≤0.001). In this model only group (athlete vs naïve) explained a significant portion of the outcome (Beta=0.809, p≤0.001), with aerobic capacity (Beta=0.295, p=0.063), WaNT peak power (Beta=0.178, p0.271) and Age (Beta=0.202, p=0.198) failing to attain significance. A scatterplot of the aerobic capacity and peak power versus performance in session 2 can be seen respectively in Figures 3 and Figure 4.

Bivariate Correlations

In the AMRAP workout the experience group's maximum aerobic capacity and number of repetition was revealed to be significantly related (r= 0.427, p=0.05). Similarly, in the naïve group the relationship was significant (r= 0.654, p=0.03). For the 21-15-9 workout VO$_2$max significantly correlated to time the experienced group (r=0.453, p=0.04) but not in the naïve group (r=0.168, p=0.64).

DISCUSSION

The research hypothesis was that higher levels of aerobic and anaerobic fitness would be associated with greater performance on CrossFit style workouts and that experience may influence this relationship. Based upon the analysis of the data from the present investigation it appears that being a CrossFit Athlete, anaerobic power, and aerobic capacities are all related to at least one form of CrossFit exercise performance. The CrossFit performance testing session in the present study were designed by a CrossFit certified trainer, and were designed to be representative of the forms of workouts prescribed for both training and also competition. Although, it should be noted that CrossFit training and competition have a greater degree of variability than can be captured in two CrossFit performance testing sessions, it was the intention of the study to design two sessions that would result in similar physiological stresses based upon the guidance of a
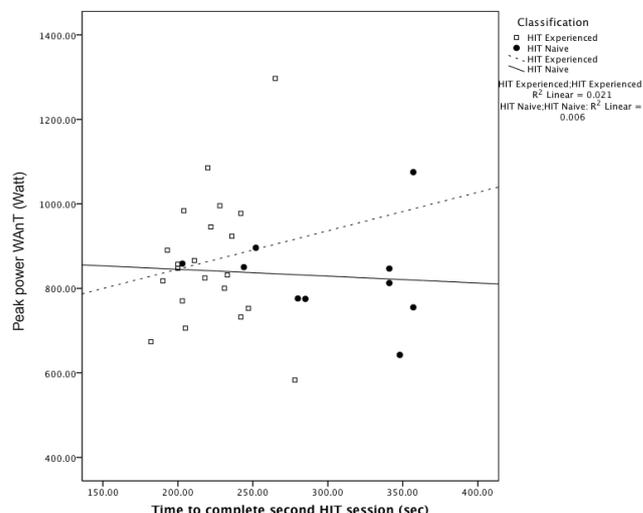

FIG. 3. Scatterplot of maximum aerobic capacity (ml O$_2 \cdot$kg$^{-1} \cdot$min^{-1}) versus time (s) on WOD 2 by CrossFit Experience.

FIG. 4. Scatterplot of peak power (Watts) versus time (s) on WOD 2 by CrossFit Experience.

certified trainer. The predictor variables explained a greater amount of variance in the AMRAP style workout than the 21-15-9 workout. In the latter only CrossFit experience was a significant predictor.

A search of the literature related to „CrossFit" revealed only one investigational study that examined aerobic capacity with CrossFit training [20]. The study examined 10 weeks of CrossFit training and reported improvements in maximum aerobic capacity. Despite the lack of comparative literature, examining the individual exercises employed in the CrossFit prescriptions did yield some pertinent information. Farrar, Mayhew and Koch [16] reported that a similar weight Kettlebell (16kg) used for continuous swings over the course of 12 minutes resulted in an average of 65% of maximum aerobic capacity and 86.8% of heart rate maximum. The population of college males in the study was very similar in baseline characteristics to the population of the present study (Age: 20.8 ± 1.1, Height: 179 ± 3 cm, Weight: 77.3 ± 7.7 kg, VO_2max: 52.78 ml$\cdot$kg$^{-1}\cdot$min^{-1}). Though not entirely the same as the AMRAP workout in the present investigation, the similar modality and duration bore enough semblances to draw some basic comparisons. In the present investigation, there was a significant association between the 12-minute AMRAP workout and VO_2max, a stronger association than with anaerobic peak power assessed via the WaNT. The results from Farrar, Mayhew and Koch [16] offer some support for this finding as they reported that a similar time course of kettlebell swings represented 65% VO_2max exercise. While the first workout did not consist entirely of kettlebell swings, approximately 1/3 of the prescribed activity was kettlebell swings of the same weight, with the remaining similarly involving lower body musculature in the repetition.

While the regression analysis for the 21-15-9 session did not result in as strong of a prediction of performance, it did provide valuable insight into a second form of common CrossFit exercise. The 21-15-9 included more technically demanding movements (sumo deadlift high pull, box jump) that may have proved to be a limiting factor for some of the CrossFit -naïve participants. In examining Figures 3 and 4, one can see the spread of the performance data for given levels of aerobic capacity and peak power. When the participants are separated by CrossFit experience, VO_2 max significantly correlates to time on the second CrossFit test in the experienced group ($r=0.453$, $p=0.03$) but not in the naïve group ($r=0.168$, $p=0.64$). While it was not the intention of this study to examine the relationship of aerobic capacity and anaerobic power in participants based upon backgrounds in CrossFit training, the correlations do suggest that lack of experience may have an effect on relationship of fitness to CrossFit performance results.

While the present investigation provides some information about the relationship of two well-known measures of anaerobic power and aerobic capacity to CrossFit exercise performance, it is not without limitation. Since the present investigation is only a study of relationship, it is not known if CrossFit exercise will promote increases in either anaerobic power or aerobic fitness. It should also be noted that the exercise session are not representative of the total breath of exercises typically prescribed by CrossFit. Additionally the sessions had to be performed individually in order for time and reps to be quantified, in a true CrossFit setting the workouts would be performed in a group. One delimitation for the present study was that no participates experienced any injuries during the course of the study. Based upon these preliminary findings, future studies are warranted to determine the impact of chronic CrossFit -style exercise on aerobic fitness and anaerobic performance measures.

CONCLUSIONS

For CrossFit athletes and enthusiasts, it is important to understand the qualities associated with success in an exercise regimen in order to make the most appropriate choices for clients. The AMRAP-style workout performance was not as closely associated with CrossFit experience and thus might be a better choice for CrossFit novices, while the 21-15-9 rep scheme workout was highly related to CrossFit experience and thus might be better suited to those individuals with experience. The AMRAP workout performance was also associated with both aerobic fitness and anaerobic power, and thus is likely a good choice for clients that have higher levels of fitness.

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REFERENCES

1. Hak PT, Hodzovic E, Hickey B The nature and prevalence of injury during CrossFit training. J Strength Cond Res. 2013; Nov 22 [Epub ahead of print].
2. Joondeph SA, Joondeph BC. Retinal detachment due to CrossFit training injury. Case Rep Ophthalmol Med. 2013:1898378. doi: 10.1155/2013/189837.
3. Partridge JA, Knapp BA, Massengale BD. An investigation of motivational variables in CrossFit facilities. J Strength Cond Res. 2014;28(6):1714-1721.
4. Bompa TO. Periodization training for sport. Champaign: Human Kinetics; 1999.
5. Rische P. CrossFit 's relationship with Reebok enhances its financial and commercial credibility. Forbes. 2011; Retreived from http://www.forbes.com/sites/sportsmoney/2011/07/22/CrossFits-relationship-with-reebok-enhances-its-financial-and-commercial-credibility/
6. Glassman G. What is fitness? CrossFit Journal. 2002; Retrieved from http://journal.CrossFit .com/
7. Kilgore L, Rippetoe M. Redefining fitness for health and fitness professionals. J Exerc Physiol Online. 2007;10(1):34-39.
8. American College of Sport Medicine. ACSM's guidelines for exercise testing and prescription. Baltimore: Lippincott, Williams and Wilkins; 2000.
9. Castro D. The history of the CrossFit Games. CrossFit Journal 2010; Retrieved

from http://journal.CrossFit .
com/2010/07/games-history.tpl

10. Rankovic G, Mutavdzic V, Toskic D, Preljevic A, Kocic M, Nedin G, & Damjanovic N. Aerobic capacity as an indicator in different kinds of sports. Bosn J Basic Med Sci. 2011;10(1):44-48.

11. Cronin J, Sleivert G. Challenges in understanding the influence of maximal power training on improving athletic performance. Sports Med. 2005;35(3):213-234.

12. Paine J, Uptgraft J, & Wylie R. CGSC CrossFit Study: A study prepared for Command and General Staff College of the United States Army. 2010; Retrieved from http://cgsc.cdmhost.com/cdm/ singleitem/collection/p124201coll2/ id/580/rec/1

13. Sell K, Taveras K, Ghigiarelli J. Sandbag training: A sample 4-week training program. Strength Cond J. 2011;33(4):88-96.

14. Henry T. Resistance training for Judo: Functional strength training concepts and principles. Strength Cond J. 2011;33(6):40-49.

15. Dodd DJ, Alvar BA. Analysis of acute explosive training modalities to improve lower-body power in baseball players. J Strength Cond Res. 2007;21(4): 1177-1182.

16. Farrar RE, Mayhew JL, Koch AJ. Oxygen cost of kettlebell swings. J Strength Cond Res. 2010;24(4):1034-1036.

17. Bellar D, Judge LW. Modeling and relationship of respiratory exchange ratio to athletic performance. J Strength Cond

Res. 2012;26(9):2484-2489.

18. Bellar D, Judge LW, Davis GR. Description and predictive value of a novel method for determining the respiratory compensation point using standard scores. J Strength Cond Res. 2015;29(5):1433-1438.

19. Bellar D, Tomescu V, Judge LW. Relationship of an equivalence point for change in VCO2 and VO2 to endurance performance. J Strength Cond Res. 2013;27(5):1394-1399.

20. Smith MM, Sommer AJ, Starkoff BE, Devor ST. CrossFit -based high-intensity power training improves maximal aerobic fitness and body composition. J Strength Cond Res. 2013;27(11):3159-72.