# Metabolic and Cardiovascular response to the CrossFit workout 'Cindy'

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# METABOLIC AND CARDIOVASCULAR RESPONSE TO THE CROSSFIT WORKOUT 'CINDY': A PILOT STUDY

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**ABSTRACT**

Metabolic and Cardiovascular Response to the CrossFit workout 'Cindy'. CrossFit is a fast growing sport of fitness that not only serves as a form of competition but as a form of general exercise training. Little is known about this conditioning program and a better understanding of the metabolic and cardiovascular demands is needed. PURPOSE: It is the purpose of this pilot study is to examine the acute metabolic and cardiovascular demands of a named CrossFit workout using semi- to well-trained subjects in order to establish a proper control exercise. METHODS: 7 men and 2 women (mean age = 27.2 ± 9.6) who have trained in CrossFit for at least 3 months participated in the study. Each subject performed a graded exercise test on a treadmill to determine maximal oxygen consumption ($VO_{2max}$). All subjects performed the named CrossFit workout called 'Cindy', which consisted of as many rounds possible of 5 pull-ups, 10 push-ups, and 15 air squats in 20-minutes. A portable metabolic analyzer was used to record volume of oxygen consumption ($VO_2$) and rate of caloric expenditure ($kcals \cdot min^{-1}$). The subjects also wore a portable heart rate (HR) monitor. Means ± SD were determined for the following variables: $VO_2$, $\%VO_{2max}$, HR, $\%HR_{max}$, $kcals \cdot min^{-1}$, METs and total kcals. RESULTS: The results demonstrated that 'CINDY' resulted in average $VO_2$ of 33.3 ± 5.5 $ml \cdot kg^{-1} \cdot min^{-1}$, which corresponded to 63.8 ± 12.3 % $VO_{2max}$. In addition, the workout elicited a heart rate of 170.8 ± 13.5 $beats \cdot min^{-1}$. Furthermore, the subjects expended 13 ± 2.9 $kcals \cdot min^{-1}$, corresponding with a total caloric expenditure 260.6 ± 59.3 kcals. The average MET level was 9.5 ± 1.5. CONCLUSION: The findings of this study suggest that 'Cindy' could be classified as "vigorous intensity" based on established American College of Sports Medicine $HR_{max}$ guidelines i.e., between 76 - 96 % of $HR_{max}$, while $VO_{2max}$ parameters where classified as "moderate intensity" i.e., between 46 to 64% of $VO_{2max}$. Further investigation is needed to compare the metabolic response of other popular CrossFit workouts.

**Keywords:** CrossFit, High-Intensity Exercise, VO2, HR, Heart Rate

## INTRODUCTION

In recent years professional and governmental organizations have begun emphasizing the importance of physical activity and its role in preventative medicine, health improvement, and maintenance (Garber et al. 2011). Physical activity has been shown to improve overall facets of health such as improved skeletal muscle strength, cardio-respiratory function, and metabolic control (Garber et al. 2011). As the understanding of adaption to exercise evolves, so too does the application. In this regard, there has been an increased interest in short duration, high-intensity exercise bouts, specifically the exercise programing of CrossFit. This relatively new application of exercise, has gained a strong following within the active community. Much of this growth can be attributed to purported reports of rapid weight loss and increased cardiovascular capacity (Smith et al. 2013), while also offering varying, time-efficient workouts.

The underlying philosophy of CrossFit training is to prepare an athlete to successfully perform both randomized and diverse tasks (Glassman 2002). According to CrossFit, in order to train across a wide spectrum of physical fitness components (e.g., strength, power, endurance) within one exercise scheme, programming must incorporate both resistance (e.g., deadlift, power clean, snatch, etc.) and endurance (e.g., running, rowing, cycling, etc.) modalities within a single bout (Glassman 2002; Glassman 2007). In lieu of this programming philosophy, workouts of the day (WODs) constantly vary and are rarely duplicated. However, there are a few WODs that are 'named' and revisited in order to track progress. Furthermore, the primary objective of a traditional WOD is to attempt to complete the prescribed tasks as fast as possible, creating a short duration and high-intensity session.

To date, very little empirical evidence exists regarding any physiological response to CrossFit, chronic or acute. Therefore, it is the purpose of this pilot study to examine the acute cardiovascular and metabolic demands during a bout of a named WOD in order to determine an appropriate intensity for an exercise control groups in future studies. To undertake this study, markers of chronotropic (i.e., HR, $\%HR_{max}$) and metabolic (i.e., $VO_2$, $\%VO_{2max}$, kcal) responses were measured during the named WOD 'Cindy'.

## METHODS

*Participants*

Nine semi- to well-trained apparently healthy participants (7 male, 2 female) age 27.2 yrs (± 9.6), weight 75.8 kg (± 13.9), height 173.7 cm (± 9.4) participated in this study. The pre-requisite for experience in the current investigation was a three-month minimum of CrossFit participation. In order to be classified as "well-trained" participants must be able to complete each movement of the named WOD 'Cindy' without assistance and have completed a minimum of 14-rounds for men and 10-rounds for women in a prior attempt. Prior to data collection, a signed informed consent was obtained from each participant. All participants were of low risk for cardiovascular, metabolic, and/or pulmonary diseases as determined by PAR-Q and Health History Questionnaire. No participants reported any prescribed or over the counter medication during the time of the study. Subjects were instructed to abstain from exercise 24-hours prior to each trial, and alcohol 12-hours prior. This study was approved by the Auburn University at Montgomery institutional review board.

*Experimental Design*

Each participant arrived at the laboratory on two separate occasions for data collection between the hours of 7am and 11am. On the first visit participants were familiarized with protocols and performed a graded exercise test to determine maximal oxygen consumption ($VO_{2max}$). Participants were instructed to return between 3-7 days later in order to perform the second trial, a high-intensity, short duration exercise bout named 'Cindy'.

*Graded Exercise Test*

Maximal oxygen consumption ($VO_{2max}$) and maximal heart rate ($HR_{max}$) were assessed during the first session through a graded exercise test (GXT) on a treadmill (Trackmaster, Newton, KS). Using Bruce Protocol, the workload during the GXT was increased incrementally every 3-minutes until a maximal value was reached. Expired gas (i.e., oxygen and carbon dioxide) fractions were sampled continuously using a pneumotach, mixing chamber, and gas analyzers through a portable analyzer (k4b2, COSMED USA, inc., Concord, CA). During the test, heart rate was assessed continuously using a heart rate monitor (Polar Electro Oy, Oulu, Finland). Test termination required achievement of two of the following criteria: a plateau in $VO_2$ ($\pm$ 2 $ml \cdot kg^{-1} \cdot min^{-1}$) despite an increase in workload; respiratory exchange ratio (RER) of $\geq$ 1.15; heart beat within 10 beats of age predicted maximum (220 – age), or volitional fatigue.

*Exercise Bout Protocol*

Prior to the trial participants were equipped with a portable gas analyzer K4b2 and a polar HR monitor to determine average volume of oxygen consumed ($VO_{2avg}$), heart rate ($HR_{avg}$), total energy expenditure ($EE_{total}$), and rate of caloric expenditure ($kcals \cdot min^{-1}$). Once acclimated to the equipment, participants began a 5-minute warm up on the treadmill at a self-selected intensity followed by a 1-minute rest. Following the rest period participants began the exercise bout. The CrossFit named workout "Cindy" consists of as many rounds possible of 5 pull-ups, 10 push-ups, and 15 air squats in 20-minutes. The workout required that the individual complete all prescribed repetitions for the movement before moving on to the next exercise and to do so as fast as possible. For example, all 5 pull-ups must be completed before moving on to the 10 push-ups. Each movement was standardized to ensure consistency between all participants. Pull-up form standards required the participant to start with arms fully extended, pull their chin just above the bar, and then return to the starting position and could be accomplished through strict, kipping, or butterfly variation. To perform the push-up, participants started in a plank position with the arms fully extended with the hands on the ground directly beneath the shoulders. Subjects then lowered the body until the chest came in contact with the ground, then returned to the starting position. Air-squat standards required participants to perform a traditional bodyweight squat until the hips passed the knee, then returned to starting position. Failure to achieve these standards resulted in a repeat of the repetition of that movement until successfully performed.

*Statistical Analysis*

Data was analyzed using SPSS/PASW Statistics version 18.0 (Somers, NY). Mean and standard deviations (SD) were calculated for each of the following resting variables: age (yr), height (cm), weight (kg). Mean and standard deviations (SD) were calculated for the following testing variables: $HR_{max}$ (bpm), $\%HR_{max}$, $HR_{ave}$ (bpm), $VO_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$), $\%VO_{2max}$, $VO_{2ave}$ ($ml \cdot kg^{-1} \cdot min^{-1}$), $EE_{total}$ (kcals), $EE_{ave}$ ($kcals \cdot min^{-1}$), and average metabolic equivalent (MET).


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## RESULTS

All participants completed both graded exercise testing and CrossFit bout protocol. Mean anthropomorphic values and maximal HR and $VO_2$ obtained during the first visit can be seen in Table 1. The average rounds completed during the CrossFit trial were 17.8 ± 3.7 rounds.

The $VO_{2avg}$ was 33.5 ± 5.5 $ml \cdot kg^{-1} \cdot min^{-1}$ throughout the bouts, corresponding to 63.8 ± 12.3 % of the participants $VO_{2max}$. As expected, HR rapidly increased and was sustained at an average of 170.8 ± 13.5 $beats \cdot min^{-1}$ throughout the trial. This sustained $HR_{avg}$ corresponded to 91 ± 4.2% of the mean $HR_{max}$. The average $EE_{total}$ of the 20-minute bout was 260.6 ± 59.3 kcals. The average rate of energy expenditure throughout 'Cindy' was 13 ± 2.9 $kcals \cdot min^{-1}$. When factoring body mass into energy expenditure over the 20-minute bout, the average value was 3.4 ± 0.48 kcal/kg. The average metabolic equivalent sustained throughout the bout was 9.5 ± 1.5 METs.

**Table 1.** Participant Characteristics

| **Characteristic** | **Values ± SD** |
|---|---|
| Age (yrs) | 27.2 ± 9.6 |
| Height (cm) | 173.7 ± 9.4 |
| Weight (kg) | 75.8 ± 13.9 |
| $VO_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) | 58.87 ± 6.8 |
| $HR_{max}$ (bpm) | 186 ± 11 |

## DISCUSSION

The purpose of this study was to examine cardiovascular and metabolic demands during an acute bout of the CrossFit named workout, 'Cindy'. The key findings demonstrated that cardiovascular response ($HR_{avg}$) was greater than the metabolic response ($VO_{2avg}$) as represented by the % maximal values. In terms of exercise intensity, $HR_{avg}$ was elevated enough to be categorized as vigorous intensity; while $VO_{2avg}$ was only considered moderate (Garber et al. 2011). Caloric expenditure was relatively high, while the metabolic equivalent was approximately three times greater then that at rest.

*Markers of Chronotropic and Metabolic Response*

While not measured directly in this investigation, increased heart rate (HR) at the onset of exercise is primarily caused by parasympathetic withdrawal and followed by sympathetic activation (Borresen & Lambert 2008). The magnitude of this HR response is in accordance to oxygen demand of the working tissue (Rowell 1974). In order to meet the increase oxygen demands, the heart must increase the rate of circulation. The distribution of blood can increase up to five times greater than resting values during a maximal bout of exercise (e.g., 5L/min to 25L/min) (Åstrand and Rodahl 1970). Therefore, in order to meet the increasing metabolic demands during exercise, a linear increase of HR occurs with increasing intensity.

Interestingly, the HR response of this current study increased to 91% of mean $HR_{max}$, which meets the American College of Sports Medicine (ACSM) criteria for vigorous exercising heart rate (76 -<96 $\%HR_{max}$), while the oxygen consumption was 63.8 $\%VO_{2max}$, which falls under the criteria of moderate activity (46 - ≤64 $\%VO_{2max}$) (Garber et al. 2011). Although the observed differences between intensity markers HR and $VO_2$ were unexpected, they are in agreement with previous studies that portrayed this similar effect (Burleson et al. 1998; A G


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Monteiro 2008; S. Beckham and Earnest 2000; Lagally et al. 2009).

Linear relationships are often seen between exercising heart rate and $VO_2$ during an increase in workload. However, engaging in a high-intensity exercise bout can result in a rapid rise in HR, while $VO_2$ levels struggle to produce the same response (A G Monteiro 2008; Burleson et al. 1998; Lagally et al. 2009; S. Beckham and Earnest 2000). A potential explanation for this is a greater dependence on HR with increasing exercise intensity to maintain cardiac output. As exercise intensity increases beyond 40% of $VO_{2max}$, HR becomes the primary factor of increased cardiac output (Rowell 1974). With this rise in heart rate, the venous network is unable to effectively return blood to the heart; thereby, creating a plateau in stroke volume (Allen, Byrd, and Smith 1976; Hurley et al. 1984). An additional explanation for the discrepancy observed between HR and $VO_2$ is the continuous postural changes that occur throughout the bout. Alterations in posture and redistribution of blood to active muscle groups likely present a challenge to hemodynamics and consequently increase the catecholamine response, which will lead to an elevated HR (Borst et al. 1982).

While the current investigation only elicited a moderate $\%VO_{2max}$, a previous study on HIIT, performed by Tabata et al., 1996, demonstrated conflicting results. Subjects performed a workout with seven to eight sets of cycling with a work-to-rest ratio of 20 seconds on and 10 seconds rest (2:1). Results showed linear responses of HR and $VO_2$, in which some subjects reached peaks matching $VO_{2max}$ (vigorous intensity) during the exercise bout (Tabata et al. 1996). These conflicting results may perhaps be explained by the differences in the exercise bouts themselves. The current study used a continuous high-intensity session with no scheduled rest times, which may have affected the cardiovascular and metabolic responses. In addition, the modes of training were different, as the previous study used a strictly lower body workout; the bout of ‘Cindy’ combined upper and lower body musculature. Likely differences in skeletal muscle recruitment and metabolic responses may have altered cardiovascular response due to a phenomenon known as the exercise pressor reflex. Generally, active or contracting skeletal muscle influence cardiovascular activity through alterations of blood pressure, muscle afferents, and or exercise metabolites, which subsequently increase HR (Mitchell et al. 1983). The exercise pressor reflex is believed to be a possible explanation for elevated HR and a lower oxygen consumption during low-resistance exercise (Collins et al. 1991). Dynamic low-resistance weight lifting and upper body exercise cause a greater recruitment of fast-twitch muscle fibers, which results in a greater exercise pressor reflex (Collins et al. 1991). Therefore, the discrepancy between the Tabata et al. study and the current findings may be in part due to the pressor reflex.

A study performed by Lagally et al., 2009, provided similar results to the current study and supports the claims of Collins et al., 1991. Participants underwent a 28.5-minute continuous functional exercise workout during which HR and $VO_2$ were measured. The exercise bout consisted of both upper and lower body compound exercises. Thus, increasing the amount of skeletal muscle utilized during the session, as well as, alternating between varying muscle groups, which is similar to the current investigation. The 28.5-minute workout elicited a vigorous intensity exercising HR (i.e., 82.7 $\%HR_{max}$) and a moderate intensity $\%VO_{2max}$ (i.e., 51.1), which closely relates to the findings of the current study.

*Markers of Energy Expenditure*

In addition to an elevated HR and moderate $VO_2$, results also indicated a mean MET level of 9.5 ± 1.6, which can be categorized as vigorous intensity (Garber et al. 2011). While typical high-intensity resistance training or weight lifting elicits a MET level of 6, the results of this study are more consistent with HIIT, as well as traditional aerobic modes of exercise. Examples of these include vigorous intensity calisthenics (8 MET's), circuit resistance training (8 MET's), stair-treadmill ergometer (9 MET's), stationary cycling at 200 watts (10.5 MET's), running at 5.2-6 mph (9-10 MET's), and competitive sports (8-12 MET's), such as soccer and basketball (Ainsworth et al. 2000).

In terms of energy expenditure ($EE_{total}$), participants elicited a mean of 260.6 ± 59.3 kcals, which equated to 13 ± 2.9 $kcals \cdot min^{-1}$. While the length of time for the current study was 20-minutes, Stanforth et al., 2000, had participants complete a 50-minute continuous circuit weight training exercise session, incorporating both the upper and lower body. Although the former study utilized external resistance (i.e., free weights), $EE_{total}$ was comparable to the current study (i.e., 265 kcals compared to 260.6 kcals for the current study). Thus, demonstrating that the 'Cindy' bout may provide a greater caloric expenditure versus an external resistance program of greater session duration. This may in part be due to the differences in overall HR intensity of the bouts. The current study resulted in a $\%HR_{max}$ of approximately 91%, while the Stanforth et al. study yielded only a $63\%HR_{max}$. While the current study provides a caloric expenditure response greater than multiple studies examining traditional circuit weight training (S. G. Beckham and Earnest 2000; Wilmore et al. 1978; Bloomer 2005); it is also not the only high-intensity, continual exercise study to demonstrate this (Farrar, Mayhew, and Koch 2010).

## LIMIATIONS

Due to the nature of this pilot study there are limitations that must be addressed. The sample size of the current study can be considered a limitation with only 9 subjects (7-male, 2-female). Because "Cindy" is a rigorous workout for females, it is difficult to recruit enough subjects who were physically capable of enduring the rigors of the 20-min workout involving pull-ups and push-ups. Furthermore, the goal of this pilot study was to determine the average oxygen consumption and HR response of the CrossFit workout "Cindy", and not to compare within or outside the population, in that this was a descriptive study.

## CONCLUSION

CrossFit is a relatively new and popular form of high-intensity exercise training. To date, little empirical evidence regarding metabolic or cardiovascular responses during an acute bout of CrossFit exists. Understanding the aforementioned physiological responses to a bout of exercise becomes important when considering the application and prescription of exercise. In this regard, the metabolic and cardiovascular responses observed during the single bout were of adequate duration and intensity to be classified as moderate cardiorespiratory training, according to ACSM guidelines (Garber et al. 2011). The exercise bout was also sufficient in expending an increased amount of energy (i.e., kcals/min) for the short duration of the workout.

In summary, the examined CrossFit workout 'Cindy' provides a moderate stimulus to cardiovascular training, while increasing HR to a vigorous high. Furthermore, 'Cindy' provides a high rate of caloric expenditure during a relatively short duration bout. These findings provide information necessary for creating an exercise intensity based control bout for studies examining a CrossFit workout of this type. Further investigation is needed to examine the anaerobic properties of CrossFit (i.e., Lactate) as well as catecholamine responses in order to better understand the physiological response to this type of training. In addition, due to the complex make up of CrossFit and its programming, a deeper investigation is needed to examine the different modalities within a CrossFit WOD (i.e., Olympic lifting, gymnastic movements, etc.).

## REFERENCES


1. A G Monteiro, D. A. Alveno. 2008. "Acute Physiological Responses to Different Circuit Training Protocols." *The Journal of Sports Medicine and Physical Fitness* 48 (4): 438–42.

2. Ainsworth, B E, W L Haskell, M C Whitt, M L Irwin, A M Swartz, S J Strath, W L O'Brien, et al. 2000. "Compendium of Physical Activities: An Update of Activity Codes and MET Intensities." *Medicine and Science in Sports and Exercise* 32 (9 Suppl): S498–504.

3. Allen, T. Earl, Ronald J. Byrd, and Douglas P. Smith. 1976. "Hemodynamic Consequences of Circuit Weight Training." *Research Quarterly. American Alliance for Health, Physical Education and Recreation* 47 (3): 299–306. ;p

4. Åstrand, Per-Olof, and Kåre Rodahl. 1970. "Textbook of Work Physiology-4th: Physiological Bases of Exercise."

5. Beckham, S G, and C P Earnest. 2000. "Metabolic Cost of Free Weight Circuit Weight Training." *The Journal of Sports Medicine and Physical Fitness* 40 (2): 118–25.

6. Beckham, Sg, and Cp Earnest. 2000. "Metabolic Cost of Free Weight Circuit Weight Training." *The Journal of Sports Medicine and Physical Fitness* 40 (2): 118–25.

7. Bloomer, Richard J. 2005. "Energy Cost of Moderate-Duration Resistance and Aerobic Exercise." *Journal of Strength and Conditioning Research / National Strength & Conditioning Association* 19 (4): 878–82.

8. Borresen, Jill, and Michael I Lambert. 2008. "Autonomic Control of Heart Rate during and after Exercise : Measurements and Implications for Monitoring Training Status." *Sports Medicine (Auckland, N.Z.)* 38 (8): 633–46.

9. Borst, C., W. Wieling, J. F. van Brederode, A. Hond, L. G. de Rijk, and A. J. Dunning. 1982. "Mechanisms of Initial Heart Rate Response to Postural Change." *American Journal of Physiology - Heart and Circulatory Physiology* 243 (5): H676–H681.

10. Burleson, Max A., Harold S. O'Bryant, Michael H. Stone, Mitchell A. Collins, and Travis Triplett-McBride. 1998. "Effect of Weight Training Exercise and Treadmill Exercise on Post-Exercise Oxygen Consumption:" *Medicine & Science in Sports & Exercise* 30 (4): 518–22.

11. Collins, M. A., K. J. Cureton, D. W. Hill, and C. A. Ray. 1991. "Relationship of Heart Rate to Oxygen Uptake during Weight Lifting Exercise." *Medicine and Science in Sports and Exercise* 23 (5): 636–40.

12. Dixie Stanfoth, Philip R. Stanforth. 2000. "Physiologic and Metabolic Responses to a Body Pump Workout." *The Journal of Strength & Conditioning Research* 14 (2).

13. Farrar, Ryan E, Jerry L Mayhew, and Alexander J Koch. 2010. "Oxygen Cost of Kettlebell Swings." *Journal of Strength and Conditioning Research / National Strength & Conditioning Association* 24 (4): 1034–36.

14. Garber, Carol Ewing, Bryan Blissmer, Michael R. Deschenes, Barry A. Franklin, Michael J. Lamonte, I-Min Lee, David C. Nieman, and David P. Swain. 2011. "Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory, Musculoskeletal, and Neuromotor Fitness in Apparently Healthy Adults." *Medicine and Science in Sports and Exercise* 43 (7): 1334–59.

15. Glassman, Greg. 2002. "Foundations by Greg Glassman." *CrossFit Journal*. http://journal.crossfit.com/2002/04/foundations.tpl.

16. Glassman, Greg. 2007. "Understanding CrossFit by Greg Glassman." *CrossFit Journal*. http://journal.crossfit.com/2007/04/understanding-crossfit-by-greg.tpl

17. Hurley, BF, Seals, DR, Ehsani AA, Cartier, LJ, Dalsky GP, Hagberg, JM, and Holloszy, JO. 1984. "Effects of High-Intensity Strength Training on Cardiovascular Function." *Medicine and Science in Sports and Exercise* 16 (5): 483–88.

18. Lagally, Kristen M, Jeanine Cordero, Jon Good, Dale D Brown, and Steven T McCaw. 2009. "Physiologic and Metabolic Responses to a Continuous Functional Resistance Exercise Workout." *Journal of Strength and Conditioning Research / National Strength & Conditioning Association* 23 (2): 373–79.

19. Mitchell, J H, M P Kaufman, and G A Iwamoto. 1983. "The Exercise Pressor Reflex: Its Cardiovascular Effects, Afferent Mechanisms, and Central Pathways." *Annual Review of Physiology* 45 (1): 229–42.

20. Rowell, L. B. 1974. "Human Cardiovascular Adjustments to Exercise and Thermal Stress." *Physiological Reviews* 54 (1): 75–159.

21. Smith, Michael M, Allan J Sommer, Brooke E Starkoff, and Steven T Devor. 2013. "Crossfit-Based High Intensity Power Training Improves Maximal Aerobic Fitness and Body Composition." *Journal of Strength and Conditioning Research / National Strength & Conditioning Association* 27 (11): 3159–72.

22. Stanforth D, Stanforth P, Hoemeke M. Physiologic and Metabolic Responses to a Body Pump Workout. : The Journal of Strength & Conditioning Research. 2000, 14(2), 144-150

23. Tabata I, Nishimura K, Kouzaki M, Hirai Y, Ogita F, Miyachi M, Yamamoto K. Effects of moderate-intensity endurance and high-intensity intermittent training on anaerobic capacity and VO2max: *Medicine and Science in Sports and Exercise*. 28: 1327–1330, 1996.

24. Wilmore, J H, R B Parr, P Ward, P A Vodak, T J Barstow, T V Pipes, G Grimditch, and P Leslie. 1978. "Energy Cost of Circuit Weight Training." *Medicine and Science in Sports* 10 (2): 75–78.