Acute Cardiorespiratory and Metabolic Effects of a Sandbag Resistance Exercise Protocol

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Abstract

Ratamess, NA, Kang, J, Kuper, JD, O'Grady, EA, Ellis, NL, Vought, IT, Culleton, E, Bush, JA, and Faigenbaum, AD. Acute cardiorespiratory and metabolic effects of a sandbag resistance exercise protocol. *J Strength Cond Res* 32(6): 1491–1502, 2018—The purpose of this study was to examine the acute cardiorespiratory and metabolic effects of a sandbag (SB) resistance exercise protocol and compare the responses to time-matched treadmill running protocols. Eight healthy, resistance-trained men (21.1 ± 1.0 years; 86.1 ± 7.8 kg) completed 4 protocols of equal duration in random sequence: (a) SB, (b) treadmill running at 60% of $\dot{V}O_2$ reserve (60$\dot{V}O_2$R), (c) treadmill running at 80% of $\dot{V}O_2$ reserve (80$\dot{V}O_2$R), and (d) a control protocol. The SB protocol was 16 minutes in duration and consisted of 3 circuits of 8 multiple-joint exercises (with 11-, 20-, or 48-kg SBs) performed for as many repetitions as possible for 20 seconds followed by a 10-second rest interval before beginning the next exercise. Two minutes of rest was allowed between circuits. Breath-by-breath oxygen consumption ($\dot{V}O_2$) and heart rate (HR) were recorded throughout each protocol and for 30 minutes postexercise (PE) and blood lactate was determined before and immediately after each protocol. Blood lactate was significantly higher after SB compared with 60$\dot{V}O_2$R and 80$\dot{V}O_2$R. Mean and peak HR in SB was significantly higher than 60$\dot{V}O_2$R but not different from 80$\dot{V}O_2$R. Mean $\dot{V}O_2$ and energy expenditure (EE) in SB was significantly lower than 60$\dot{V}O_2$R and 80$\dot{V}O_2$R during each protocol but significantly higher after SB compared with 60$\dot{V}O_2$R and 80$\dot{V}O_2$R PE. Compared with 60$\dot{V}O_2$R and 80$\dot{V}O_2$R, respiratory exchange ratio was significantly higher during SB and through 5 minutes PE, but was significantly lower at 25–30 minutes PE after SB. Sandbag, as performed in this study, provides a superior metabolic stimulus to treadmill running during the PE period; however, the SB results demonstrate inferior EE compared with running at 60$\dot{V}O_2$R and 80$\dot{V}O_2$R.

Key Words resistance training, running, oxygen consumption, circuit training, interval training

Introduction

Metabolic training (i.e., high-intensity interval training) programs have become popular within the strength and conditioning and general fitness communities. Metabolic training programs integrate several modalities including resistance exercise (RE), speed, agility, and plyometric and aerobic forms of exercise that use large muscle-mass exercises performed almost continuously with very little rest in between sets (4,30,41). The integrated, continuous training structure performed with moderate to high intensities yield large cardiovascular and metabolic demands compared with traditional circuit structures (41) and has the capacity to improve several health- and skill-related fitness components (4,26,30). Studies have shown that these types of training programs can increase aerobic fitness, muscle strength, power, and endurance (4,26,30) and are popular, in part, because they are time efficient (11,30). Although many participants use metabolic training programs to increase muscle strength, hypertrophy, endurance, power, and motor performance, another primary goal for trainees is to augment energy expenditure (EE), thereby leading to greater potential body fat reductions. However, only few studies have examined EE during different metabolic training protocols.

The source of resistance for the RE component of metabolic training can vary dramatically. Resistance exercise embodies multiple forms of resistance including the most basic element of one's body weight to more elaborate forms such as free weights and related equipment, machines, elastic bands, whole-body vibration devices, ropes, kettlebells (KBs), and various types of strength implements (10,20,28,34,35). One such implement of resistance is a sandbag (SB).

Sandbags have long been advocated as a unique resistance training (RT) implement beneficial to strength training and conditioning (23,39). Sandbags vary in size and shape, provide unbalanced and unstable resistance, are believed to

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32(6)/1491–1502

Journal of Strength and Conditioning Research

Table 1. Descriptive characteristics.

	Subjects (n = 8; mean ± SD)
Age (y)	21.1 ± 1.0
Height (cm)	181.7 ± 4.8
Body mass (kg)	86.5 ± 7.4
Body fat (%)	12.1 ± 1.8
Resistance training experience (y)	6.8 ± 2.4
$\dot{V}O_2max$ (ml·kg^{-1}·min^{-1})	46.8 ± 6.7

increase stabilizer muscle activation during exercise, and provide a potent stimulus for grip strength training (23,39). However, a recent study found no difference in core muscle activation between an SB and barbell clean and jerk (6). It has also been suggested that SBs may provide the athlete with a larger transfer of training effect to performance of occupational tasks (39). A large number of exercises can be performed with SBs especially because some models have handles which improve gripping capacity. However, the efficacy of SBs during RT remains relatively unknown. Wright et al. (45) developed an SB throw conditioning test for wrestlers consisting of 7 throws per minute for seven 1-minute rounds. Other studies have examined the use of SBs as a functional assessment tool for various types of timed carrying, dragging, and loading/stacking tasks (12,15,24,25,31,37). However, acute physiological responses and subsequent adaptations to SB training remain understudied.

Given the paucity of scientific information regarding SB RE, the purpose of this study was to quantify the metabolic and cardiovascular responses to a single SB RE protocol. A secondary purpose was to compare these responses to traditional running programs of similar duration at 60 and 80% of $\dot{V}O_2$ reserve. It was hypothesized that the SB protocol would elicit potent cardiorespiratory and metabolic responses comparable with running; however, it would provide augmented EE during the PE period.

Methods

Experimental Approach to the Problem

To examine the primary hypothesis of the present investigation, subjects were pretested for $\dot{V}O_2$peak and flat treadmill running performance, and subsequently did a nonexercise control (CT) protocol plus 3 exercise protocols of similar duration (16 minutes): (a) an SB protocol performed for 3 sets of 8 exercises in circuit manner using Tabata intervals (42; where as many repetitions as possible were performed in 20 seconds followed by 10 seconds of rest); (b) treadmill running at 60% of $\dot{V}O_2$ reserve ($\dot{V}O_2R$); and (c) treadmill running at 80% of $\dot{V}O_2R$. Blood lactate was measured pre-exercise and PE, and oxygen consumption ($\dot{V}O_2$), heart rate (HR), and performance data were collected during each protocol. This study design enabled us to examine and quantify the acute cardiorespiratory and metabolic responses to an SB circuit RE protocol and compare these responses with 2 treadmill running protocols of similar duration.

Subjects

Eight healthy, resistance-trained men (18-23 years old) agreed to participate in this study (Table 1). Each subject initiated the study in a trained state (i.e., were RT 2–4 days per week, but had limited experience using SBs) and none were taking any medications/supplements such as anabolic steroids known to affect RE performance. Subjects underwent one session of familiarization with study procedures before testing. Familiarization focused on subjects' ability to perform all the SB exercises with good technique. During this time, height was measured to the nearest 0.1 cm using a wall-mounted stadiometer and body mass was measured to the nearest 0.1 kg using an electronic scale. Percent body fat was estimated through a three-site skinfold test. The sites measured were the pectoral, anterior thigh, and abdominal skinfolds using methodology previously described (21). Body density was calculated using the equation of Jackson and Pollock (21) and percent body fat was calculated using the equation of Siri (40). The same research assistant performed all skinfold

Table 2. Repetition performance during the sandbag resistance exercise protocol.*

	Set 1	Set 2	Set 3	Total
Front squat	12.8 ± 1.8	11.3 ± 2.1†	8.5 ± 3.4†‡	32.5 ± 6.0
Clean	9.4 ± 2.2	9.3 ± 2.0	7.8 ± 2.6	26.4 ± 6.0
Bear hug squat	12.4 ± 2.3	9.8 ± 1.9†	7.6 ± 2.8†	29.8 ± 5.2
Rotational DL	10.5 ± 2.9	8.5 ± 1.9†	7.0 ± 2.9†‡	26.0 ± 6.7
Lunge with rotation	8.8 ± 2.6	8.0 ± 1.9	7.8 ± 1.3	24.5 ± 4.3
Lateral drag	11.9 ± 1.6	11.6 ± 1.5	9.9 ± 1.6†‡	33.4 ± 4.0
Overhead press	15.3 ± 2.6	12.3 ± 4.1	11.9 ± 5.4	39.9 ± 8.2
Shouldering	8.9 ± 1.1	7.4 ± 2.0†	8.8 ± 1.7	25.0 ± 3.2

*DL = deadlift.
†$p \leq 0.05$ compared with set 1.
‡$p \leq 0.05$ compared with set 2.

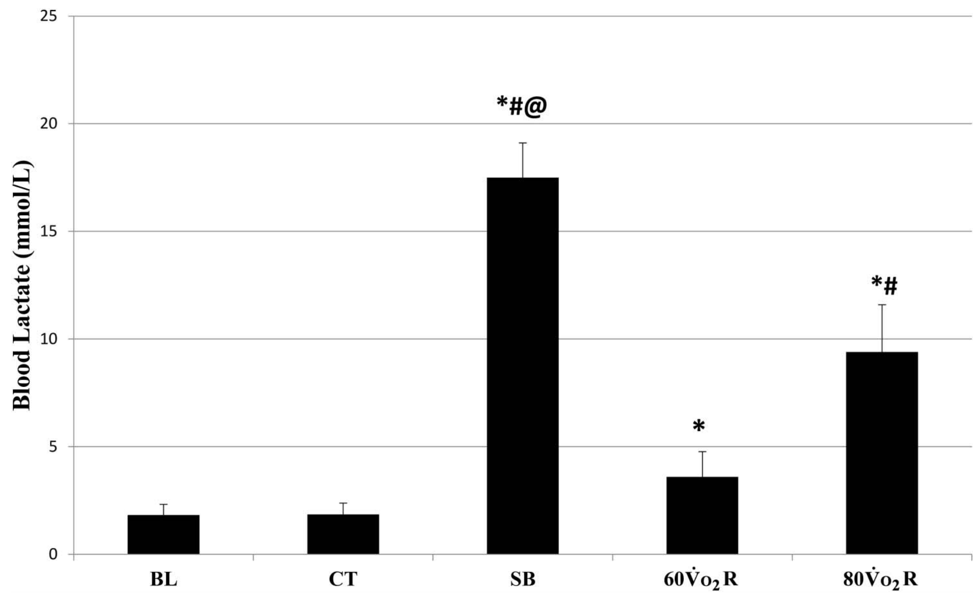

Figure 1. Blood lactate responses. BL = baseline; CT = post control protocol; SB = post SB resistance exercise protocol; $60\dot{V}O_2R$ = post running protocol at 60% of $\dot{V}O_2$peak; $80\dot{V}O_2R$ = post running protocol at 80% of $\dot{V}O_2$peak; *$p \leq 0.05$ from BL and CT; #$p \leq 0.05$ compared with $60\dot{V}O_2R$; @$p \leq 0.05$ compared with $80\dot{V}O_2R$.

assessments. This study was approved by the College of New Jersey and each subject subsequently signed an informed consent document before participation. No subject had any physiological or orthopedic limitations that could have affected exercise performance as determined by completion of a health history questionnaire.

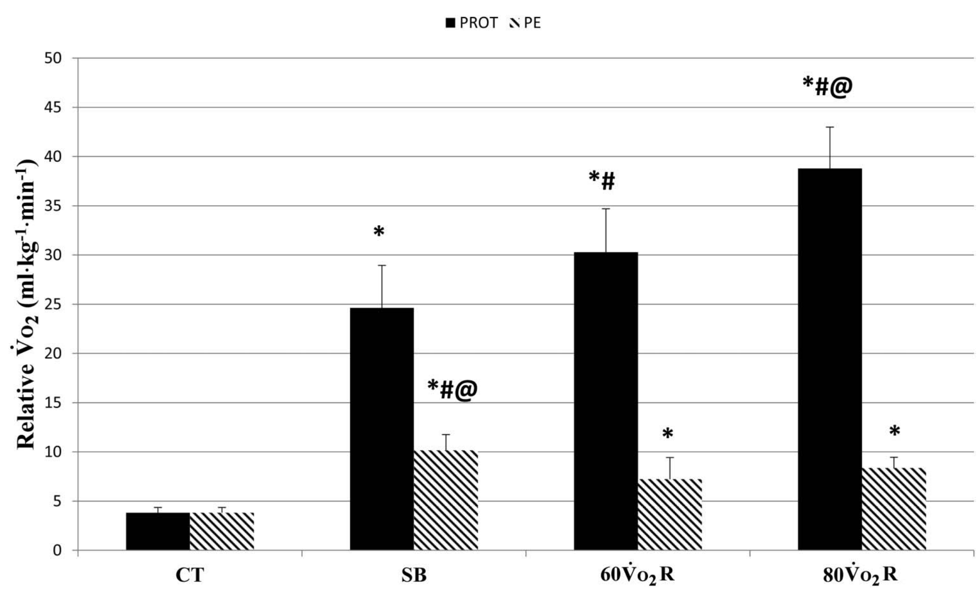

Figure 2. Mean oxygen consumption ($\dot{V}O_2$) responses. CT = control protocol; SB = SB resistance exercise protocol; $60\dot{V}O_2R$ = running protocol at 60% of $\dot{V}O_2$peak; $80\dot{V}O_2R$ = running protocol at 80% of $\dot{V}O_2$peak; PROT = mean $\dot{V}O_2$ during each protocol; PE = mean $\dot{V}O_2$ during the 30-minute postexercise period; *$p \leq 0.05$ from CT; #$p \leq 0.05$ compared with SB; @$p \leq 0.05$ compared with $60\dot{V}O_2R$.

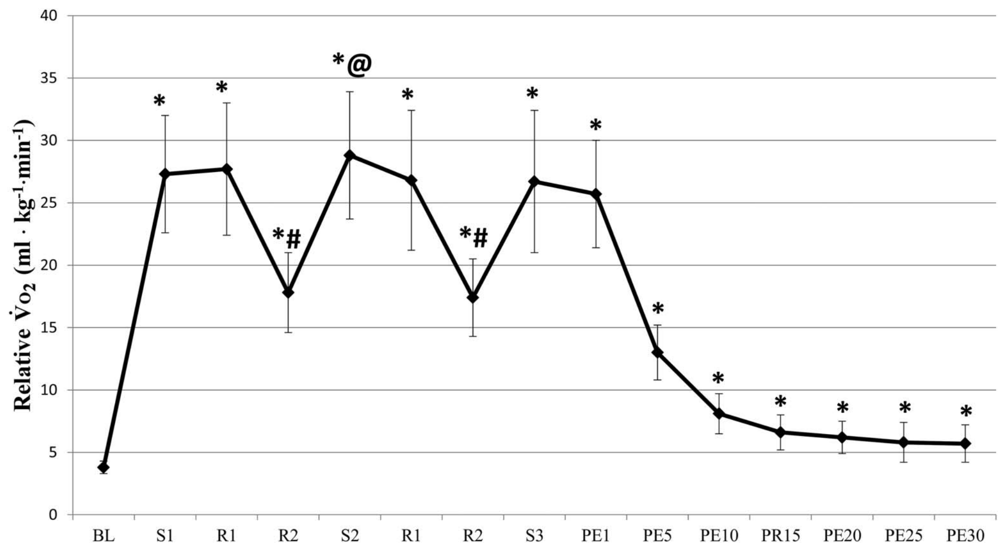

Figure 3. Mean oxygen consumption ($\dot{V}O_2$) responses during the SB protocol. S1 = first set; S2 = second set; S3 = third set; R1 = first minute of rest after set; R2 = second minute of rest after set; PE = postexercise; *$p \leq 0.05$ from baseline; #$p \leq 0.05$ compared with S1 and R1 and S2 and R1; @$p \leq 0.05$ compared with all exercise and PE values.

Procedures

Peak Aerobic Capacity Testing. All subjects reported to the laboratory for maximal aerobic capacity testing. Subjects refrained from exercise for at least 24 hours before each testing session. $\dot{V}O_2$peak was assessed with a progressive, multistage ramp protocol on a treadmill using a metabolic data collection system (MedGraphics ULTIMA Metabolic System; MedGraphics Corporation, Saint Paul, MN, USA). It consisted of 2-minute stages at a speed of 6.0 mph with increments in percent grade of 2.5% per stage. All subjects were verbally encouraged to continue exercise until volitional exhaustion. Breath-by-breath $\dot{V}O_2$ data were obtained and $\dot{V}O_2$peak was determined by recording the highest measure. Gas analyzers were calibrated before each trial using gases and guidelines provided by the manufacturer (MedGraphics Corporation).

Running Test. Approximately 48 hours after the $\dot{V}O_2$peak test, subjects performed a flat treadmill running test (0% grade) to establish velocities for the running protocols. It consisted of 2-minute stages (starting at 5.0 mph) with increments in velocity of 0.5 mph each stage (after a general warm-up of walking at 3.5 mph) and was terminated when subjects could no longer volitionally continue or achieve at least 90–95% of their $\dot{V}O_2$. All subjects were verbally encouraged to volitionally continue or achieve at least 90–95% of $\dot{V}O_2$peak. $\dot{V}O_2$ was obtained for each breath. Gas analyzers were calibrated before each trial using gases and guidelines provided by manufacturer (MedGraphics Corporation).

Experimental Protocols. After baseline (BL) testing, each subject reported to the Human Performance Laboratory (HPL) at a standard time of day per subject on 4 occasions (in random sequence) separated by 48–72 hours and at least 2 hours postprandial. On arrival, subjects were weighed, fitted with a mask, and connected to the metabolic system after calibration with known gas levels (MedGraphics ULTIMA Metabolic System, MedGraphics Corporation), fitted with a Polar HR monitor (Polar Electro, Inc., Woodbury, NY, USA), provided a resting blood sample through a finger stick for determination of blood lactate, and sat quietly for 10 minutes for determination of pre-exercise resting $\dot{V}O_2$ and HR. Baseline $\dot{V}O_2$ data were obtained after the 10-minute resting period and recorded (and averaged) over a 3-minute period. During the familiarization period, $\dot{V}O_2$ data were collected on 2 occasions to determine test-retest reliability. Reliability was shown to be high for the metabolic measurements ($r = 0.90$).

In random sequence, subjects completed 1 of 4 protocols: (a) an SB RE protocol; (b) treadmill running at 60% of $\dot{V}O_2$ reserve (60$\dot{V}O_2$R); (c) treadmill running at 80% of $\dot{V}O_2$R (80$\dot{V}O_2$R); or (d) a nonexercise quiet sitting CT protocol. For the CT protocol, subjects remained seated for 46 minutes to match the duration of the exercise protocols (i.e., 16 minutes of exercise plus 30 minutes PE). Oxygen consumption and HR were measured throughout. Breath-by-breath relative $\dot{V}O_2$, respiratory exchange ratio (RER), minute ventilation (V_E), and HR data were collected and averaged for the 16- and 30-minute periods, respectively.

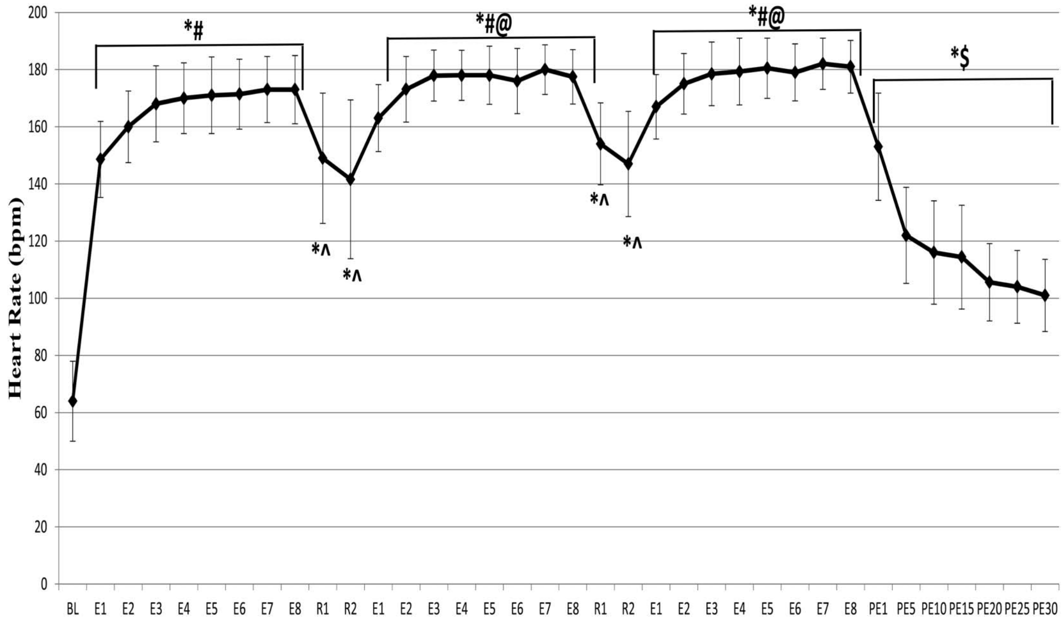

Figure 4. Heart rate (HR) responses during the SB protocol. E = exercise number; R1 = first minute of rest after set; R2 = second minute of rest after set; PE = postexercise; *$p \leq 0.05$ from baseline (BL); #$p \leq 0.05$ from E1 to E8; @$p \leq 0.05$ compared with all exercises in set 1; ^$p \leq 0.05$ compared with all exercise values; \$$p \leq 0.05$ from PE1 to PE30.

For the exercise protocols, subjects reported to the HPL at a standardized time of day per subject at least 2 hours postprandial. On arrival, each subject was encouraged to drink water ad libitum to prehydrate and was fitted with a respiratory mask, Polar HR monitor, connected to the metabolic system, and sat quietly for 10 minutes for pre-exercise HR and $\dot{V}O_2$ measurements. Subjects subsequently performed a standard 5-minute warm-up consisting of light stretching and 5 minutes of treadmill walking at 4.0 mph.

The SB protocol was 16 minutes in duration and consisted of 3 circuits of 8 SB exercises (front squat, clean, bear hug squat, rotational deadlift [DL], rotational reverse lunge, lateral drag from a push-up position, shoulder-to-shoulder press, and shouldering from the floor) performed at a fast cadence (for as many repetitions as possible) for 20 seconds followed by a 10-second rest interval (RI) before beginning the next exercise (42). Two minutes of rest was allowed after each circuit. Each subject used a 48-kg SB for the first 4 exercises, and 11- or 20-kg SBs for the final 4 exercises (11 kg for the lateral drag and 20 kg for the remaining 3 exercises). The SBs had 5 handles for ease of gripping (Ultimate Sandbags; DVRT Ultimate Sandbag Fitness, Scottsdale, AZ, USA). Subjects were verbally encouraged throughout to maximize repetition performance. Proper exercise technique was used and only those repetitions that met the established criteria were counted. Total numbers of repetitions were counted and recorded, HR, ratings of perceived exertion (RPEs), and metabolic data ($\dot{V}O_2$, EE, RER, and V_E) were collected. Subjects sat quietly for an additional 30 minutes to quantify the PE response.

The treadmill running protocols were performed at 0% grade and velocities corresponding to 60 and 80% of $\dot{V}O_2R$ (determined by the flat running test), respectively, for an equal amount of time of 16 minutes to the SB protocol. Velocity was decreased as needed to target the respective $\dot{V}O_2$ as the protocol progressed. Breath-by-breath $\dot{V}O_2$ and HR were recorded throughout each protocol and for 30 minutes PE.

Metabolic and Cardiorespiratory Measurements. Heart rate, absolute $\dot{V}O_2$, relative $\dot{V}O_2$, RER, and V_E data were recorded during each protocol. Individual breath-by-breath data points for all metabolic variables were averaged for the entire circuit and for each minute of rest in between sets for the SB protocol and averaged for the entire exercise and 5-minute PE periods during the running protocols. The time corresponding to the initiation of each set, the time of the completion of each set, and the RI length between sets were precisely recorded and used subsequently for determination of each phase of the protocols. Heart rate was measured after each set of each exercise and RI during the SB protocol and each minute during the running protocols. Data were averaged for the entire protocol and for each 5-minute interval PE. Gross EE in kcals per min for each protocol was estimated by multiplying absolute $\dot{V}O_2$ $(L\cdot min^{-1})$

Table 3. Energy expenditure responses.*

	CT	SB	$60\dot{V}O_2R$	$80\dot{V}O_2R$
EE ($kcal \cdot min^{-1}$)				
Exercise	1.58 ± 0.2	10.61 ± 1.7†	12.82 ± 1.9†‡	16.56 ± 1.6†‡§
PE	1.60 ± 0.2	4.32 ± 0.7†	2.90 ± 1.1†‡	3.56 ± 0.5†‡
EE (kcals)				
Exercise	25.3 ± 3.6	169.8 ± 27.1†	205.1 ± 30.3†‡	265.0 ± 26.2†‡§
PE	47.4 ± 6.7	129.6 ± 22.4†	87.0 ± 32.8†‡	106.8 ± 14.3†‡
Total EE	72.7 ± 10.3	299.4 ± 45.7†	292.1 ± 52.1†	371.9 ± 37.5†‡§
EE (kJ)				
Aerobic exercise	105.9 ± 15.0	709.6 ± 113.1†	859.8 ± 127.2†‡	1,107.3 ± 109.3†‡§
PE	198.6 ± 28.0	542.2 ± 93.5†	375.7 ± 116.1†‡	435.6 ± 54.4†‡
Anaerobic	0.0 ± 0.0	85.6 ± 15.5†	9.3 ± 5.8†‡	40.4 ± 8.8†‡§
Total EE	304.5 ± 43.0	1,337.3 ± 197.0†	1,244.8 ± 200.4†	1,583.3 ± 156.7†‡§

*CT = control protocol; SB = post SB resistance exercise protocol; $60\dot{V}O_2R$ = post running protocol at 60% of $\dot{V}O_2$peak; $80\dot{V}O_2R$ = post running protocol at 80% of $\dot{V}O_2$peak; EE = energy expenditure; PE = postexercise.
†$p \leq 0.05$ compared with CT.
‡$p \leq 0.05$ compared with SB.
§$p \leq 0.05$ compared with $60\dot{V}O_2R$.

by 5.05 $kcal \cdot L^{-1}$ when all RER values were ≥1.0. For RER values during exercise or rest ranging from 0.85 to 0.98, $\dot{V}O_2$ ($L \cdot min^{-1}$) was multiplied by 4.86–4.98 $kcal \cdot L^{-1}$, respectively. Pre-exercise (BL) EE was estimated by multiplying absolute $\dot{V}O_2$ ($L \cdot min^{-1}$) by 4.80 $kcal \cdot L^{-1}$ to match BL RER. In addition, EE was also expressed in kJ. Aerobic EE was estimated at 1 LO_2 = 21.1 kJ (38) for RER values ≥1.00 or 1 L O_2 = 20.1–20.8 kJ for resting or PE data where RER values were between 0.86 and 0.95. Anaerobic EE for the entire protocol was estimated from blood lactate concentrations using the following equation (8,38): EE (kJ) = Δ[LA] × body mass (kg) × 3 ml O_2. Data were converted to L O_2 and multiplied by 21.1 kJ. Total EE was calculated by summing aerobic EE, anaerobic EE, and PE EE. Energy expenditure per minute was calculated by dividing total EE by the protocol (exercise and PE) duration.

Blood Lactate and Ratings of Perceived Exertion. Whole blood lactate was assessed in duplicate using a portable lactate analyzer (Lactate Plus Meter; Nova Biomedical, Waltham, MA, USA) taken at the fingertip using a sterile lancet. Blood lactate samples were taken at rest and immediately after each exercise/CT protocol. Reliability of this analyzer has been shown to be high (19). After each set of SB exercise, RPE were obtained using a 10-point (0–10) scale. After each min of running RPEs were obtained using a Borg 15-point (6–20) scale. Each RPE scale was used to examine time effects within each protocol and not used to compare the running protocols with the SB protocol.

Statistical Analyses

Descriptive statistics (mean ± *SD*) were calculated for all dependent variables. A 2-way (time point × protocol) analysis of variance with repeated measures was used to analyze within-subject performance, $\dot{V}O_2$, RPE, HR, and lactate data. Subsequent Tukey's post hoc tests were used to determine differences when significant main effects were obtained. Partial eta-square (η^2) effect sizes were determined for treatment effects and interpreted using the following criteria: 0.01 = small; 0.06 = medium; and 0.13 = large. For all statistical tests, a probability level of $p \leq 0.05$ denoted statistical significance.

Results

Exercise Performance

Treadmill running velocities were significantly reduced ($p < 0.001$) by 12 and 18%, respectively, for $60\dot{V}O_2R$ and $80\dot{V}O_2R$, from the start to the completion of each protocol to maintain the targeted $\dot{V}O_2$ values. Treadmill running velocities were reduced from 2.5 ± 0.2 (range = 2.2–2.7) and 3.3 ± 0.5 (range = 2.7–3.6) $m \cdot s^{-1}$ for $60\dot{V}O_2R$ and $80\dot{V}O_2R$, respectively, to 2.2 ± 0.3 (range = 1.8–2.4) and 2.7 ± 0.5 (range = 2.1–3.4) $m \cdot s^{-1}$ from beginning to the end of each running protocol. Repetition performance data are presented in Table 2. A significant time effect ($p < 0.001$; $\eta^2 = 0.50$) was observed where repetition performance declined from set 1 to set 3 for most exercises. Most notable reductions were seen in the front squat, bear hug squat, rotational DL, and lateral drag exercises.

Blood Lactate

Blood lactate results are presented in Figure 1. A significant time effect was observed ($p < 0.001$; $\eta^2 = 0.96$) where blood lactate concentrations were significantly elevated immediately PE after the SB, $60\dot{V}O_2R$, and $80\dot{V}O_2R$ protocols.

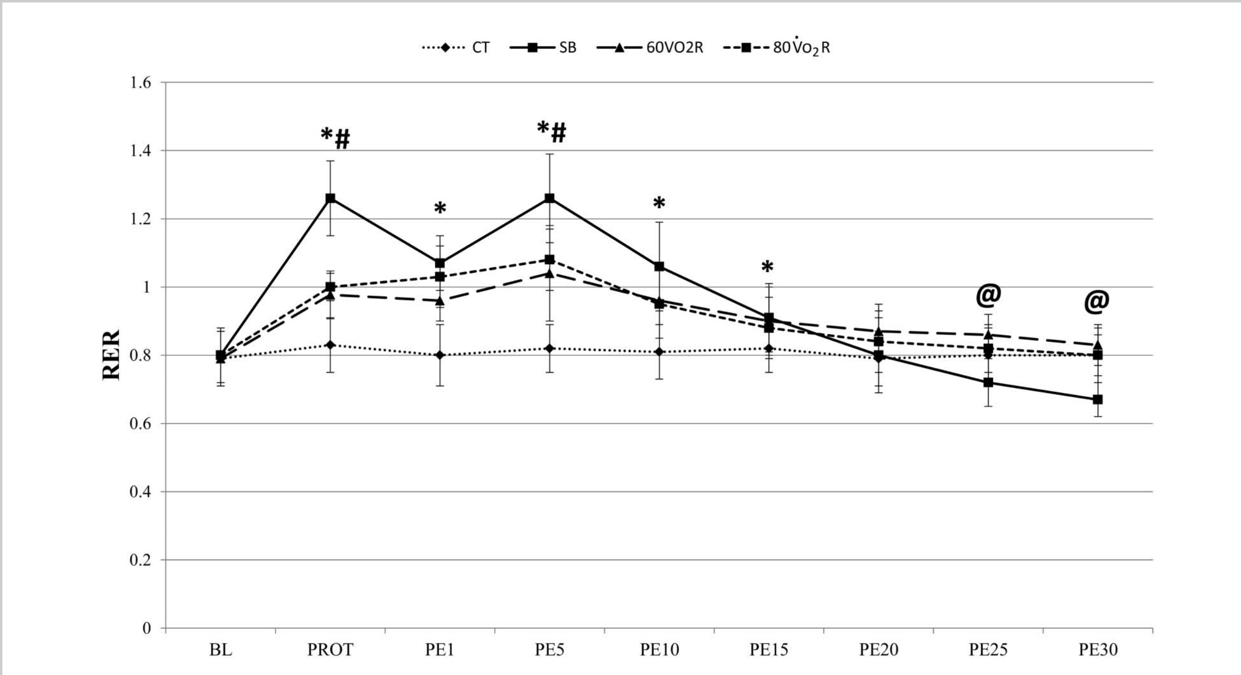

Figure 5. Respiratory exchange ratio responses during the SB, $60\dot{V}O_2R$, $80\dot{V}O_2R$, and CT protocols. SB = post SB resistance exercise protocol; $60\dot{V}O_2R$ = post running protocol at 60% of $\dot{V}O_2$peak; $80\dot{V}O_2R$ = post running protocol at 80% of $\dot{V}O_2$peak; CT = control protocol; PROT = exercise protocol; PE = postexercise; *$p \leq 0.05$ from BL and CT; #$p \leq 0.05$ in SB compared with $60\dot{V}O_2R$ and $80\dot{V}O_2R$; @$p \leq 0.05$ in SB compared with CT, $60\dot{V}O_2R$, and $80\dot{V}O_2R$.

In addition, a significant interaction was observed ($p < 0.001$) where blood lactate concentrations after the SB protocol were significantly higher than $60\dot{V}O_2R$ and $80\dot{V}O_2R$. In addition, blood lactate concentration after the $80\dot{V}O_2R$ protocol was significantly higher than $60\dot{V}O_2R$.

Oxygen Consumption

Mean $\dot{V}O_2$ results are presented in Figure 2. A significant protocol effect was observed ($p < 0.001$; $\eta^2 = 0.98$) where the $80\dot{V}O_2R$ protocol was significantly higher than all protocols. The $60\dot{V}O_2R$ protocol was significantly higher than SB and CT and SB was significantly higher than CT. A significant PE effect was observed ($p < 0.001$; $\eta^2 = 0.86$) where the SB protocol was significantly higher than all protocols. No significant difference was observed between $60\dot{V}O_2R$ and $80\dot{V}O_2R$ ($p = 0.09$); however, both of these protocols were significantly higher than CT.

Mean $\dot{V}O_2$ results for the SB protocol are presented in Figure 3. Significant time effects were observed from beginning to completion of the protocol ($p < 0.001$; $\eta^2 = 0.94$). All exercise and PE values were significantly higher than BL. $\dot{V}O_2$ was significantly highest during each set (S1, S2, and S3) and first min of rest (R1 and PE1) compared with R2. The highest mean value was seen during S2 ($p = 0.001$). All PE values were significantly higher than BL. $\dot{V}O_2$ during PE significantly decreased from PE1 to PE20, whereas no significant further decreases were observed between PE20 and PE30. Peak $\dot{V}O_2$ values obtained during SB (38.7 ± 7.5 $ml \cdot kg^{-1} \cdot min^{-1}$) averaged ~83% of $\dot{V}O_2$peak, whereas mean $\dot{V}O_2$ values obtained during the SB protocol (24.6 ± 4.3 $ml \cdot kg^{-1} \cdot min^{-1}$) averaged ~53% of $\dot{V}O_2$peak.

Heart Rate

Heart rate values were significantly elevated during all exercise and PE trials ($p < 0.001$; $\eta^2 = 0.97$). Compared with CT (65.9 ± 14.0 $b \cdot min^{-1}$), mean exercise HR values were significantly higher during the SB (169.7 ± 11.2 $b \cdot min^{-1}$), $60\dot{V}O_2R$ (151.8 ± 9.8 $b \cdot min^{-1}$), and $80\dot{V}O_2R$ (170.5 ± 13.5 $b \cdot min^{-1}$) protocols. No significant differences were observed between SB and $80\dot{V}O_2R$, although both protocols yielded significantly higher HR values than $60\dot{V}O_2R$. Similar results were observed for peak HR (SB = 183.0 ± 8.7 $b \cdot min^{-1}$; $60\dot{V}O_2R$ = 160.4 ± 11.8 $b \cdot min^{-1}$; and $80\dot{V}O_2R$ = 177.4 ± 14.4 $b \cdot min^{-1}$). Mean HR during the 30-minute PE period in SB (116.7 ± 14.1 $b \cdot min^{-1}$) was significantly higher than $60\dot{V}O_2R$ (87.6 ± 13.1 $b \cdot min^{-1}$) and $80\dot{V}O_2R$ (101.5 ± 9.5 $b \cdot min^{-1}$) and mean HR in $80\dot{V}O_2R$ was significantly higher than $60\dot{V}O_2R$.

The acute HR responses to the SB protocol are presented in Figure 4. A significant time effect was observed ($p < 0.001$; $\eta^2 = 0.94$). All exercise and PE values were significantly higher than BL. Heart rate values significantly

Table 4. Ratings of perceived exertion during the SB protocol.*

	Set 1	Set 2	Set 3	Mean
Front squat	5.75 ± 1.7	7.88 ± 1.2†	8.38 ± 1.2†‡	7.33 ± 1.0
Clean	6.00 ± 1.4	7.50 ± 1.2§	8.75 ± 1.4†‡	7.42 ± 1.1
Bear hug squat	7.00 ± 1.5	8.38 ± 1.2	9.38 ± 1.1†‡	8.25 ± 1.0¶
Rotational DL	7.00 ± 1.2	8.25 ± 1.1†	9.38 ± 0.7†‡	8.21 ± 0.9¶
Lunge with rotation	6.71 ± 1.0	8.13 ± 1.0†	9.13 ± 1.1†‖	8.06 ± 0.8
Lateral drag	6.38 ± 1.1	7.88 ± 1.1†	9.00 ± 1.1†‡	7.75 ± 0.9
OH press	6.88 ± 1.1	8.25 ± 1.2†	9.13 ± 1.0†‡	8.08 ± 1.0¶
Shouldering	7.13 ± 1.0	8.50 ± 1.3†	9.25 ± 1.0†‡	8.29 ± 1.0¶

*SB = sandbag; DL = deadlift; OH = overhead.
†$p \leq 0.05$ compared with set 1.
‡$p \leq 0.05$ compared with set 2.
§$p = 0.06$ compared with set 1.
‖$p = 0.06$ compared with set 2.
¶$p \leq 0.05$ compared with front squat and clean.

increased from the first exercise (E1) to completion of the last exercise (E8) for each of the 3 sets. Heart rate values seen during the RIs (R1 and R2) were significantly lower than all exercise values with the exception of the first exercise of the first set. Heart rate values seen during the first set for each exercise were significantly lower than the HR values of corresponding exercise seen during sets 2 and 3. No significant differences were observed for individual exercise HRs between sets 2 and 3. Heart rate decreased significantly from PE1 to PE10, from PE15 to PE 20, and from PE25 to PE30.

Energy Expenditure

Energy expenditure data are presented in Table 3. Significant exercise (kcals·min^{-1}) protocol ($p < 0.001$; $\eta^2 = 0.98$) and PE ($p < 0.001$; $\eta^2 = 0.80$) effects were observed. All exercise values were significantly higher than CT. Acute EE during 80$\dot{V}O_2$R was significantly higher than 60$\dot{V}O_2$R and SB and the EE response during 60$\dot{V}O_2$R was significantly higher than SB. During the PE period, EE was significantly higher in SB than in 60$\dot{V}O_2$R and 80$\dot{V}O_2$R whereas no differences in EE were observed between 60$\dot{V}O_2$R and 80$\dot{V}O_2$R. All PE exercise EE values were significantly higher than those of CT.

Significant running EE (kcals and kJ) protocol effects were observed during exercise ($p < 0.001$; $\eta^2 = 0.97$), PE ($p < 0.001$; $\eta^2 = 0.86$), and total kcals of EE combined ($p < 0.001$; $\eta^2 = 0.96$). During exercise, all EE values were significantly higher than those of CT. Acute EE during 80$\dot{V}O_2$R was significantly higher than during 60$\dot{V}O_2$R and SB and the EE response during 60$\dot{V}O_2$R was significantly higher than during SB. During the PE period, EE was significantly higher in SB than in 60$\dot{V}O_2$R and 80$\dot{V}O_2$R, whereas no differences in EE were observed between 60$\dot{V}O_2$R and 80$\dot{V}O_2$R. All PE exercise EE values were significantly higher than those of CT. Total EE was significantly higher in 80$\dot{V}O_2$R compared with 60$\dot{V}O_2$R and SB, whereas no significant differences were observed between 60$\dot{V}O_2$R and SB. A significant exercise protocol effect ($p < 0.001$; $\eta^2 = 0.92$) was observed for anaerobic EE (kJ) where EE in SB was significantly higher than in 60$\dot{V}O_2$R and 80$\dot{V}O_2$R and EE in 80$\dot{V}O_2$R was significantly higher than in 60$\dot{V}O_2$R.

Ventilation

Significant mean ($p < 0.001$; $\eta^2 = 0.96$) and peak ($p < 0.001$; $\eta^2 = 0.97$) exercise protocol and mean PE ($p < 0.001$; $\eta^2 = 0.88$) responses were observed. Mean exercise V_E values for SB (86.7 ± 11.8 L·min^{-1}), 60$\dot{V}O_2$R (65.3 ± 9.2 L·min^{-1}), and 80$\dot{V}O_2$R (92.0 ± 16.0 L·min^{-1}) were significantly higher than those for CT (8.9 ± 1.2 L·min^{-1}). In addition, peak exercise V_E values for SB (102.7 ± 14.1 L·min^{-1}), 60$\dot{V}O_2$R (73.3 ± 9.7 L·min^{-1}), and 80$\dot{V}O_2$R (101.2 ± 14.1 L·min^{-1}) were significantly higher than those for CT (9.6 ± 1.3 L·min^{-1}). Mean and peak V_E values during SB and 80$\dot{V}O_2$R were significantly higher than during 60$\dot{V}O_2$R, whereas no significant difference was observed between SB and 80$\dot{V}O_2$R ($p = 0.34$ and 0.58, respectively). Mean PE V_E values for SB (35.4 ± 8.4 L·min^{-1}), 60$\dot{V}O_2$R (17.1 ± 4.4 L·min^{-1}), and 80$\dot{V}O_2$R (21.6 ± 3.5 L·min^{-1}) were significantly higher than CT (8.8 ± 1.2 L·min^{-1}). Mean PE V_E values after SB were significantly higher than after 60$\dot{V}O_2$R and 80$\dot{V}O_2$R and PE V_E values in 80$\dot{V}O_2$R were significantly higher than in 60$\dot{V}O_2$R.

Respiratory Exchange Ratio

Acute RER responses are shown in Figure 5. A significant time and protocol effect was observed ($p < 0.001$; $\eta^2 = 0.85$). Respiratory exchange ratio values observed during SB, 60$\dot{V}O_2$R, and 80$\dot{V}O_2$R were significantly higher than those of CT (and from BL) during exercise and through 15 minutes PE. During exercise and at PE5, RER values seen during SB were significantly larger than the values seen during 60$\dot{V}O_2$R and 80$\dot{V}O_2$R. No significant differences were observed between 60$\dot{V}O_2$R and 80$\dot{V}O_2$R during exercise ($p = 0.58$) or PE5 ($p = 0.21$). Respiratory exchange ratio values seen between PE10 and PE20 did not significantly differ between exercise conditions. However, RER values obtained during SB at PE25 and PE30 were significantly lower than values obtained during CT, 60$\dot{V}O_2$R, and 80$\dot{V}O_2$R (with no significant differences observed between 60$\dot{V}O_2$R and 80$\dot{V}O_2$R).

Ratings of Perceived Exertion

Data on RPE for the SB protocol are presented in Table 4. A significant time effect was observed ($p < 0.001$; $\eta^2 = 0.65$). Values of RPE significantly increased from set 1 to set 3 in all exercises and increased significantly from set 1 to set 2 in all

but 2 exercises (clean and bear hug squat). Significant increases in RPE were observed from set 2 to set 3 in all but 1 of the exercises (lunge with rotation). Highest mean RPE values were seen for the bear hug squat, rotational DL, overhead press, and shouldering exercises. The mean RPE for the entire SB protocol was 7.92 ± 1.0. For the running protocols (on a 15-point 6 to 20 Borg RPE scale), mean RPE for the 80$\dot{V}O_2$R protocol (12.9 ± 1.1) was significantly higher ($p = 0.004$; $\eta^2 = 0.71$) than that of the 60$\dot{V}O_2$R protocol (10.1 ± 1.4).

Discussion

The salient finding from this study was that the SB protocol elicited a substantial cardiorespiratory and metabolic stimulus. It was hypothesized that the SB protocol would elicit potent cardiorespiratory and metabolic responses comparable with running; however, it would provide augmented EE during the PE period. Although mean $\dot{V}O_2$ and EE seen during the SB protocol was significantly lower than those seen during the 60$\dot{V}O_2$R and 80$\dot{V}O_2$R protocols, mean $\dot{V}O_2$ and EE were significantly higher after the SB protocol compared with 60$\dot{V}O_2$R and 80$\dot{V}O_2$R during the 30-minute PE period. Total EE (exercise and PE) was significantly higher in 80$\dot{V}O_2$R compared with 60$\dot{V}O_2$R and SB; however, the SB protocol produced similar total EE as 60$\dot{V}O_2$R. Mean HR during SB protocol was significantly higher than that during 60$\dot{V}O_2$R but not different from 80$\dot{V}O_2$R. Compared with 60$\dot{V}O_2$R and 80$\dot{V}O_2$R, RER was significantly higher during the SB protocol and through 5 minutes PE, but was significantly lower at 25–30 minutes PE. Ratings of perceived exertion observed during the SB protocol increased significantly with each set yielding high mean protocol RPE values comparable with other circuit RE protocols (41). These data show that performing SB RE with Tabata intervals poses a significant cardiorespiratory stress similar to running at 80% of $\dot{V}O_2$R and provides superior EE during the PE period. However, continuous running protocols seem to maximize EE observed during exercise.

The blood lactate response seen during the SB protocol was 4.9 times greater than 60$\dot{V}O_2$R and 1.9 times greater than 80$\dot{V}O_2$R. This was not surprising considering the intense anaerobic nature of RE and subsequent greater recruitment of fast-twitch muscle fibers. Previous studies have shown relatively high lactate responses during circuit RE (1,13,41) with the responses lower than the lactate concentrations (~17.5 mmol·L^{-1}) observed in this study. Wright et al. (45) reported blood lactate concentrations of up to 13.4 mmol·L^{-1} during a 7-minute SB conditioning test in wrestlers. The lactate response observed during the SB protocol was greater than another study examining a protocol consisting of KB swings using Tabata intervals (11) and previous studies from our laboratory examining traditional RE after aerobic exercise (36) and battling rope protocols (34,36). Although differences in protocol design, subject physical characteristics, and technology of lactate assessment contribute significantly to the lactate responses seen during RE, a critical element to the present SB protocol was the use of Tabata intervals (42). Other studies have examined Tabata intervals during RE primarily using KB swings (11,44) and other KB exercises (44) and reported lower blood lactate concentrations (11) than this study. Our protocol emphasized performance with as many repetitions as possible per set (as opposed to a standard number) and very short 10-second RIs (with the exception of the 2-minute intercircuit RIs). The 20-second set durations coupled with only 10 seconds of rest during each circuit (and use of several large muscle-mass exercises with heavy SBs) likely accounted for the large lactate response and indicates that an SB RE protocol consisting of Tabata intervals (42) provides a substantial anaerobic stimulus to trainees.

The SB protocol yielded a mean EE of ~11 kcals·min^{-1}, and ~795 kJ in 16 minutes, slightly higher EE values than a previous study (~9.5 kcals·min^{-1}) examining a KB protocol using Tabata intervals (44). However, these mean $\dot{V}O_2$ and EE data were significantly lower than the running protocols. Mean EE was 17 and 36% lower during the SB protocol compared with 60$\dot{V}O_2$R and 80$\dot{V}O_2$R, respectively, encompassing a range seen in other studies comparing aerobic exercise to KB protocols (20). This confirms other reports demonstrating the superiority of continuous aerobic exercise in augmenting the acute $\dot{V}O_2$ and EE responses to exercise (2,9,16,20). Bloomer (2) compared cycling at 70% of $\dot{V}O_2$ max to traditional RE (squats; 60–70% of 1RM with 90–120 seconds RIs) for 30 minutes and reported a 39% difference in EE of 442 and 269 kcal, respectively. Elliot et al. (9) reported EE of ~432, 362, and 248 kcals during 40 minutes of cycling (80% of HRmax), circuit RE (4 sets of 15 repetitions with 50% of 1RM), and traditional RE (3 sets of 3–8 repetitions with 80–90% of 1RM). Hulsey et al. (20) reported EE of ~12.5 and 17.1 kcals·min^{-1}, respectively, for a 10-minute KB swing workout (35 seconds of work followed by 25 seconds of rest) compared with a 10-minute treadmill run at a matched RPE.

Although the gap in EE between aerobic and RE was narrowed in this study, the continuity of aerobic exercise seems to be a key variable to maximizing the acute EE responses. Our data (Figure 3) show that relative $\dot{V}O_2$ was mostly maintained during RE and the 1st minute of rest; however, it declined significantly during the 2nd minute of rest. Peak $\dot{V}O_2$ values obtained during the SB protocol (~38.7 ml·kg^{-1}·min^{-1}) averaged ~83% of $\dot{V}O_2$peak, whereas mean $\dot{V}O_2$ values (~24.6 ml·kg^{-1}·min^{-1}) averaged ~53% of $\dot{V}O_2$peak. These mean relative $\dot{V}O_2$ values were less than a KB swing workout (~34.1 ml·kg^{-1}·min^{-1}) with no major RI between rounds (20), but higher than a KB protocol (~22.6 ml·kg^{-1}·min^{-1}) consisting of Tabata intervals with no major RI between rounds (44). It seems that the $\dot{V}O_2$ reductions seen during extended RIs during RE may negatively impact total EE. However, when total EE was calculated to include anaerobic contributions and the PE

response, no significant differences in EE were seen between the SB and 60$\dot{V}O_2R$ protocols (despite slightly higher values observed during the SB protocol), thereby indicating that running beyond 60% of $\dot{V}O_2$peak was needed to augment EE compared with the SB protocol used in this study.

A noteworthy finding was that $\dot{V}O_2$ and EE after the SB protocol was significantly greater than PE 60$\dot{V}O_2R$ and PE 80$\dot{V}O_2R$. Energy expenditure after the SB protocol was 33 and 17.6% greater than 60$\dot{V}O_2R$ and 80$\dot{V}O_2R$, respectively, during the 30-minute PE period. In addition, SB RER values at 25 and 30 minutes PE were significantly lower than CT, 60$\dot{V}O_2R$, and 80$\dot{V}O_2R$, indicative of greater fat oxidation toward the latter end of the recovery period. These data indicate that the intense anaerobic nature of this SB protocol may have had its largest impact during the PE period. These data support previous findings indicating that the most substantial PE response will be elicited by an anaerobic stress with a high degree of perturbation (3). The rise in PE $\dot{V}O_2$ has been attributed to elevated blood lactate levels, reduced pH, glycogen resynthesis, elevated temperature, oxygen replacement in muscle and circulation, ATP-PC resynthesis, sodium-potassium pump activity, cardiovascular demand, increased V_E, triglyceride-fatty acid cycling, tissue damage and PE elevations in protein synthesis, elevated sympathetic nervous system activity, and acute hormonal elevations (i.e., catecholamines, cortisol, thyroid hormones, and the superfamily of growth hormones) (3,18,43).

Previous studies have shown that RE elicits a substantial PE response (3,9,27,32), and the response is greater than that of aerobic exercise (5,9,14). The interaction of the RE selection of exercises (and muscle-mass involvement), intensity, volume, and RI length between sets and exercises seems to govern the magnitude of the PE response (9,17,18,29), and the response may be greater with circuit-type protocols. Haltom et al. (18) compared circuit training with 20- or 60-second RI and reported a ~28% greater PE response over 1 hour for the 20-second protocol. Murphy and Schwarzkopf (29) compared traditional RE with circuit training protocol and reported greater PE response after circuit training. Kelleher et al. (22) reported greater EE during the PE period when supersets were used to reduce workout time compared with a traditional set scheme matched for exercise selection, loading, and volume. However, Elliot et al. (9) reported similar EE during the PE period after circuit and traditional RE. It has been suggested that the lack of recovery in between sets of circuit RE increases the PE EE response (7). Our data confirm the findings of augmented PE EE and demonstrate that a time-efficient SB protocol using Tabata intervals elicits a superior PE EE response to treadmill running of up to 80% of $\dot{V}O_2R$; however, further research is warranted examining extended PE periods beyond 30 minutes.

Our results indicated that this SB protocol elicited a substantial rise in mean HR, similar to values observed during the 80$\dot{V}O_2R$ protocol. The mean HR value seen during the SB protocol is higher (2,9,11,44), similar to (10,41), and lower (16,20) than some HR values seen in other studies examining circuit RE or continuous RE protocols, and is lower than mean HR reported during a 7-minute SB throw test (45). This SB protocol yielded a mean HR equivalent to ~86% of HRmax in our subject pool, which is similar to or slightly lower than HR observed during 10–12 minutes of continuous or interval KB swings (10,20), a level capable of eliciting cardiovascular improvements over time (20,26). Considering that other studies examining circuit RT have reported improved cardiorespiratory fitness (4,26,30), it is possible that aerobic fitness improvements may occur using a program such as the one used in this study. McRae et al. (26) examined 4 weeks of circuit training consisting of 8 sets of Tabata intervals performed for one body mass exercise per workout (either burpees, mountain climber, squat and thrusts, or jumping jacks) and reported an 8% increase in $\dot{V}O_2$max, which was similar to improvements seen with 30-minute treadmill running program. Thus, the intense nature of this training structure seems to be a sufficient stimulus to improve cardiorespiratory fitness in addition to increasing muscle strength, power, and endurance (4,26,30).

Mean exercise V_E values for the SB (~87 $L \cdot min^{-1}$) and 80$\dot{V}O_2R$ (~92 $L \cdot min^{-1}$) protocols were significantly higher than those of 60$\dot{V}O_2R$ (~65 $L \cdot min^{-1}$). Several studies examining acute V_E responses to RE have shown values in the range of 18–70 $L \cdot min^{-1}$ (2,5,33,43). Williams and Kraemer (44) reported V_E values ranging from ~40 to 65 $L \cdot min^{-1}$ during a KB protocol consisting of Tabata intervals. The V_E data seen in this study were more comparable with studies examining battling rope protocols (34,35). These data indicate that the SB protocol used in this study elicited a substantial V_E response comparable with running at 80% of $\dot{V}O_2$peak.

A possible limitation of this study was that only a limited number of SBs were available for use (i.e., only 3 weights were used for performance of the 8 exercises). The goal was to study SBs in a way they are commonly used in RT and often facilities may be limited to few SBs of various size. It is likely that the use of lighter or heavier bags per exercise could have influenced the total numbers of repetitions performed and possibly other metabolic or cardiovascular variables. Pilot work from our laboratory indicated that all subjects were comfortably able to tolerate the SB weights per exercise during nonfatigued and partially-fatigued conditions. Given the continuous nature of metabolic training protocols and high levels of fatigue induced, we chose to use an SB mass of ~55% of body mass for the first 4 exercises and ~13–24% of body mass for the last 4 exercises. It is important to note that continuous metabolic programs such as the one used in this study make it difficult to use several pieces of equipment, especially when performed in group settings. In fact, other studies using Tabata intervals or similar quasi-continuous protocols during RE (primarily with KBs) have used either one size KB for men and women (11,20) or a narrow range of sizes (44). However, performing

as many repetitions as possible per exercise increases the metabolic demand despite the absolute or relative level of loading used per exercise. Thus, the results of this study must be viewed within the context of the exercises selected, the masses of SBs used, and the use of Tabata intervals (42).

In summary, to the best of our knowledge, this was the first study to quantify acute metabolic responses to an RE protocol consisting entirely of SB exercises. The SB protocol using Tabata intervals elicited a substantial cardiorespiratory and metabolic stimulus as indicated by high mean HR, RPE, and blood lactate responses. Although the aerobic treadmill running protocols elicited greater mean $\dot{V}O_2$ and EE responses during exercise, the SB protocol elicited a significantly greater EE during the PE period, thereby demonstrating potential advantages for aerobic and anaerobic fitness improvements.

Practical Applications

Strength and conditioning and fitness professionals constantly seek alternative methods to improve health- and skill-related components of fitness. In some instances, time efficiency may be needed. Therefore, programs that combine multiple exercise modalities may serve as an attractive alternative. The use of metabolic programs, or high-intensity interval training, has increased over recent years because of the combined integration of several modalities that can improve several fitness components in a time-efficient manner (4,26,30). The use of SBs in metabolic training programs has also increased because they provide an unstable form of resistance and could be used to mimic many movements seen in sports, daily living, or in tactical occupations. The results of this study demonstrated that the SB RE protocol provided a large cardiorespiratory and metabolic stimulus that could potentially enhance several components of fitness in resistance-trained adults. It also demonstrated that few SBs can be used to design a time-efficient circuit that could serve as an alternative or supplemental form of RT.

Acknowledgments

The authors thank a dedicated group of subjects and laboratory assistants for their participation in this study. Funding was provided by The School of Nursing, Health & Exercise Science Seed Grant at TCNJ.

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