Effects of Rest Interval Length on Acute Battling Rope Exercise Metabolism

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Abstract

Ratamess, NA, Smith, CR, Beller, NA, Kang, J, Faigenbaum, AD, and Bush, JA. Effects of rest interval length on acute battling rope exercise metabolism. *J Strength Cond Res* 29(9): 2375–2387, 2015—The purpose of this study was to quantify and compare the acute metabolic responses to battling rope (BR) exercise using 2 different rest intervals. Twelve men and 10 women (age = 20.8 ± 1.3 years) performed a control protocol and 2 BR exercise protocols on separate days (48–72 hours) in random order while connected to a metabolic system. The BR protocol consisted of 8 sets of 30-second intervals (15 seconds of single-arm waves and 15 seconds of double-arm waves) using either a 1-minute (1RI) or 2-minute (2RI) rest interval length. A metronome was used to standardize repetition number/frequency for each exercise, that is, 15 waves for each arm for single-arm waves and 15 repetitions of double-arm waves. The mean oxygen consumption ($\dot{V}O_2$) values for the entire protocol were significantly higher during the 1RI than 2RI protocol, and values in men were 11.1% (1RI) and 13.5% (2RI) higher than women, respectively, and equated to 52.8 ± 5.5% (men) and 50.0 ± 11.2% (women) of $\dot{V}O_2max$ during 1RI and 40.5 ± 4.5% (men) and 37.7 ± 11.0% (women) of $\dot{V}O_2max$ during 2RI. Energy expenditure values were significantly higher during the 1RI than the 2RI protocol in men (11.93 ± 1.4 vs. 8.78 ± 1.4 $kcal \cdot min^{-1}$) and women (7.69 ± 1.3 vs. 5.04 ± 1.7 $kcal \cdot min^{-1}$) with values in men statistically higher than women. Blood lactate, mean protocol minute ventilation, and heart rate were significantly higher during the 1RI protocol than the 2RI protocol, and these data were significantly higher in men compared with women. These data demonstrate that BR exercise poses a significant cardiovascular and metabolic stimulus with the mean effects augmented with the use of a short rest interval.

Key Words rope training, single-arm waves, double-arm waves, oxygen consumption, $\dot{V}O_2max$

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Introduction

The strength training and conditioning of athletes has grown to include numerous modalities using various implements or objects that provide a unique element of resistance (16). Over the past 20 years, the acute training program variable that has seen the greatest expansion in exercise prescription is the exercise selection (15,17). In addition to traditional use of free weights and machines, exercise prescription has grown to include exercises performed with equipment such as kettle bells, sand bags and heavy bags, kegs, bands/chains, tires, body weight suspension devices, sledge hammers, sleds, thick bars, various strongman implements (i.e., log bars, super yokes, farmer's walk bars, and stones), and ropes (16,18). Although many of these pieces of equipment have been used in training for an extensive number of years, several have resurged in popularity and are commonly included in comprehensive strength training and conditioning programs of athletes.

Rope training has increased in popularity in numerous areas from general health and fitness trainees to professional athletes. Ropes are used for multiple purposes, that is, climbing, pulling, and suspension training. In fact, ropes have been used historically in various settings including physical education classes, gymnastics training, and the training of tactical and combat athletes (4,14,25). However, battling ropes (BRs) are most commonly used for undulations, or wave training, to increase strength, endurance, and provide potent metabolic and cardiovascular responses (1,6,12,21,27). Waves are generated through multiple movement patterns as the ropes are anchored at a fixed point. A large number of exercises can be performed, for example, single- and double-arm waves, and several others can be performed when using different postures (standing, kneeling, lunge, squat) and integrated with other modalities such as plyometric drills and footwork agility (lateral shuffles, hops, etc.) (1,12,27). The length and diameter of the ropes, as well as the velocity and amplitude of the waves, are thought to govern exercise intensity (1,12,27). However, only 2 studies (6,21) have examined BR exercise to date. These studies have shown significant metabolic responses to various exercises including single- and double-arm waves and double-arm slams (6,21), and larger metabolic responses have been shown compared with several traditional resistance exercises (21). However, the metabolic responses to protocols using different rest intervals remain unknown. Thus, the primary purpose of this study was to quantify and compare the acute metabolic responses to BR exercise using 2 different rest intervals in men and women. It was hypothesized that BR exercises using a shorter rest interval would elicit the greatest acute metabolic responses and the responses would be higher in men than women.

Methods

Experimental Approach to the Problem

To examine the primary hypothesis of this investigation, subjects were tested for $\dot{V}O_2$max and subsequently performed 2 BR exercise protocols on 2 occasions separated by at least 48 hours in random order. The BR protocol consisted of 8 sets of 30-second intervals (15 seconds of single-arm waves and 15 seconds of double-arm waves) using either a 1-minute (1RI) or 2-minute (2RI) rest interval length. Breath-by-breath oxygen consumption, heart rate (HR), blood lactate, and ratings of perceived exertion (RPE) data were collected. This experimental design enabled us to metabolically quantify 2 BR protocols of different rest interval length and compare the responses between men and women.

Subjects

Twenty-two healthy college-aged men ($N = 12$) and women ($N = 10$) aged between 19 and 25 years agreed to participate in this study (Table 1). Each subject exercised regularly before initiating the study, and none were taking any medications or supplements known to affect exercise performance. Most subjects had no prior experience with battle ropes. Thus, subjects underwent 1 week of familiarization (2–3 sessions) with study procedures before testing. Familiarization focused on subjects' ability to perform the BR exercises properly while wearing a respiratory mask. During this time, height was measured using a wall-mounted stadiometer and body mass was measured using an electronic scale. Percent body fat was estimated by a 3-site skinfold test. The sites measured were the pectoral, anterior thigh, and abdominal skinfolds for men and the thigh, triceps, and suprailiac skinfolds for women using methodology previously described (9,10). Body density was calculated using the equations of Jackson and Pollock (9,10), and percent body fat was calculated using the equation of Siri (26). The same research assistant performed all skinfold assessments for men and women, respectively. This study was approved by The College of New Jersey's Institutional Review Board, 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.

Table 1. Subject descriptive characteristics.

	Men ($N = 12$)	Women ($N = 10$)
Age (y)	20.4 ± 1.1	21.2 ± 1.5
Height (cm)	181.5 ± 6.9	165.2 ± 4.8*
Body mass (kg)	84.6 ± 9.7	59.1 ± 5.2*
Body mass index ($kg \cdot m^{-2}$)	25.7 ± 2.3	21.6 ± 1.4*
Body fat (%)	14.7 ± 3.8	24.4 ± 3.1*
$\dot{V}O_2$max ($ml \cdot kg^{-1} \cdot min^{-1}$)	51.1 ± 3.4	49.0 ± 7.6

*$p \leq 0.05$ compared with men.

Maximal Aerobic Capacity ($\dot{V}O_2$max) 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. $\dot{V}O_2$max was assessed using a progressive multistage ramp protocol on a treadmill using a metabolic system (MedGraphics ULTIMA Metabolic System; MedGraphics Corporation, St. 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 $\dot{V}O_2$max was determined by recording the highest measure. Gas analyzers were calibrated before each trial using gases provided by MedGraphics Corporation: (a) calibration gas: 5% CO_2, 12% O_2, and balance N_2 and (b) reference gas: 21% O_2 and balance N_2.

Control Protocol

Subjects reported to the laboratory at a standardized time of day at least 2 hours postprandial to perform the control condition. The control protocol involved a quiet sitting period 30 minutes in duration (to match the approximate duration of the 2RI protocol plus 10-minute postexercise period) to provide baseline (BL) nonexercise metabolic data. Subjects were fitted with a respiratory mask, attached to the metabolic system, and sat quietly for 30 minutes in a semirecumbent position. Baseline breath-by-breath relative $\dot{V}O_2$, respiratory exchange ratio (RER), and minute ventilation (V_E) data were collected and averaged for the 30-minute period.

Battling Rope Protocols

Subjects reported to the laboratory at a standardized time of day at least 2 hours postprandial similar to the control condition. On arrival, each subject was encouraged to drink water ad libitum to prehydrate and was subsequently fitted with a respiratory mask that was placed over the subjects' face, fastened, and carefully checked for proper sealing. Subjects were also fitted with a Polar HR monitor (Polar Electro Inc., Woodbury, NY, USA), which was used to measure HR pre-exercise, during each set of BR exercise, and after each minute of recovery. Subsequently, each subject was positioned on a reclining chair and sat quietly for 10 minutes

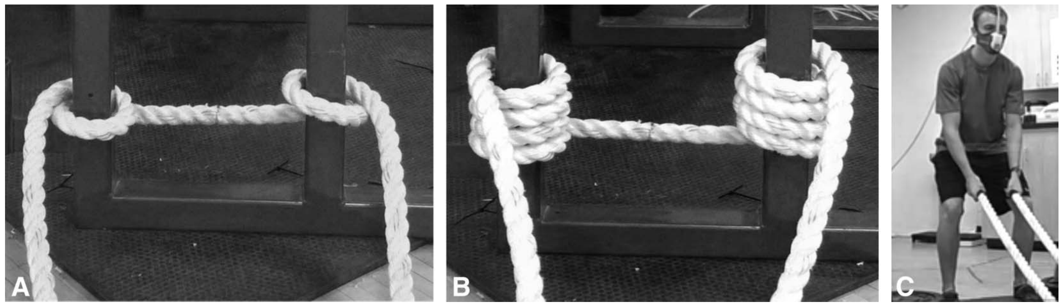

Figure 1. Battling rope anchoring positions for men (A) and women (B). C) Initiation of a protocol in a male subject.

before measurement of BL HR and oxygen consumption (which was recorded over a 3-minute period). Breath-by-breath oxygen uptake ($\dot{V}O_2$) was measured throughout each protocol through a metabolic system (MedGraphics ULTIMA Metabolic System; MedGraphics Corporation). Gas analyzers were calibrated with gases of known composition before collection of metabolic data. Heart rate data presented are the values obtained after each set and minute of recovery and at 5-minute intervals after exercise. 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 ($R = 0.90$).

Following BL measures, each subject performed a warm-up consisting of 3 minutes of stationary cycling and 1–2 practice sets of BR exercise to accustom to the standardized cadence. Subjects performed 3 sets of 30-second bouts of exercise using either a 1RI or 2RI length in between sets. Testing sequence was randomized such that half subjects began with the 1RI protocol and half began with the 2RI protocol. Subjects were given 48–72 hours in between sessions. Each set was divided into 2 consecutive 15-second bouts consisting of 2 BR exercises. Subjects performed 15 seconds of single-arm alternating waves followed by 15 seconds of double-arm waves with a half-squat. A metronome was used to standardize cadence. For single-arm waves, subjects performed 15 repetitions for each arm in 15 seconds. For the double-arm waves, 1 repetition was performed per second totaling 15 altogether. Two metronomes were used with each prescribed cadence. A research assistant kept time and provided a verbal "switch" signal to begin the next exercise. The BR used was 10.9 kg, 15.2 m (50 feet) in length, 3.8 cm in thickness, and was anchored in a low position to a power rack 10–12 inches from the floor (see Figures 1A–C for setup). For men, a single loop was used at the anchor point. To standardize cadence/repetitions between genders, the rope was looped 4 times at the anchor point for women as fewer loops were shown to make it very difficult to reach the desired cadence using proper technique and range of motion. Thus, pilot work before the study showed that these looping patterns best standardized repetition performances at the selected cadences in our sample of women. The

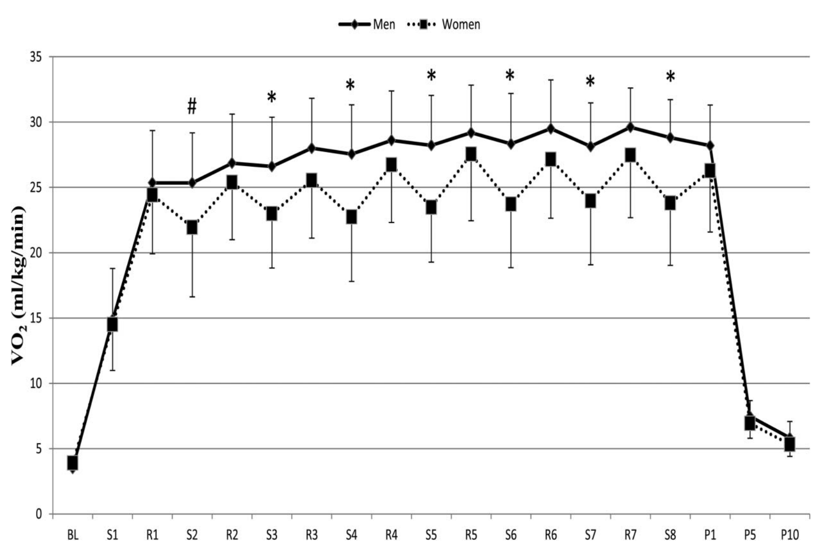

Figure 2. Acute $\dot{V}O_2$ responses during the 1RI protocol. BL = baseline; S1 = set 1; R1 = rest interval 1; S2 = set 2; R2 = rest interval 2; P1 = 1 minute after exercise; P5 = 5 minutes after exercise; P10 = 10 minutes after exercise. All values from S1 through P10 were significantly higher than BL. Values seen during the RIs were significantly higher than the corresponding $\dot{V}O_2$ values seen during the set. *$p \leq 0.05$ between groups; #$p = 0.09$ between groups.

multiple loops applied to 2 beams of the power rack were used to minimize rope collisions to better enable subjects to maintain the standardized cadence. Following each protocol, subjects were seated for 10 minutes for collection of postexercise metabolic and HR data.

Blood Lactate Measurement and Ratings of Perceived Exertion

Whole blood lactate was assessed in duplicate by 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 during the control protocol and before and after each BR protocol. Reliability of this analyzer has been shown to be high (8). After each set, RPE were obtained using a category ratio (CR) 10-point (0–10) scale.

Metabolic and Cardiorespiratory Measurements

Heart rate, absolute $\dot{V}O_2$, relative $\dot{V}O_2$, RER, and ventilation (V_E) data were recorded during the entire protocol. Individual breath-by-breath data points for all metabolic variables were averaged for the entire set and for the entire RI in between sets. 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. Gross energy expenditure (EE) in kilocalories per minute for each protocol was estimated by multiplying absolute $\dot{V}O_2$ (in liters per minute) 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, $\dot{V}O_2$ (in liters per minute) was multiplied by 4.86–4.98 kcal$\cdot$L^{-1}, respectively. Pre-exercise (BL) EE was estimated by multiplying absolute $\dot{V}O_2$ (in liters per minute) by 4.80 kcal$\cdot$L^{-1} to match BL RER. In addition, EE of each BL protocol was expressed in kilojoules and kilojoules per minute. Aerobic EE was estimated at 1 L O_2 = 21.1 kJ (6,23) for RER values ≥1.00 or 1 L O_2 = 20.1–20.8 kJ for resting or postexercise 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 (3,6,23): 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 postexercise EE. Energy expenditure per minute was calculated by dividing total EE by the protocol (exercise and postexercise) duration.

Statistical Analyses

Descriptive statistics (mean ± *SD*) were calculated for all dependent variables. A group × time point analysis of variance with repeated measures was used to analyze within-subject metabolic, RPE, and HR data. Subsequent Tukey's post hoc tests were used to determine differences when significant main effects were obtained. For all statistical tests, a probability level of $p \leq 0.05$ denoted statistical significance.

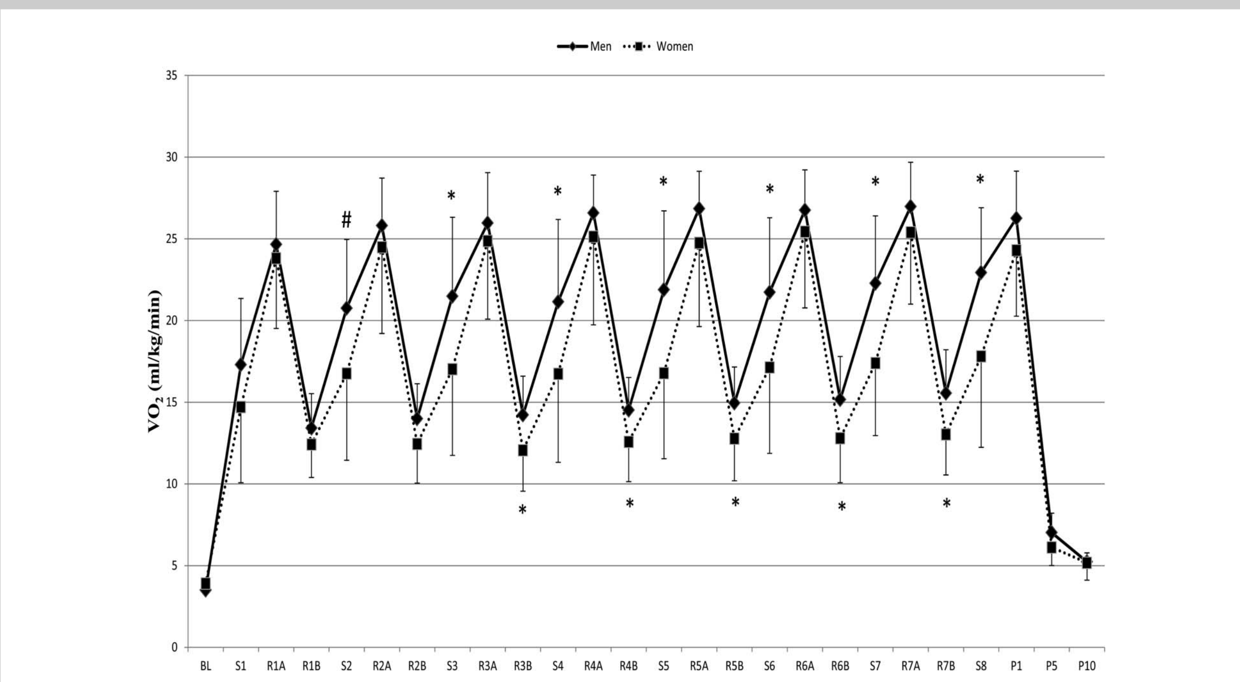

Figure 3. Acute $\dot{V}O_2$ responses during the 2RI protocol. BL = baseline; S1 = set 1; R1A = rest interval 1 (first minute of rest); R1B = rest interval 1 (second minute of rest); S2 = set 2; R2A = rest interval 2 (first minute of rest), R2B = rest interval 2 (second minute of rest); P1 = 1 minute after exercise; P5 = 5 minutes after exercise; P10 = 10 minutes after exercise. All values from S1 through P10 were significantly higher than BL. Values seen during the RIs were significantly different than the corresponding $\dot{V}O_2$ values seen during the set. *$p \leq 0.05$ between groups; #$p = 0.06$ between groups.

Results

Quiet Sitting Protocol

The results of the 30-minute quiet sitting protocol were relative $\dot{V}O_2 = 3.56 \pm 0.6$ ml·kg^{-1}·min^{-1} (men) and 3.92 ± 0.4 ml·kg^{-1}·min^{-1} (women); RER = 0.86 ± 0.1 (men) and 0.87 ± 0.1 (women); and $V_E = 8.25 \pm 1.6$ L·min^{-1} (men) and 7.55 ± 0.7 L·min^{-1} (women). Resting aerobic EE for the 30-minute quiet sitting protocol was 1.45 ± 0.26 kcal·min^{-1} or 6.08 ± 1.1 kJ·min^{-1} (men) yielding a total of 43.5 kcal (182.4 kJ) of EE and 1.14 ± 0.14 kcal·min^{-1} or 4.77 ± 0.6 kJ·min^{-1} (women) yielding a total of 34.2 kcal (143.1 kJ) of EE.

Relative $\dot{V}O_2$

Relative $\dot{V}O_2$ data are presented in Figures 2 and 3. Figure 2 depicts the acute $\dot{V}O_2$ responses observed during the 1RI protocol. Significant time and group ($p < 0.001$) effects were observed. All values from S1 through P10 were significantly higher than BL in both groups. Analysis of $\dot{V}O_2$ observed during each set revealed that S1 was significantly lower than sets 2–8; set 2 was significantly lower than sets 3–8; set 3 was significantly lower than sets 5–8; and $\dot{V}O_2$ peaked during sets 4–8 where values did not significantly differ. The mean $\dot{V}O_2$ values during each specific RI were higher than the respective set value. In comparing the RIs, R1 was significantly lower than R2–R7; R2 was significantly lower than R3–R7; R3 was significantly lower than R4–R7; R4 was significantly lower than R5–R7; and R5, R6, and R7 did not significantly differ. Significant gender differences were shown only for mean set $\dot{V}O_2$ values. No difference was seen during set 1. However, a trend was observed during set 2 ($p = 0.09$), and values from sets 3–8 were significantly higher in men than women. No group differences were observed at any postexercise time point.

Figure 3 depicts $\dot{V}O_2$ responses during the 2RI protocol. Significant time and group ($p < 0.001$) effects were observed. All values from S1 through P10 were significantly higher than BL in both groups. Analysis of set $\dot{V}O_2$ revealed that S1 was significantly lower than S2–S8; S2 was significantly lower than S3, S7, and S8; S3, S5, and S6 were significantly lower than S8; S4 was significantly lower than S7 and S8; and S3–S6 did not significantly differ; S7 and S8 did not significantly differ. The mean $\dot{V}O_2$ values during each specific first minute of the RI were significantly higher than the corresponding set value, and each value during the second minute of rest was significantly lower than the corresponding set value. In comparing the first minute of rest: R1 was significantly lower than R2–R7; R2 was significantly lower than R4–R7; and R3, R4, R5, R6, and R7 did not significantly differ. In comparing the second minute of rest, R1 was significantly lower than R4–R7; R2 was significantly lower than R5–R7; R3 was significantly lower than R4–R7; R4 was significantly lower than R7; and R5, R6, and R7 did not significantly differ. Significant gender differences were shown only for mean set $\dot{V}O_2$ values and during the second minute of rest. For each set, a trend ($p = 0.06$) was seen during S2 and S3–S7 were significant indicating that values in men tended to be higher than women. During the second minute of rest, the mean $\dot{V}O_2$ values during R3B, R4B, R5B, R6B, and R7B were all significantly higher in men than women. No group differences were observed at any postexercise time point.

Comparisons between 1RI and 2RI protocols revealed that the mean $\dot{V}O_2$ values during S2–S8 were significantly higher in 1RI than 2RI in men and women. No difference

Table 2. Comparison of battling rope exercise mean oxygen consumption (ml·kg^{-1}·min^{-1}).

	Single-arm waves	Double-arm waves
Set 1		
1RI–Men	10.6 ± 3.2	19.1 ± 5.0*
1RI–Women	10.3 ± 2.7	18.7 ± 4.9*
2RI–Men	13.0 ± 3.9	21.6 ± 5.1*
2RI–Women	10.6 ± 3.3	18.8 ± 6.1*
Set 2		
1RI–Men	23.6 ± 3.3	27.1 ± 4.6*
1RI–Women	19.9 ± 4.6†	24.0 ± 6.3*
2RI–Men	16.6 ± 3.7	24.9 ± 5.1*
2RI–Women	13.5 ± 4.0‡	20.0 ± 6.7*‡
Set 3		
1RI–Men	24.6 ± 3.5	28.6 ± 4.3*
1RI–Women	21.1 ± 3.1†	24.9 ± 5.3*‡
2RI–Men	17.4 ± 4.3	25.6 ± 5.8*
2RI–Women	13.6 ± 3.8†	20.4 ± 6.9*†
Set 4		
1RI–Men	25.1 ± 3.6	30.0 ± 4.4*
1RI–Women	21.1 ± 3.9†	24.4 ± 6.2*†
2RI–Men	17.3 ± 4.8	24.9 ± 5.8*
2RI–Women	13.3 ± 4.0†	20.1 ± 7.2*†
Set 5		
1RI–Men	25.8 ± 3.7	30.6 ± 4.4*
1RI–Women	21.8 ± 3.9†	25.2 ± 4.9*†
2RI–Men	18.0 ± 4.4	25.7 ± 5.6*
2RI–Women	13.6 ± 4.1†	20.0 ± 6.7*†
Set 6		
1RI–Men	26.3 ± 3.6	30.4 ± 4.4*
1RI–Women	21.4 ± 4.5†	26.0 ± 5.8*†
2RI–Men	18.0 ± 4.0	25.4 ± 5.4*
2RI–Women	13.8 ± 4.0†	20.5 ± 6.7*†
Set 7		
1RI–Men	25.5 ± 3.1	30.8 ± 3.9*
1RI–Women	21.7 ± 5.0†	26.3 ± 5.4*†
2RI–Men	18.2 ± 3.7	26.3 ± 4.8*
2RI–Women	14.0 ± 3.5†	20.8 ± 5.8*†
Set 8		
1RI–Men	26.0 ± 2.6	31.6 ± 3.5*
1RI–Women	21.7 ± 4.4†	25.9 ± 5.6*†
2RI–Men	18.3 ± 3.9	27.5 ± 4.3*
2RI–Women	13.8 ± 4.6†	21.9 ± 6.8*†

*$p \leq 0.05$ between exercises.
†$p \leq 0.05$ between groups.
‡$p = 0.06$–0.08 between groups.

was seen between 1RI and 2RI during S1. The mean $\dot{V}O_2$ values during the first minute of rest during S4–S7 were significantly higher in 1RI than 2RI in men and women. No differences were seen between 1RI and 2RI during the first minute of rest during S1–S3. The pattern of $\dot{V}O_2$ elevation was consistently high in 1RI but showed greater valleys during the second minute of rest in 2RI.

The mean $\dot{V}O_2$ values for the entire protocol were significantly higher during 1RI (27.0 ± 3.3 $ml\cdot kg^{-1}\cdot min^{-1}$ and 24.1 ± 4.2 $ml\cdot kg^{-1}\cdot min^{-1}$ in men and women, respectively) than 2RI (20.7 ± 2.5 $ml\cdot kg^{-1}\cdot min^{-1}$ and 18.0 ± 4.0 $ml\cdot kg^{-1}\cdot min^{-1}$ in men and women, respectively), and values in men were 11.1% (1RI) and 13.5% (2RI) higher than women, respectively ($p = 0.05$). These mean $\dot{V}O_2$ values equated to 52.8 ± 5.5% (men) and 50.0 ± 11.2% (women) of $\dot{V}O_2max$ during 1RI and 40.5 ± 4.5% (men) and 37.7 ± 11.0% (women) of $\dot{V}O_2max$ during 2RI. The 1RI percent was statistically greater ($p < 0.001$) than 2RI. However, no

TABLE 3. Comparison of energy expenditure ($kcal\cdot min^{-1}$) between protocols.

	Men 1RI	Men 2RI	Women 1RI	Women 2RI
Baseline	1.40 ± 0.5	1.39 ± 0.4	1.07 ± 0.2	1.09 ± 0.3
Set 1	6.23 ± 1.7*	7.22 ± 1.6*	4.31 ± 1.1*	3.99 ± 1.5*
R1A	10.83 ± 1.6†	10.49 ± 1.7†	7.27 ± 1.3†	6.45 ± 2.0†
R1B		5.72 ± 1.0‡		3.48 ± 1.0‡
Set 2	10.91 ± 1.7§	8.77 ± 1.5§‖	6.45 ± 1.6§	4.73 ± 1.8§‖
R2A	11.53 ± 1.5¶	10.97 ± 1.5#	7.54 ± 1.2‖	6.81 ± 2.3#
R2B		5.98 ± 1.2**		3.58 ± 1.0**
Set 3	11.48 ± 1.9††	9.10 ± 1.1‖‡‡	6.78 ± 1.1††	4.84 ± 1.8‖‡‡
R3A	11.97 ± 1.6#	11.04 ± 1.6	7.56 ± 1.3#	6.93 ± 2.2
R3B		6.05 ± 1.1**		3.46 ± 1.1**
Set 4	11.89 ± 1.9††	8.94 ± 1.1‖§§	6.74 ± 1.5††	4.78 ± 1.8‖§§
R4A	12.23 ± 1.6‖‖	11.30 ± 1.3	7.97 ± 1.4‖‖	6.99 ± 2.5
R4B		6.18 ± 0.9¶¶		3.56 ± 1.1¶¶
Set 5	12.19 ± 1.8	9.27 ± 1.8‖‡‡	6.98 ± 1.2	4.72 ± 1.8‖‡‡
R5A	12.48 ± 1.4	11.43 ± 1.4	8.24 ± 1.6	6.86 ± 2.4
R5B		6.37 ± 1.1		3.67 ± 1.1
Set 6	12.22 ± 1.7	9.19 ± 1.6‖‡‡	7.08 ± 1.5	4.79 ± 1.8‖‡‡
R6A	12.62 ± 1.5	11.39 ± 1.5	8.14 ± 1.5	7.01 ± 2.3
R6B		6.46 ± 1.3		3.61 ± 1.1
Set 7	12.11 ± 1.7	9.44 ± 1.6‖‡‡	7.21 ± 1.5	4.84 ± 1.7‖‡‡
R7A	12.65 ± 1.3	11.48 ± 1.5‖	8.20 ± 1.5	7.00 ± 2.2‖
R7B		6.63 ± 1.3		3.71 ± 1.0
Set 8	12.35 ± 1.6	9.72 ± 1.5‖	7.09 ± 1.4	4.99 ± 1.9‖
P1	11.93 ± 1.1	11.00 ± 1.4##	7.78 ± 1.4	7.01 ± 1.1##
P5	3.16 ± 0.5##	2.97 ± 0.5##	2.06 ± 0.3##	1.82 ± 0.3##
P10	2.47 ± 0.5##	2.20 ± 0.3##	1.58 ± 0.3##	1.52 ± 0.4##
Total mean	11.93 ± 1.4	8.78 ± 1.4‖	7.69 ± 1.3	5.04 ± 1.7‖
Aerobic EE (kJ)	532.5 ± 68.1	734.1 ± 95.4‖	329.9 ± 58.5	444.9 ± 95.4‖
Aerobic EE ($kJ\cdot min^{-1}$)	48.4 ± 6.2	36.7 ± 4.8‖	30.0 ± 5.3	22.3 ± 4.8‖
Anaerobic EE (kJ)	57.8 ± 17.1	50.3 ± 14.0‖	29.2 ± 10.8	23.7 ± 14.0‖
PE EE (kJ)	205.7 ± 31.8	193.4 ± 27.6‖	127.3 ± 21.3	120.4 ± 20.6‖
Total EE (kJ)	796.0 ± 111.9	977.8 ± 121.0‖	486.4 ± 63.9	589.0 ± 125.6‖
Total EE ($kJ\cdot min^{-1}$)	35.9 ± 5.1	32.6 ± 4.0‖	22.1 ± 2.9	19.6 ± 4.2‖

*$p \le 0.05$ compared with S2 through S8.
†$p \le 0.05$ compared with R2A through R7A.
‡$p \le 0.05$ compared with R4B through R7B.
§$p \le 0.05$ compared with S3 through S8.
‖$p \le 0.05$ compared with 1RI.
¶$p \le 0.05$ compared with R3A through R7A.
#$p \le 0.05$ compared with R4A through R7A.
**$p \le 0.05$ compared with R5B through R7B.
††$p \le 0.05$ compared with S5 through S8.
‡‡$p \le 0.05$ compared with S8.
§§$p \le 0.05$ compared with S7 and S8.
‖‖$p \le 0.05$ compared with R5A through R7A.
¶¶$p \le 0.05$ compared with R7B.
##$p \le 0.05$ compared with previous value.

significant differences were observed between men and women ($p = 0.99$). Peak $\dot{V}O_2$ values during each protocol equated to 75.5 ± 6.5% (men) and 72.4 ± 14.5% (women) of $\dot{V}O_2$max during 1RI and 69.6 ± 7.2% (men) and 67.9 ± 16.8% (women) of $\dot{V}O_2$max during 2RI. The 1RI percent was statistically greater ($p = 0.008$) than 2RI. However, no significant differences were observed between men and women ($p = 0.72$).

Specific BR exercise mean $\dot{V}O_2$ data are presented in Table 2. Values tended to increase with each successive set. The mean $\dot{V}O_2$ data during the double-arm waves were significantly higher than single-arm waves at every time point during 1RI and 2RI. All values from S2–S8 were significantly higher in 1RI than 2RI. During 1RI and 2RI, mean $\dot{V}O_2$ values during S3–S8 were significantly higher in men than women.

Table 4. Heart rate (b·min^{-1}) responses to battling rope protocols.

	Men 1RI	Men 2RI	Women 1RI	Women 2RI
Baseline	66.0 ± 8.7	65.8 ± 9.0	66.4 ± 6.9	65.8 ± 7.3
Set 1	163.8 ± 17.3*	163.5 ± 11.2*	152.0 ± 22.4*	155.7 ± 15.2*
R1A	139.3 ± 18.9†	128.4 ± 19.9†	121.9 ± 19.3†	121.8 ± 21.0†
R1B		114.9 ± 13.3‡		103.9 ± 23.9‡
Set 2	168.5 ± 14.5§‖	165.1 ± 11.1§	164.4 ± 11.4§‖	159.5 ± 16.7§
R2A	143.2 ± 19.8‖¶	135.0 ± 19.5¶	138.2 ± 18.4‖¶	125.7 ± 26.9¶
R2B		120.3 ± 17.9#		115.3 ± 20.4#
Set 3	172.7 ± 12.3‖**	167.8 ± 12.5**	165.9 ± 13.8‖**	160.1 ± 17.3**
R3A	149.0 ± 18.3‖††	140.1 ± 19.9††	142.0 ± 18.7‖††	133.7 ± 24.2††
R3B		126.0 ± 16.2‡‡		118.5 ± 19.5‡‡
Set 4	175.1 ± 11.5‖§§	168.6 ± 11.0§§	170.5 ± 12.8‖§§	161.2 ± 17.2§§
R4A	152.9 ± 16.6‖‖‖	142.1 ± 19.6¶¶	146.9 ± 17.7‖‖‖	138.0 ± 21.4¶¶
R4B		128.1 ± 17.7##		119.7 ± 19.6##
Set 5	177.8 ± 11.4‖***	170.8 ± 10.8†††	172.2 ± 12.2‖***	162.5 ± 15.7†††
R5A	157.9 ± 14.7‖‡‡‡	147.3 ± 19.5§§§	145.9 ± 16.9‖‡‡‡	142.3 ± 21.1§§§
R5B		131.6 ± 17.7‖‖‖		124.4 ± 21.7‖‖‖
Set 6	178.8 ± 10.9‖¶¶¶	172.9 ± 9.7###	172.7 ± 12.7‖¶¶¶	166.0 ± 15.7###
R6A	159.8 ± 14.7‖§§§	148.3 ± 22.4	151.0 ± 18.2‖§§§	145.1 ± 22.0
R6B		134.0 ± 18.6		128.4 ± 21.0
Set 7	180.4 ± 10.1‖****	174.3 ± 8.8****	175.1 ± 14.2‖****	165.5 ± 18.2****
R7A	161.3 ± 17.4	152.1 ± 17.9	155.7 ± 19.1	145.4 ± 21.1
R7B		136.8 ± 17.8		129.4 ± 22.6
Set 8	182.2 ± 10.2	177.4 ± 9.0	175.1 ± 14.7	167.1 ± 17.6
P1	155.0 ± 14.9‖††††	148.1 ± 17.8††††	142.5 ± 20.4‖††††	136.7 ± 21.3††††
P5	109.9 ± 10.5††††	108.6 ± 12.5††††	105.3 ± 15.7††††	101.1 ± 19.4††††
P10	105.3 ± 11.6††††	103.1 ± 11.1††††	101.1 ± 15.0††††	99.0 ± 16.0
Protocol mean	164.2 ± 14.6‖	147.5 ± 15.5	156.6 ± 16.2‖	140.4 ± 20.0

*$p \leq 0.05$ compared with S2 through S8.
†$p \leq 0.05$ compared with R2A through R7A.
‡$p \leq 0.05$ compared with R2B through R7B.
§$p \leq 0.05$ compared with S3 through S8.
‖$p \leq 0.05$ compared with 2RI.
¶$p \leq 0.05$ compared with R3A through R7A.
#$p \leq 0.05$ compared with R3B through R7B.
**$p \leq 0.05$ compared with S4 through S8.
††$p \leq 0.05$ compared with R4A through R7A.
‡‡$p \leq 0.05$ compared with R4B through R7B.
§§$p \leq 0.05$ compared with S5 through S8.
‖‖$p \leq 0.05$ compared with R6A through R7A.
¶¶$p \leq 0.05$ compared with R5A through R7A.
##$p \leq 0.05$ compared with R5B through R7B.
***$p \leq 0.05$ compared with S7 and S8.
†††$p \leq 0.05$ compared with S6 through S8.
‡‡‡$p \leq 0.05$ compared with R6A and R7A.
§§§$p \leq 0.05$ compared with R7A.
‖‖‖$p \leq 0.05$ compared with R6B and R7B.
¶¶¶$p \leq 0.05$ compared with S7 and S8.
###$p \leq 0.05$ compared with S8.
****$p \leq 0.05$ compared with S8.
††††$p \leq 0.05$ compared with previous value.

Respiratory Exchange Ratio and Energy Expenditure

The mean protocol RER values did not significantly differ between protocols or gender (1RI: men = 1.13 ± 0.09; women = 1.18 ± 0.33; 2RI: men = 1.14 ± 0.06; women = 1.06 ± 0.08). Energy expenditure data are presented in Table 3. Significant time and gender effects were observed ($p < 0.0001$). All EE (in kilocalories per minute) data from S1 through P10 were significantly greater than BL. All EE values in men were significantly higher than the corresponding value in women. During the 1RI protocol, EE significantly increased during each successive setup to S5 where it plateaued. Similar findings were observed during the RIs.

TABLE 5. Comparison of minute ventilation ($L\cdot min^{-1}$) between protocols.

	Men 1RI	Men 2RI	Women 1RI	Women 2RI
Baseline	6.0 ± 1.3	6.1 ± 1.5	5.5 ± 0.6	5.7 ± 0.8
Set 1	36.1 ± 12.0*	44.2 ± 12.4*	27.0 ± 8.5*	28.0 ± 11.5*
R1A	54.4 ± 11.2†	53.1 ± 7.2†	38.1 ± 9.0†	37.7 ± 9.1†
R1B		42.5 ± 6.9‡		28.3 ± 7.8‡
Peak	64.1 ± 14.8*	67.3 ± 18.5*	46.6 ± 12.2*	47.1 ± 14.6*
Set 2	78.5 ± 17.9§‖	67.3 ± 13.8§	47.6 ± 16.3§‖	39.5 ± 15.4§
R2A	65.2 ± 11.6¶	61.2 ± 7.9¶	45.2 ± 13.4¶	44.2 ± 15.2¶
R2B		44.9 ± 7.8#		31.3 ± 10.1#
Peak	92.7 ± 23.8§‖	88.2 ± 20.5§	58.9 ± 20.3§‖	55.8 ± 20.9§
Set 3	86.3 ± 21.8‖**	73.0 ± 17.7††	52.3 ± 17.3‖‡‡	41.9 ± 17.8††
R3A	69.9 ± 11.0§§	63.3 ± 9.5§§	46.1 ± 13.9§§	45.3 ± 14.6‖‖
R3B		45.9 ± 10.0¶¶		30.6 ± 10.2
Peak	99.6 ± 24.0‖**	93.8 ± 21.9‡‡	60.1 ± 21.0‖**	58.4 ± 22.4
Set 4	92.5 ± 23.9‖‡‡	73.0 ± 18.1‡‡	52.9 ± 18.5‖‡‡	41.5 ± 19.4††
R4A	74.8 ± 13.2‖##	65.4 ± 7.7##	49.1 ± 13.8‖##	45.9 ± 15.0‖‖
R4B		48.0 ± 8.5#		31.3 ± 10.3#
Peak	109.1 ± 26.1‖‡‡	91.4 ± 19.8‡‡	63.6 ± 21.1***	58.2 ± 21.9
Set 5	97.7 ± 26.6‖***	76.7 ± 17.6††	55.6 ± 18.8‖†††	41.6 ± 17.9††
R5A	79.5 ± 12.2‖‖‖	68.2 ± 8.9	51.8 ± 15.2‖	45.2 ± 15.9‖‖
R5B		49.1 ± 9.1		31.4 ± 12.0
Peak	115.0 ± 28.9‖†††	99.3 ± 19.6††	65.3 ± 21.4‖***	57.8 ± 22.5
Set 6	100.9 ± 26.9‖†††	76.0 ± 16.2††	56.4 ± 19.4‖†††	42.6 ± 18.2††
R6A	82.3 ± 16.8‖	68.7 ± 9.0	52.6 ± 15.2‖	47.0 ± 16.4
R6B		50.0 ± 9.1		32.1 ± 10.1
Peak	114.8 ± 28.2‖†††	99.3 ± 18.9††	67.9 ± 23.9‖	58.8 ± 22.3
Set 7	102.8 ± 28.3‖	79.3 ± 18.5††	58.8 ± 18.3‖	42.3 ± 18.3††
R7A	83.4 ± 15.1‖	70.1 ± 10.5	53.8 ± 14.4‖	47.4 ± 15.4
R7B		52.1 ± 10.5		32.3 ± 10.3
Peak	118.3 ± 27.7‖††	101.4 ± 20.8††	69.2 ± 21.3‖	58.2 ± 20.3
Set 8	106.6 ± 26.0‖	82.1 ± 18.3	58.8 ± 18.4‖	44.0 ± 19.8
Peak	127.6 ± 26.5‖	105.5 ± 20.2	68.8 ± 21.1‖	58.7 ± 25.6
P1	82.0 ± 14.8‖‡‡‡	69.6 ± 9.8‡‡‡	51.9 ± 15.7‖‡‡‡	44.5 ± 13.1
P5	28.7 ± 7.9‡‡‡	26.0 ± 5.4‡‡‡	18.8 ± 4.8‡‡‡	16.9 ± 5.2‡‡‡
P10	18.5 ± 7.7‡‡‡	15.5 ± 2.4‡‡‡	12.7 ± 3.2‡‡‡	12.2 ± 3.7‡‡‡
Protocol mean	80.7 ± 17.3‖	61.5 ± 10.0	49.7 ± 14.9‖	38.7 ± 13.8

*$p \leq 0.05$ compared with S2 through S8.
†$p \leq 0.05$ compared with R2A through R7A.
‡$p \leq 0.05$ compared with R2B through R7B.
§$p \leq 0.05$ compared with S3 through S8.
‖$p \leq 0.05$ compared with 2RI.
¶$p \leq 0.05$ compared with R3A through R7A.
#$p \leq 0.05$ compared with R6B and R7B.
**$p \leq 0.05$ compared with S4 through S8.
††$p \leq 0.05$ compared with S8.
‡‡$p \leq 0.05$ compared with S5 through S8.
§§$p \leq 0.05$ compared with R4A through R7A.
‖‖$p \leq 0.05$ compared with R6A and R7A.
¶¶$p \leq 0.05$ compared with R4B through R7B.
##$p \leq 0.05$ compared with R5A through R7A.
***$p \leq 0.05$ compared with S6 through S8.
†††$p \leq 0.05$ compared with S7 and S8.
‡‡‡$p \leq 0.05$ compared with previous value.

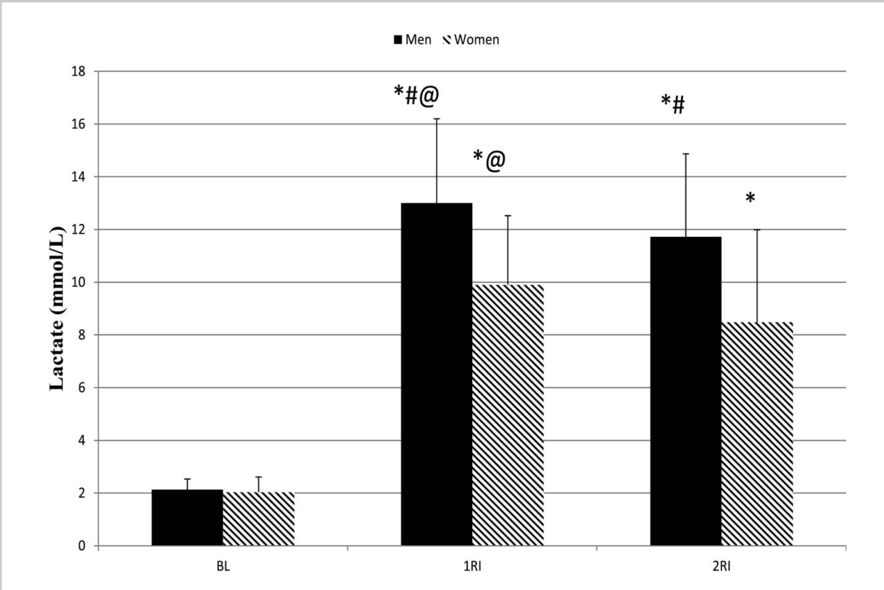

Figure 4. Blood lactate responses. BL = baseline; 1RI = 1-minute rest interval protocol; 2RI = 2-minute rest interval protocol; $*p \le 0.05$ from corresponding time point BL; $\#p \le 0.05$ between groups; $@p \le 0.05$ compared with 2RI.

During the 2RI protocol, EE significantly increased over the first 3 sets, plateaued, and then increased during S8. Energy expenditure increased significantly during the first minute of rest over the first 3 sets and then plateaued. Similar results were shown during the second minute of rest over the first 4 sets. In comparison of the 1RI and 2RI protocols, EE was significantly higher in 1RI than 2RI from S2 to S8 and only during the first minute of rest of the seventh set. Postexercise EE analysis revealed that EE decreased significantly from P1 to P5 to P10 for both protocols, and all postexercise EE values were significantly higher in 1RI than 2RI. The mean protocol EE was significantly higher in 1RI than 2RI (by 26 and 34% in men and women, respectively), and both values were significantly higher in men compared with women. Energy expenditure data were expressed in kilojoules or kilojoules per minute for quantification of aerobic and anaerobic contributions. All EE variables were significantly higher in men than women. Aerobic EE (in kilojoules per minute), anaerobic EE, total EE (in kilojoules per minute), and postexercise EE were significantly higher in 1RI than 2RI. Aerobic EE (in kilojoules) and total EE (in kilojoules) were significantly higher in 2RI than 1RI.

Heart Rate

Heart rate responses are presented in Table 4. Significant time and RI effects were observed ($p < 0.0001$) but no gender effect. All values were significantly higher than BL. All HR values immediately after each set were significantly higher than HRs obtained during the corresponding RIs. Heart rate progressively increased with each successive set for both RIs. In direct RI comparison, HRs after each set were significantly higher during 1RI than 2RI with the exception of S1. Heart rates significantly increased during the first minute of rest with each successive set for both

Table 6. Ratings of perceived exertion responses to battling rope protocols.

	Men 1RI	Men 2RI	Women 1RI	Women 2RI
Set 1	3.67 ± 1.8*	2.92 ± 1.8*	3.60 ± 1.9*	3.20 ± 1.7*
Set 2	4.04 ± 1.7†	3.71 ± 1.6†	4.4 ± 1.6†	3.85 ± 1.7†
Set 3	5.25 ± 1.5‡§	4.21 ± 1.6‡	5.4 ± 1.7‡§	4.60 ± 1.5‡
Set 4	6.08 ± 1.4§‖	4.75 ± 1.4‖	5.80 ± 1.9§‖	5.40 ± 1.0‖
Set 5	6.83 ± 1.5§¶	5.63 ± 1.4¶	6.45 ± 1.7§¶	5.95 ± 0.8¶
Set 6	7.58 ± 1.4§#	6.13 ± 1.4#	6.95 ± 1.3§#	6.55 ± 0.9#
Set 7	8.42 ± 1.2§**	6.96 ± 1.8**	7.70 ± 1.2§**	6.90 ± 1.1**
Set 8	8.83 ± 1.0§	7.29 ± 1.7	8.35 ± 0.8§	7.30 ± 1.0

$*p \le 0.05$ compared with S2 through S8.
$\dagger p \le 0.05$ compared with S3 through S8.
$\ddagger p \le 0.05$ compared with S4 through S8.
$\S p \le 0.05$ compared with 2RI.
$\| p \le 0.05$ compared with S5 through S8.
$\P p \le 0.05$ compared with S6 through S8.
$\# p \le 0.05$ compared with S7 and S8.
$**p \le 0.05$ compared with S8.

RIs (with the exception of S6 and S7 during 2RI). Heart rate values during the first minute of rest were significantly higher in 1RI than 2RI with the exception of S1. Heart rate progressively increased during the second minute of rest (2RI protocols) with each successive set with the exception of S6 and S7. Heart rates obtained P1 were significantly higher during 1RI than 2RI. However, no differences were observed at P5 or P10. The mean HRs for each protocol were significantly higher in 1RI than 2RI for men (10.2%) and women (10.3%), respectively.

Minute Ventilation

Minute ventilation (V_E) responses are shown in Table 5. Significant time and gender effects were observed ($p < 0.0001$). All V_E data from S1 through P10 were significantly greater than BL. All V_E values in men were significantly higher than the corresponding value in women. During the 1RI protocol, V_E significantly increased during each setup to S7 where it plateaued. Similar findings were observed during the RIs where V_E peaked at S6. During the 2RI protocol, V_E significantly increased over the first 4 sets, plateaued, and increased during S8. V_E increased significantly during the first minute of rest over the first 5 sets and plateaued. Similar results were shown during the second minute of rest over the first 4 sets. V_E was significantly higher in 1RI than 2RI from S2 to S8 and during the first minute of rest of sets 4–7. V_E decreased significantly from P1 to P5 to P10 for both protocols and P1 V_E values were significantly higher in 1RI than 2RI. The mean V_E for the entire protocol was significantly higher in men (by 28.3%) and women (by 22.1%) during 1RI than 2RI. The mean protocol V_E was significantly higher in men than women during 1RI (by 38%) and 2RI (by 37%). When expressed relative to body mass, the mean protocol V_E values were significantly higher during 1RI (0.97 ± 0.2 vs. 0.85 ± 0.3) than 2RI (0.73 ± 0.1 vs. 0.66 ± 0.2) in men and women, respectively. However, no significant gender difference was observed ($p = 0.27$).

Blood Lactate and Ratings of Perceived Exertion

Blood lactate and RPE responses are shown in Figure 4 and Table 6. Blood lactate was significantly elevated ($p < 0.001$) immediately postexercise following the 1RI and 2RI protocols. Lactate values were significantly higher following 1RI than the 2RI protocol. Blood lactate values after 1RI and 2RI were significantly higher in men than women ($p = 0.026$). For RPE, a significant time effect was observed ($p < 0.001$), but no gender effects were observed ($p = 0.99$). Ratings of perceived exertion increased with each successive set during 1RI and 2RI. Ratings of perceived exertion values seen during 1RI were significantly greater than 2RI during S3–S8.

Discussion

The salient findings from this study indicated that a shorter RI length increases the metabolic demands of BR exercise, and the metabolic responses were higher in men than women. One-minute RI increased the relative $\dot{V}O_2$, V_E, EE, blood lactate, HR, and RPE (for 6 of 8 sets) responses to BR exercise compared with 2RI. The mean $\dot{V}O_2$ values equated to 50–52.8% of $\dot{V}O_2$max during the 1RI protocol and 37.7–40.5% $\dot{V}O_2$max during the 2RI protocol. Interestingly, peak $\dot{V}O_2$ values equated to 72–75.5% of $\dot{V}O_2$max (1RI) and 67.9–69.6% of $\dot{V}O_2$max (2RI) indicating that BR exercise provides a potent metabolic and cardiovascular stimulus.

The mean $\dot{V}O_2$ values for the entire protocol were significantly higher during 1RI (27.0 ± 3.3 $ml \cdot kg^{-1} \cdot min^{-1}$ and 24.1 ± 4.2 $ml \cdot kg^{-1} \cdot min^{-1}$ in men and women, respectively) than 2RI (20.7 ± 2.5 $ml \cdot kg^{-1} \cdot min^{-1}$ and 18.0 ± 4.0 $ml \cdot kg^{-1} \cdot min^{-1}$ in men and women, respectively) and values in men were 11.1% (1RI) and 13.5% (2RI) higher than women, respectively. These data indicate that the acute oxygen consumption response to BR exercise is greater with shorter RIs. We have previously shown that a BR protocol consisting of 3 sets of 30-second bouts with 2-minute RIs yielded a mean protocol $\dot{V}O_2$ of 24.6 $ml \cdot kg^{-1} \cdot min^{-1}$ in men (21). This value was slightly higher than the mean protocol $\dot{V}O_2$ value reported in this study. This was most likely due to 2 critical factors relating to differences in the protocols. In our previous study (21), the 30-second bout consisted of 3 exercises performed for 10 seconds each; single-arm waves, double-arm waves, and double-arm slams, as opposed to 2 exercises of 15-second intervals (single- and double-arm waves) used in this study. The double-arm slam is considered to be a more intense exercise because it requires the subject to forcefully slam the ropes against the ground during each repetition. Although the motion is similar to a double-arm wave, the downward velocity of the ropes is augmented by near-maximal or maximal muscular contractions. Thus, the higher intensity could have increased the metabolic response. In addition, subjects in our previous study were instructed to perform as many repetitions as possible during the allotted 10-second intervals at a rapid self-selected cadence. Subjects performed an average of 54.4 repetitions per set (21) compared with the standardized 45 repetitions performed in this study. The faster cadence and higher volume per set used in our previous study likely increased the mean metabolic responses despite the use of only 3 sets compared with 8 sets used in this study.

The greater mean oxygen consumption response seen during the 1RI protocol is consistent with other modalities of training including traditional resistance exercise (19,20). The use of a 1RI protocol in this study is somewhat comparable to the study of Fountaine and Schmidt (6). They examined 10 sets of BR exercise where double-arm waves were performed at a self-selected cadence in 15-second intervals (with a mean number of 25 ± 4 repetitions per set) followed by a 45-second RI. They reported peak $\dot{V}O_2$ values of 40.2 and 31.3 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively, in men and women. In this study, peak $\dot{V}O_2$ values obtained during the 1RI protocol were 38.6 ± 4.2 $ml \cdot kg^{-1} \cdot min^{-1}$ (men) and 35.1 ± 6.7 $ml \cdot kg^{-1} \cdot min^{-1}$ (women), which equated to 75.5 ± 6.5% (men) and 72.4 ± 14.5% (women) of $\dot{V}O_2$max, respectively. Our peak $\dot{V}O_2$ values were higher in women but slightly lower than men. This was not surprising considering the protocols differed between studies, that is, rope mass, RIs, exercise selection, and protocol volume and cadence. In viewing the exercise selection, Fountaine and Schmidt (6) used only double-arm waves, whereas we used a combination of single- and double-arm waves. Although it was not our primary purpose to directly compare the 2 exercises in this study (as we did not randomize the exercise sequence to minimize an order effect), the double-arm wave yielded a larger metabolic response. Mean $\dot{V}O_2$ data obtained during the double-arm waves were significantly higher than single-arm waves at every time point during the 1RI and 2RI protocols in men and women. All $\dot{V}O_2$ values from sets 2 through 8 were significantly higher in 1RI than 2RI. The double-arm wave has a more substantial lower-body contribution because it includes a half-squat, whereas single-arm waves require less motion of the hips, knee, and ankle. It is likely that the greater lower-extremity muscle mass contribution led to the greater metabolic response. Considering that muscle mass involvement is critical to acute oxygen consumption responses seen during high-intensity intermittent exercise (20), it seems that the double-arm wave poses a stronger metabolic stimulus during BR exercise than the single-arm wave.

A progressive pattern of $\dot{V}O_2$ increase was observed during the 1RI and 2RI protocols. Relative $\dot{V}O_2$ increased progressively during the first 4 sets, peaked, and remained elevated during the 1RI protocol, whereas a more gradual increase in relative $\dot{V}O_2$ was seen during the 2RI protocol. The mean relative $\dot{V}O_2$ values seen during the first minute of rest were higher than the corresponding value during the set. Although BR exercise has been studied on a limited basis, this pattern of progressive increase over the course of multiple sets has been demonstrated in our previous study (21) and during resistance exercise (19,20). Likewise, the large mean $\dot{V}O_2$ response seen during the first minute of rest has been shown previously during resistance exercise (19–22). The anaerobic nature of high-intensity intermittent exercise imposes a limitation to a maximal rise in relative $\dot{V}O_2$. Scala et al. (22) proposed that a Valsalva maneuver, rise in blood lactate, and increased potassium, HR, and temperature stimulate an increase in V_E during the RI. Replenishment of the ATP-phosphocreatine system, buffering of H^+ from glycolytic energy metabolism, and removal of lactate occur during the recovery period, which assists in augmenting the mean $\dot{V}O_2$ response seen during the immediate recovery. However, mean $\dot{V}O_2$ values were reduced to levels lower than values seen during the corresponding set during the second minute of rest in the 2RI protocol. Thus, BR exercise seems to produce a similar pattern of elevation to resistance exercise where mean $\dot{V}O_2$ values seen during the first minute of rest are higher than those seen during the corresponding set.

Our data demonstrated that BR exercise provides an effective means of increasing gross EE with an advantage seen during the 1RI protocol. During the 1RI protocol, EE progressively increased over the first 5 sets and corresponding RIs. During the 2RI protocol, EE significantly increased over the first 3 sets, plateaued, and then increased during S8. Energy expenditure increased during the first and second minute of rest over the first 3–4 sets and then plateaued. Overall, each protocol yielded EE values of 11.9 ± 1.4 $kcal \cdot min^{-1}$ and 7.7 ± 1.3 $kcal \cdot min^{-1}$, respectively, in men and women during the 1RI protocol and 8.8 ± 1.4 $kcal \cdot min^{-1}$ and 5.0 ± 1.7 $kcal \cdot min^{-1}$, respectively, in men and women during the 2RI protocol. We have previously shown that a BR protocol consisting of single- and double-arm waves and slams at a rapid cadence with a 2RI yielded an EE of 10.3 ± 1.4 $kcal \cdot min^{-1}$ in men (21). It is likely that the differences in protocols resulted in differences in EE as our prior study used a faster cadence, higher volume of repetitions, and the addition of double-arm slams (21). In comparison, BR exercise (when matched for RI length) yields greater EE values than several traditional resistance exercises (21). We previously reported EE values ranging from 5.1 $kcal \cdot min^{-1}$ for barbell curls (3 sets of up to 10 repetitions using a 2RI) to 8.2 $kcal \cdot min^{-1}$ for squats (21). Thus, BR exercise has the potential to target several training goals including increased EE for weight loss or endurance goal-oriented programs. Further research is warranted quantifying EE of BR protocols using different exercises with shorter RIs.

Gross aerobic, anaerobic, and total EE data were calculated in kilojoules for comparative purposes. Fountaine and Schmidt (6) reported anaerobic EE of ~62.5 and 41.3 kJ, aerobic EE of 487.6 and 258.1 kJ, postexercise EE of 72.1 and 38.9 kJ, and total EE (including postexercise EE) of 622.2 and 338.3 kJ, respectively, in men and women. Compared with the 1RI protocol used in this study, these values were generally less with the exception of anaerobic EE whose values were similar between studies. It is likely the protocols accounted for the difference as we used 30-second intervals with 1RI and included the single-arm wave, whereas Fountaine and Schmidt (6) used 15-second intervals with 45-second RI including only double-arm waves.

The blood lactate response was higher following the 1RI protocol. However, the lactate response to both 1RI and 2RI protocols was significantly less in women compared to men indicating that women. Previous studies have shown that women have faster recovery capacity during moderate-to-high-intensity exercise than men (2,11). Women have been shown to have reduced ATP depletion (5), faster ATP recovery (5), lower blood lactate (7,11) and subsequent higher percent reliance and contribution from aerobic sources to total EE (24), lower epinephrine (7), lower RER (13), and lower glycogen breakdown in type I fibers (5) in response to maximal sprint and resistance exercise. The lower lactate response may be indicative of a reduced reliance on glycolysis during high-intensity exercise in women. Interestingly, RPE did not differ between genders. Although RPE increased with each set and values were higher during the 1RI protocol (from sets 3–8), the response was similar between men and women. The lack of differences seen between genders indicates that both men and women perceived each protocol with similar difficulty despite women demonstrating a reduced lactate response. The results of this study support previous studies demonstrating a reduced lactate response to high-intensity exercise in women while perceived exertion was similar (11).

An interesting element to this study was the high HR and V_E shown. Fountaine and Schmidt (6) reported mean HRs of 158 and 165 $b \cdot min^{-1}$ and peak HRs of 171 and 183 $b \cdot min^{-1}$ in men and women, respectively. These values were comparable to those observed during the 1RI protocol in this study, that is, mean protocol HRs of 164 and 157 $b \cdot min^{-1}$ in men and women, respectively. We previously showed a mean HR of approximately 154 bpm using a 2RI BR protocol (21). These data were comparable to the mean HRs of approximately 148 and 140 $b \cdot min^{-1}$ observed in men and women, respectively, in this study. In all 3 studies, HRs observed during protocols using 45 seconds to 1RIs produce mean HRs equivalent to 81–86% of maximum predicted HR (6) with peak HRs approaching ~94% of maximum predicted HR (6) and 2RI protocols produced men HRs approximately 72–77% of maximum predicted HR (21).

We previously showed a mean protocol V_E of ~79.7 $L \cdot min^{-1}$ during a 2RI BR protocol in men (21). We reported a mean protocol V_E of 81 $L \cdot min^{-1}$ for the 1RI protocol and 62 $L \cdot min^{-1}$ for the 2RI protocol in this study. Although both protocols used a 2RI, the protocol in the previous study could be viewed as more difficult as we included a third exercise, double-arm slams, and subjects used a maximal cadence yielding more repetitions per 30-second interval (21). These protocol differences likely accounted for the 2RI differences seen between studies. Peak V_E values of approximately 128 $L \cdot min^{-1}$ were seen in men at the end of the 1RI protocol. These data exceeded V_E values commonly seen during traditional resistance exercise (19–21). The mean V_E absolute response in women was considerably less than values seen in men presumably because of body size differences. However, these gender differences disappeared when V_E values were expressed relative to body mass. Nevertheless, BR exercise does appear to pose a significant metabolic stimulus with the effects augmented to a greater extent with a short RI.

In summary, a shorter RI length increases the metabolic demands of BR exercise, and the metabolic responses were higher in men than women. The mean $\dot{V}O_2$ values for the entire protocol were significantly higher during the 1RI than 2RI protocol, and values in men were 11.1 and 13.5% higher than women, respectively. The 1RI protocol increased relative $\dot{V}O_2$, V_E, EE (in kilocalories per minute), blood lactate, HR, and RPE (for 6 of 8 sets) responses to BR exercise significantly more than the 2RI protocol (although the 2RI protocol yielded higher total EE due to the longer duration). These data demonstrate that BR exercise poses a significant cardiovascular and metabolic stimulus with mean effects augmented with a short RI.

Practical Applications

Battling rope exercise is a modality that is increasing in popularity among athletes and fitness enthusiasts. Battling rope protocols are used for a variety of training goals including increased strength, power, local muscular endurance, and agility. Moreover, BR exercise is a challenging modality that can target weight loss and body fat reductions through increased EE. The results of this study and 2 previous studies (6,21) indicate that BR exercise can stimulate high levels of EE often greater than EE seen during traditional resistance exercise. In addition, the high cardiovascular demand could potentially provide a novel stimulus for improving maximal aerobic capacity and metabolic health.

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