Metabolic Profile of Reciprocal Supersets in Young, Recreationally Active Women and Men

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Abstract

Realzola, RA, Mang, ZA, Millender, DJ, Beam, JR, Bellovary, BN, Wells, AD, Houck, JM, and Kravitz, L. Metabolic profile of reciprocal supersets in young, recreationally active females and males. *J Strength Cond Res* 36(10): 2709–2716, 2022—Reciprocal supersets (RSSs) are a time-efficient style of resistance exercise (RE) that consist of performing 2 consecutive exercises with opposing muscle groups while limiting rest times between them. Previous research in men indicates a RSS has an increased physiological response when compared with traditional RE (TRAD). No between-sex comparison of metabolic data for RSSs exists. The purpose of this study was to create a metabolic profile for RSSs in men and women. Eighteen resistance-trained individuals underwent 2 bouts of volume-load equated RE: RSS and TRAD. Reciprocal superset exercises were split into 3 clusters: (a) hexagonal bar deadlift superset with leg press, (b) chest press superset with seated row, and (c) overhead dumbbell press superset with latissimus dorsi pull-downs. The TRAD protocol, doing the same exercises, emulated hypertrophy emphasis training. Oxygen uptake ($\dot{V}O_2$), heart rate (HR), blood lactate ([BLa]), rate of perceived exertion (RPE), and excess post-exercise oxygen consumption (EPOC) were measured. Aerobic and anaerobic energy expenditure were estimated using $\dot{V}O_2$ and lactate, respectively. The level of significance set for this study was $p \leq 0.05$. Regardless of sex, a RSS elicited significantly greater average $\dot{V}O_2$, HR, [BLa], RPE, and anaerobic and aerobic energy expenditures, and was completed in a shorter time compared with TRAD ($p \leq 0.05$). When compared with women, men had significantly greater EPOC, average [BLa], and anaerobic and aerobic energy expenditures during RSSs ($p \leq 0.05$). The average [BLa] and aerobic energy expenditure of the men were also significantly greater than the women during TRAD ($p \leq 0.05$). This study suggests that a RSS is a metabolically demanding RE session that may elicit increases in musculoskeletal, cardiorespiratory, and physiological adaptations while decreasing the duration of exercise.

Key Words: resistance training, oxygen uptake, heart rate, musculoskeletal

Introduction

Resistance exercise (RE) is an exercise modality used by a variety of populations to elicit positive adaptations for health and sports performance. For example, RE may be used to decrease fall risk and to increase independence and quality of life in adults (34). Similarly, athletes may incorporate RE to improve sport performance by increasing power, speed, and strength (15,21,27). Studies have shown that RE aids in the development and preservation of muscle mass (2,27,31), supporting positive outcomes in both athletes and general populations. In fact, investigations have shown that consistently performing RE at intensities ranging from 30 to 100% of 1 repetition maximum can elicit muscle hypertrophy, increases in lean body mass, and other positive health benefits (39,43). Traditional RE (TRAD) involves completing a set of repetitions (reps) to meet certain criteria (i.e., momentary muscular fatigue, a certain number of reps, and training to a prescribed repetition in reserve), followed by an adequate rest period before the next bout of the same exercise. Recently, studies have shown that shortening rest times play a key role in creating a more potent metabolic stimulus by triggering greater increases in heart rate (HR), oxygen uptake ($\dot{V}O_2$), and blood lactate ([BLa]) (26,35,37). Although the benefits of exercise are well known, only 51.6% of adults meet the American College of Sports Medicine's (ACSM) aerobic activity guidelines, 29.3% meet muscle strengthening guidelines, and 20.6% meet both aerobic and muscle strengthening guidelines, with most blaming a lack of time as the main barrier (9). Incorporating different exercise training styles, which are more time efficient, may improve exercise compliance for many adults, as well as athletes during seasonal training blocks when time management in training is imperative.

Reciprocal supersets (RSSs), also known as opposite action superset training (30), consists of performing 2 consecutive exercises with opposing muscle groups with minimal rest duration between the movements (26). With RSSs, if a person does a "push" movement (i.e., bench press), then the next immediate exercise will be a "pull" movement (i.e., seated row), followed by a brief rest. Reciprocal superset training may be a practical tool for satisfying exercise recommendations while reducing the total exercise session time. Training programs with lower rest times, such as RSSs, have been shown to elicit greater metabolic energy costs (11,19,26), increases in [BLa], and increases in excess post-exercise oxygen consumption (EPOC) when compared with TRAD (26). These benefits, when coupled with a decrease in exercise duration, make RSSs a potentially favorable training modality for athletes with time-demanding training schedules.

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Although previous research has evaluated isometric strength, rate of force development, and muscle endurance of supersets (30), only Kelleher et al. (26) evaluated the metabolic cost of RSS compared with TRAD, which only included male subjects. However, female and male athletes have used RSSs for years in their training programs. Therefore, the purpose of the current study was to create a metabolic profile for RSSs in men and women. We hypothesized that the average $\dot{V}O_2$ as a percentage of max (%$\dot{V}O_2$max), average HR as a percentage of max (%HRmax), average [BLa], average rate of perceived exertion (RPE), and EPOC would be greater during RSSs compared with TRAD. Also, our second hypothesis was that there would be sex differences in average [BLa] responses during both bouts of RE but that there would be no difference in %$\dot{V}O_2$max, %HRmax, average RPE, and EPOC.

Methods

Experimental Approach to the Problem

This study used a repeated-measures, cross-over design to compare the metabolic and cardiorespiratory responses of 2 volume-load equated total-body RE sessions. The independent variables were the style of RE (RSS or TRAD) and sex (men or women), whereas dependent variables were %HRmax, %$\dot{V}O_2$max, anaerobic energy expenditure, aerobic energy expenditure, EPOC aerobic energy expenditure, average lactate, EPOC, average RPE, and session duration. Subjects visited the exercise physiology laboratory on 4 separate occasions for a $\dot{V}O_2$max test, 10repetition maximum (RM) testing, RSS session, and TRAD session. Each visit was separated by a minimum of 48 hours and a maximum of 98 hours and occurred during the same time of the day to avoid the influence of diurnal hormones and circadian rhythms. Subjects were instructed to follow the pre-test guidelines before their trials, which were no exercise or alcohol 24 hours before the session, no caffeine 4 hours before, and at least a pint of water as well as a small meal consumed 2–3 hours before the session. Before training, subjects were asked if they had followed guidelines and were instructed to return another time if they had not. The experiment was designed to specifically focus on the effect of rest duration between exercise sets between RSS and TRAD. Therefore, trials could not be randomized to equate total volume-load between RSS and TRAD. Each subject completed RSSs first, followed by matched sets, repetitions, and loads for the TRAD session. This methodology is based on studies by Kelleher et al. (26) and Howard et al. (22), which showed that subjects reached volitional fatigue earlier and with fewer reps in RSSs when compared with TRAD. Thus, the session with fewer reps needed to be completed first to match total volume-load in the second session. Volume-load (sets × reps × load) was calculated during the RSS session and equated during the TRAD session.

Subjects

Subjects were 18 apparently healthy, resistance-trained and aerobically fit men (n = 9, 24.1 ± 3.7) and women (n = 9, 22.8 ± 3.9; *SD*). All subjects self-reported through the Health History questionnaire and Physical Activity Readiness Questionnaire (PARQ) that they were participating in weekly >150 minutes of moderate-to-vigorous exercise, which included a blend of aerobic and resistance training. Subjects reported that they were free of cardiovascular, metabolic, viral, kidney, and liver disease with no orthopedic injuries that would prevent them from exercise. Furthermore, subjects had engaged in at least 2 $d\cdot wk^{-1}$ of total-body RE for >12 months and had a $\dot{V}O_2$max >50th percentile for their age and sex, which qualified them as resistance-trained and aerobically fit (34). All subjects self-reported that they were familiar with the RE performed in this study, and they had previous experience with circuit training. Before exercise began, height (cm) and body mass (kg) were measured without shoes using a Holtain Limited Stadiometer (Crvmvch Dyfe, Great Britain) to the nearest 1 cm, and Detecto Digital Scale (Webb City, MO) to the nearest 0.1 kg, respectively. In addition, body fat percentage (BF%) was measured using a 3-site skinfold: chest, abdomen, and thigh for men, and triceps, suprailliac, and thigh for women (24,25). These values were used to estimate body density and BF % (42). The study was approved by the University of New Mexico's university institutional review board, and written informed consent was provided by subjects.

Procedures

Maximum Oxygen Uptake Testing. All subjects performed a running $\dot{V}O_2$max test on a motorized treadmill (C966i, Precor Inc., Woodinville, WA). Expired gases were continuously measured using breath-by-breath sampling (K5; Cosmed, Concord, CA) to obtain metabolic variables during exercise. The metabolic gas analyzer was calibrated before each exercise session in accordance with manufacturer's guidelines. An 11-breath running average was used to process the data (38). For the $\dot{V}O_2$max trial, the highest 11-breath averaged data point was recorded as $\dot{V}O_2$max. All $\dot{V}O_2$max tests were performed at a 3.0% grade and initial running speed was selected to correspond with an intensity that could be maintained for 30 + minutes. The speed was increased by 0.1 mph every 15 seconds (0.4 $mph\cdot min^{-1}$) until subjects reached volitional fatigue and voluntarily terminated the test. The maximal oxygen consumption was confirmed when an individual attained at least 2 of the following 4 criteria: HR within 10 beats of age predicted maximal HR, a $\dot{V}O_2$ plateau of $\leq$150 $ml\cdot min^{-1}$, respiratory exchange ratio (RER) > 1.15, or RPE >17. All subjects satisfied at least 2 of the 4 of these criteria.

Ten Repetition Maximum Determination. Before performing each exercise, a proper lifting technique and cadence were demonstrated by a researcher who was certified by the National Strength and Conditioning Association (NSCA), ACSM, or National Athletic Training Association. After observing proper form and descriptions of each exercise, subjects performed 5–10 minutes of a self-selected warm-up before executing the first set of RE with ~50% of their self-estimated 10RM for 8–10 repetitions. After a 3–5 minutes rest period, successive sets were performed, and researchers continued to add mass for each set until a successful 10RM was determined. A rest period of 3–5 minutes was provided between each set, as recommended by the NSCA (12). All 10RMs were determined within 3 attempts, within the same day. The 10RMs were determined for the following exercises (which were used for the RSS and TRAD sessions): hexagonal bar deadlift, leg press, chest press, seated row, overhead dumbbell press, and latissimus (lat) dorsi pull-down. Subjects were given 3–5 minutes of rest between exercises.

Reciprocal Superset Protocol. Before the RSS trial began, subjects repeated the self-selected 5–10-minute warm-up that was performed before their 10RM session. Next, they donned a Garmin HR monitor (Garmin HRM, Olathe, KS) and were fitted for the portable metabolic analyzer (Cosmed-K5), which was worn as a reverse backpack. Exercises were performed in the following order: hexagonal bar deadlift ("pull"), leg press ("push"), chest press ("push"), seated row ("pull"), overhead dumbbell press ("push"), and lat dorsi pull-downs ("pull"). A RSS was performed by completing the first exercise and immediately completing the second exercise in the superset (SS) cluster. Reciprocal SS trials were split into 3 clusters: hexagonal bar deadlift SS with leg press (SS cluster 1), chest press SS with seated row (SS cluster 2), and overhead dumbbell press SS with lat pull-downs (SS cluster 3). Although a hexagonal bar deadlift and a leg press both have simultaneous flexion at the hip and knees, they are reciprocal in that when performed correctly, a hexagonal bar deadlift is a "pull" movement, whereas the leg press is a "push" movement. Subjects had 1 minute of rest before repeating another bout of the same SS cluster. Each SS cluster was completed 4 times before moving to the next SS cluster. On completion of each SS cluster, subjects had 2 minutes of rest before continuing to the next SS cluster. Subjects performed all sets to concentric muscle failure and maintained a rep range of 12–15 repetitions for each set at an intensity that was calculated as 75% of their 10RM. Blood lactate and RPE were measured at 5 time points: pre-exercise, post-SS cluster 1, post-SS cluster 2, post-SS cluster 3, and 5-minute post-exercise. After RE was completed, EPOC was measured for 20 minutes, during which the subjects remained seated while wearing the Cosmed-K5 system and mask. A diagram of the experimental protocol can be found in Figure 1A. Volume-load was calculated for each lift (sets × reps × load) and was replicated during the subsequent TRAD session. The duration of exercise session was timed, denoted as the beginning of the first repetition to after the last repetition.

Traditional Resistance Exercise Protocol. For the TRAD session, all procedures were replicated from the RSS trial, including the warm-up, exercises, order of exercises, sets, repetitions, and intensity. Rest intervals varied between the RSS trials and the TRAD trials. For TRAD trials, subjects were given 90 seconds of rest between every set of RE. The 90-second rest intervals were performed to emulate traditional hypertrophy RE as much as possible, and it has recently been proposed that lifters performing hypertrophy style training should use rest intervals between 60 and 180 seconds (17,40). All sets of each RE were performed consecutively before moving to the next RE to simulate traditional bodybuilder workouts. The [BLa] and RPE were measured pre-exercise; on completion of the last sets of leg press, seated row, and lat pull-downs; and 5-minute post-exercise. A diagram of the protocol can be found in Figure 1B. Volume-load from the RSS session was replicated during TRAD, and a stopwatch was used to determine the time to completion. Excess post-exercise oxygen consumption was measured for 20 minutes as described with the RSS session.

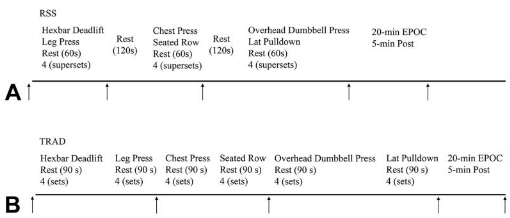

Figure 1. A) Reciprocal supersets (RSSs) and (B) traditional resistance exercise (TRAD) protocols ("↑" indicates rate of perceived exertion and blood lactate sample). EPOC = excess post-exercise oxygen consumption; lat = latissimus; hexabar = hexagonal bar.

Metabolic/Heart Rate Measurement. Expired gases were continuously measured using breath-by-breath sampling (K5; Cosmed, Concord, CA) during all RE trials, and the metabolic gas analyzer was calibrated before each exercise session in accordance with manufacturer's guidelines. The average $\dot{V}O_2$ for RSSs and TRAD during the exercise session were taken from the 11-breath averaged data and expressed as %$\dot{V}O_2$max. The average $\dot{V}O_2$ for RSSs and TRAD during EPOC was taken from the 11-breath averaged data. Heart rate was monitored continuously during all sessions of exercise using a Garmin HR monitor (Garmin HRM, Olathe), which was integrated with the metabolic gas analyzer. For the $\dot{V}O_2$max trial, the highest HR achieved was recorded as HRmax while the average HR for RSSs and TRAD was calculated and expressed as %HRmax.

Blood Lactate and Rate of Perceived Exertion. Blood lactate was measured using a handheld [BLa] meter (Lactate Plus, NOVA Biomedical, MA). Researchers sterilized the earlobe with alcohol wipes before using a lancet to collect a small blood sample. Measurements were taken in duplicate, and the average of the 2 measurements was recorded. Subjects were asked their RPE using the 6–20 Borg RPE scale (4). Rating of perceived exertion and [BLa] were measured concurrently at the following time-points during RSSs and TRAD: pre-exercise, post-SS cluster 1, post-SS cluster 2, post-SS cluster 3, and 5-minute post-exercise.

Estimated Aerobic and Anaerobic Energy Expenditure Calculations. An estimation of the average aerobic energy expenditure ($kJ \cdot min^{-1}$) for each subject during each exercise session and during EPOC was calculated using the following formula: (avg $\dot{V}O_2$ [$ml \cdot kg^{-1} \cdot min^{-1}$] × body mass [kg] × 0.001 $ml \cdot L^{-1}$ × 20.9 $kJ \cdot min^{-1}$) (41). An estimation of the anaerobic energy expenditure ($kJ \cdot min^{-1}$) for each subject during each session was calculated using the following formula: (peak [BLa] [$mmol \cdot L^{-1}$] −resting [BLa] [$mmol \cdot L^{-1}$]) × body mass (kg) × 3.0 ml O_2 × 20.9/exercise duration (41).

Statistical Analyses

Independent samples *t*-tests were used to detect differences between sexes for the following demographic and descriptive dependent variables: height, body mass, BF%, age, and $\dot{V}O_2$max. The Pearson correlation coefficients were computed to assess the reliability of the dependent variables measured during the RSS and TRAD. Two (protocol) × 2 (sex) mixed repeated measures analyses of variance were used to compare the results of all dependent variables. Pairwise comparisons for statistically significant interactions were analyzed using Tukey's HSD procedure and reported as mean ± *SD*. Statistically significant within-subject main effects were analyzed using paired samples *t*-tests and reported as mean ± *SD*. Statistically significant between-subject main effects were analyzed using independent samples t-tests and reported as mean ± *SD*. The alpha-level was set to $p \leq 0.05$ for all statistical analyses. The assumption of equality of variances was checked using the Levene test for all analyses. If this assumption was violated ($p \leq 0.05$), the Welch test for unequal variances was checked. The assumption of normality was checked using the Shapiro-Wilk test for the independent samples *t*-tests. If this assumption was violated ($p \leq 0.05$), the Mann-Whitney *U* test was used. Data were analyzed using the statistical package JASP (version 0.12, Amsterdam, The Netherlands).

Results

Demographics

Several significant anthropometric differences were detected between male and female groups. All anthropometric data are displayed in Table 1.

Reliability of Dependent Variables Between Protocols

No control group or condition was present in this study. Therefore, we provided reliability data for all dependent variables measured during the RSS and TRAD in Table 2. All dependent variables, except RPE, were significantly related ($p \leq 0.05$).

Percentage of Maximum Oxygen Uptake

No significant interaction was found between sex and protocol, $F_{(1,16)} = 0.187$, $p = 0.671$, $\omega^2 = 0.000$. There was a significant within-subjects main effect of protocol, $F_{(1,16)} = 113.063$, $p < 0.001$, $\omega^2 = 0.479$, but there was no significant between-subjects main effect of sex, $F_{(1,16)} = 0.052$, $p = 0.822$, $\omega^2 = 0.000$. After combining the male and female data, the %$\dot{V}O_2$max was significantly higher during RSSs compared with TRAD (Table 3).

Percentage of Maximum Heart Rate

No significant interaction was found between sex and protocol, $F_{(1,16)} = 0.755$, $p = 0.398$, $\omega^2 = 0.000$. There was a significant within-subjects main effect of protocol, F (1,15) = 83.565, $p < 0.001$, $\omega^2 = 0.512$, but there was no significant between-subjects main effect of sex, $F_{(1,16)} = 0.118$, $p = 0.735$, $\omega^2 = 0.000$. After combining the male and female data, the %HRmax was significantly higher during RSSs compared with TRAD (Table 3).

Session Duration

No significant interaction was found between sex and protocol, $F_{(1,16)} = 0.217$, $p = 0.648$, $\omega^2 = 0.000$). There was a significant within-subjects main effect of protocol, $F_{(1,16)} = 2{,}594.787$, $p < 0.001$, $\omega^2 = 0.941$, but there was no significant between-subjects main effect of sex, $F_{(1,16)} = 0.785$, $p = 0.389$, $\omega^2 = 0.000$. After combining the male and female data, the duration was significantly greater during TRAD compared with RSSs (Table 3).

Table 1

Demographic, anthropometric, and aerobic fitness information for men (*n* = 9) and women (*n* = 9).*

	Male	Female
Age (yrs)	24.1 ± 3.7	22.8 ± 3.9
Height (cm)	177.3 ± 4.7†	165.5 ± 7.4
Body mass (kg)	82.4 ± 9.9†	61.0 ± 8.2
BF%	10.5 ± 4.4†	22.6 ± 5.2
$\dot{V}O_2$max (ml·kg^{-1}·min^{-1})	57.5 ± 7.7†	45.8 ± 8.9

*BF% = body fat percentage; $\dot{V}O_2$max = maximum oxygen uptake.
†Significantly different from women, $p \leq 0.05$.

Excess Post-Exercise Oxygen Consumption

No significant interaction was found between sex and protocol, $F_{(1,16)} = 2.820$, $p = 0.113$, $\omega^2 = 0.027$. There was a significant within-subjects main effect of protocol, $F_{(1,16)} = 10.341$, $p = 0.005$, $\omega^2 = 0.125$, and a significant between-subjects main effect of sex, $F_{(1,16)} = 6.587$, $p = 0.021$, $\omega^2 = 0.237$. After combining the male and female data, the EPOC was significantly greater during RSSs compared with TRAD (Table 3), and within each trial, the men had significantly greater EPOCs than the women (Table 4).

Anaerobic Energy Expenditure

A significant interaction was found between sex and protocol, $F_{(1,16)} = 10.677$, $p = 0.005$, $\omega^2 = 0.163$ for anaerobic energy expenditure. There was a significant within-subjects main effect of protocol, $F_{(1,16)} = 87.845$, $p < 0.001$, $\omega^2 = 0.636$, and a significant between-subjects main effect of sex, $F_{(1,16)} = 23.992$, $p < 0.001$, $\omega^2 = 0.561$. After combining the male and female data, the anaerobic energy expenditure was significantly greater during RSSs compared with TRAD (Table 3). Further, the men had significantly greater anaerobic energy expenditure than the women during RSSs, but not during TRAD (Table 4).

Aerobic Energy Expenditure

A significant interaction was found between sex and protocol, $F_{(1,16)} = 12.217$, $p = 0.003$, $\omega^2 = 0.099$, for exercise aerobic energy expenditure. There was a significant within-subjects main effect of protocol, $F_{(1,16)} = 132.705$, $p < 0.001$, $\omega^2 = 0.564$, and a significant between-subjects main effect of sex, $F_{(1,16)} = 61.576$, $p < 0.001$, $\omega^2 = 0.771$. After combining the male and female data, the exercise aerobic energy expenditure was significantly greater during RSSs compared with TRAD (Table 3), and within each trial, the men had significantly greater exercise aerobic energy expenditure than the women (Table 4).

A significant interaction was not found between sex and protocol, $F_{(1,16)} = 3.714$, $p = 0.072$, $\omega^2 = 0.038$ for EPOC aerobic energy expenditure. There was a significant within-subjects main effect of protocol, $F_{(1,16)} = 10.367$, $p = 0.005$, $\omega^2 = 0.119$, and a significant between-subjects main effect of sex, $F_{(1,16)} = 44.872$, $p < 0.001$, $\omega^2 = 0.709$. After combining the male and female data, the EPOC aerobic energy expenditure was significantly greater during RSSs compared with TRAD (Table 3), and within each trial, the men had significantly greater EPOC aerobic energy expenditure than the women (Table 4).

Average Lactate

No significant interaction was found between sex and protocol, $F_{(1,16)} = 0.800$, $p = 0.384$, $\omega^2 = 0.000$, for average [BLa]. There was a significant within-subjects main effect of protocol, $F_{(1,16)} = 73.502$, $p < 0.001$, $\omega^2 = 0.538$, and a significant between-subjects main effect of sex, $F_{(1,16)} = 15.086$, $p = 0.001$, $\omega^2 = 0.439$. After combining the male and female data, the average [BLa] was significantly greater during RSSs compared with TRAD (Table 3), and within each trial, the men had significantly greater average [BLa] than the women (Table 4).

Average Rate Of Perceived Exertion

No significant interaction was found between sex and protocol, $F_{(1,16)} = 1.153$, $p = 0.299$, $\omega^2 = 0.003$). There was a significant

Table 2

Reliability between dependent variables measured during the RSS and TRAD.*†

Dependent variable	Pearson's *r*	*p*	95% CI
$\%\dot{V}O_2max$	0.782	<0.001‡	0.496 to 0.915
%HRmax	0.566	0.014‡	0.134 to 0.817
EPOC ($ml \cdot kg^{-1} \cdot min^{-1}$)	0.692	0.001‡	0.332 to 0.876
Average lactate ($mmol \cdot L^{-1}$)	0.729	<0.001‡	0.397 to 0.892
Anaerobic energy expenditure ($kJ \cdot min^{-1}$)	0.869	<0.001‡	0.677 to 0.950
Aerobic energy expenditure ($kJ \cdot min^{-1}$)	0.942	<0.001‡	0.849 to 0.979
EPOC aerobic energy expenditure ($kJ \cdot min^{-1}$)	0.863	<0.001‡	0.63 to 0.948
Average RPE	0.270	0.278	−0.225 to 0.654
Duration (min)	0.867	<0.001‡	0.671 to 0.949

*RPE = rate of perceived exertion; EPOC = excess post-exercise oxygen consumption; CI = confidence interval; $\%\dot{V}O_2max$ = percentage of maximum oxygen uptake; %HRmax = percentage of maximum heart rate; RSS = reciprocal superset; TRAD = traditional resistance exercise.

†RSS: *N* = 18, TRAD: *N* = 18.

‡Statistically significant, $p \leq 0.05$.

within-subjects main effect of protocol, $F_{(1,16)} = 47.674$, $p < 0.001$, $\omega^2 = 0.496$, but there was no significant between-subjects main effect of sex, $F_{(1,16)} = 0.645$, $p = 0.434$, $\omega^2 = 0.000$. After combining the male and female data, the RPE was significantly greater during RSSs compared with TRAD (Table 3.

Discussion

The primary finding in this study was that the metabolic load during RSSs was significantly greater than that of TRAD, given that % HRmax, $\%\dot{V}O_2max$, RPE, average [BLa], and EPOC were significantly higher for RSSs. Furthermore, higher aerobic and anaerobic energy expenditure occurred during the RSS trial when compared with TRAD. It is meaningful to note that the duration of the trials (RSS vs. TRAD) was significantly different (26.7 ± 2.9 minutes vs. 45.6 ± 1.9 minutes, $p < 0.001$), although volume-load was equated between trials. This time-saving advantage is the foremost importance of the RSS training method, given that time constraints are cited as a main barrier to exercise in adults (9). For athletes, a RSS may be a suitable training stimulus during phases where they need to streamline their workouts due to the demands of competition.

A secondary finding in this research was that male subjects had a significantly higher average [BLa] response during the RSS and TRAD when compared with women. Differences in average [BLa] in men when compared with women is likely due to having larger muscle mass, which has been shown to produce higher levels of lactate (6). Similarly, lean body mass and the ability to recruit muscle mass during exercise may also play a role in [BLa] accumulation (23). Furthermore, it has been shown that women have a higher amount of type I muscle fibers (8), which have a high capacity for aerobic energy supply and are more fatigue resistant than type II fibers (30,36). Larger amounts of type I muscle fibers may allow women to recover faster (8) and rely less on glycolytic energy systems during high-intensity exercise, thus decreasing the amount of [BLa] accrued during exercise (13).

In addition, given the decreased recovery time during RSSs, higher average [BLa] and RPE occurred in both sexes. The increase in [BLa] may have been caused by greater anaerobic

Table 3

Post hoc comparisons between protocols for $\%\dot{V}O_2max$, %HRmax, EPOC, average lactate, anaerobic energy expenditure, average RPE, and duration.*†

Dependent variable	Condition	Mean ± *SD*	Mean difference (95% CI)	*p*	Effect size (Cohen's *d*)
$\%\dot{V}O_2max$	RSS	40.9 ± 6.9‡	11.2 (9.0–13.4)	<0.001	2.568
	TRAD	29.7 ± 4.5			
%HRmax	RSS	75.8 ± 7.6‡	14.3 (11.0–17.6)	<0.001	2.170
	TRAD	61.5 ± 6.3			
EPOC ($ml \cdot kg^{-1} \cdot min^{-1}$)	RSS	8.37 ± 1.85‡	1.00 (0.31–1.69)	0.007	0.720
	TRAD	7.37 ± 0.91			
Average lactate ($mmol \cdot L^{-1}$)	RSS	8.5 ± 2.3‡	3.2 (2.4–4.0)	<0.001	2.033
	TRAD	5.3 ± 1.5			
Anaerobic energy expenditure ($kJ \cdot min^{-1}$)	RSS	1.86 ± 0.92‡	1.21 (0.87–1.55)	<0.001	1.764
	TRAD	0.65 ± 0.28			
Aerobic energy expenditure ($kJ \cdot min^{-1}$)	RSS	31.8 ± 9.5‡	8.8 (7.2–10.4)	<0.001	2.715
	TRAD	23.0 ± 6.2			
EPOC aerobic energy expenditure ($kJ \cdot min^{-1}$)	RSS	12.6 ± 4.1‡	1.5 (0.5–2.5)	0.005	0.759
	TRAD	11.1 ± 2.8			
Average RPE	RSS	12.1 ± 1.2‡	2.5 (1.7–3.3)	<0.001	1.620
	TRAD	9.6 ± 1.3			
Duration (min)	RSS	26.7 ± 2.8‡	18.9 (18.1–19.7)	<0.001	12.293
	TRAD	45.6 ± 1.9			

*RPE = rate of perceived exertion; EPOC = excess post-exercise oxygen consumption; CI = confidence interval; $\%\dot{V}O_2max$ = percentage of maximum oxygen uptake; %HRmax = percentage of maximum heart rate; RSS = reciprocal superset; TRAD = traditional resistance exercise.

†RSS: *N* = 18, TRAD: *N* = 18.

‡Significantly different than TRAD, $p \leq 0.05$.

Table 4

Post hoc comparisons between sex for EPOC, average lactate, anaerobic and aerobic energy expenditure, and EPOC aerobic energy expenditure.*†

Dependent variable	Condition	Mean ± *SD*	Mean difference (95% CI)	*p*	Effect size (Cohen's *d*)
EPOC ($ml\cdot kg^{-1}\cdot min^{-1}$)	RSS (males)	9.30 ± 1.81‡	1.87 (0.24 to 3.50)	0.027	1.145
	RSS (females)	7.43 ± 1.43			
	TRAD (males)	7.78 ± 0.81	0.82 (0 to 1.65)	0.051	0.996
	TRAD (females)	6.96 ± 0.84			
Average lactate ($mmol\cdot L^{-1}$)	RSS (males)	9.8 ± 2.0‡	2.7 (0.8 to 4.5)	0.007	1.448
	RSS (females)	7.2 ± 1.7			
	TRAD (males)	6.3 ± 1.0‡	2.0 (1.0 to 3.1)	< 0.001	1.924
	TRAD (females)	4.3 ± 1.0			
Anaerobic energy expenditure ($kJ\cdot min^{-1}$)	RSS (males)	2.51 ± 0.83‡	1.30 (0.68 to 1.93)	< 0.001	1.387
	RSS (females)	1.21 ± 0.38			
	TRAD (males)	0.88 ± 0.16	0.46 (−0.17 to 1.08)	0.189	0.486
	TRAD (females)	0.42 ± 0.16			
Aerobic energy expenditure ($kJ\cdot min^{-1}$)	RSS (males)	39.8 ± 6.2‡	16.0 (10.6 to 21.4)	< 0.001	2.025
	RSS (females)	23.4 ± 2.7			
	TRAD (males)	28.4 ± 3.7‡	10.7 (5.3 to 16.1)	< 0.001	1.351
	TRAD (females)	17.7 ± 2.0			
EPOC aerobic energy expenditure ($kJ\cdot min^{-1}$)	RSS (males)	15.8 ± 3.0‡	6.5 (4.1 to 8.9)	< 0.001	2.690
	RSS (females)	9.4 ± 1.7			
	TRAD (males)	13.4 ± 2.1‡	4.6 (3.1 to 6.2)	< 0.001	2.981
	TRAD (females)	8.8 ± 0.7			

*EPOC = excess post-exercise oxygen consumption; CI = confidence interval; RSS = reciprocal superset; TRAD = traditional resistance exercise.

†Men: *n* = 9, women: *n* = 9.

‡Significantly different than women.

metabolism, specifically the accumulation of pyruvate being greater than the clearance of pyruvate through oxidative metabolism (41). Increases in [BLa] production also correlate to an accumulation of hydrogen ions, which are believed to interfere with muscle excitation and contraction coupling through calcium binding to troponin (23). Such an increase in hydrogen ions can reduce the functional capacity of muscle fibers and place an increased emphasis on larger motor unit recruitment (23). The findings in this study are consistent with previous studies where rest times were decreased (26,37). Kelleher et al. (26) found that RSSs in men elicited significant increases in [BLa], which was attributed to a decrease in rest times. This study findings are in line with Ratamess et al. (37), who found that [BLa] responses were significantly less in women when compared with men in high-intensity, short-rest, battle ropes exercise. Similarly, RPE was significantly higher during RSSs when compared with TRAD, although no sex differences were present. Higher RPE during an intense session may be indicative of enough stimuli to promote resistance adaptations, as RPE has been used as a marker of the psychophysiological response to a training session (16,21). Furthermore, RPE can be used as a tool to use for proper training progression, and a lack of difference between sexes during the RSS and TRAD means that similar work was performed respective to the athlete.

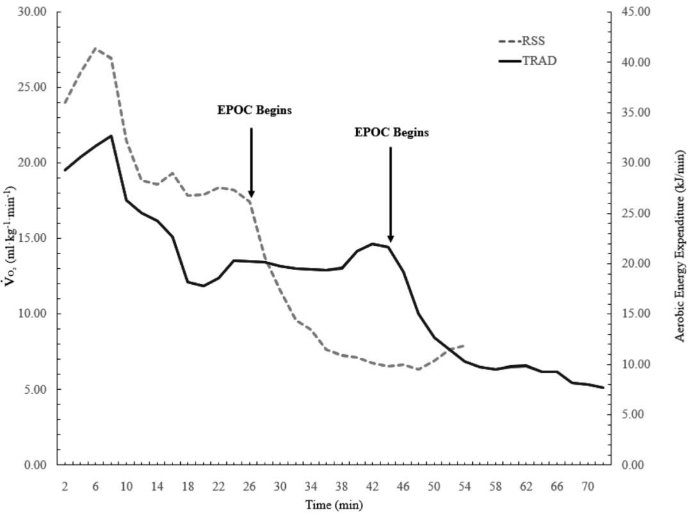

Figure 2. Oxygen consumption responses during reciprocal supersets (RSSs) and traditional resistance exercise (TRAD). Measurements were an average of 2-minute time intervals during sessions. EPOC = excess post-exercise oxygen consumption.

Responses of %HRmax and %$\dot{V}O_2$max during RSSs were higher when compared with TRAD. According to the ACSM's guidelines, these values define a RSS as a moderate-to-vigorous intensity aerobic exercise, which is important for the fulfillment of 150 minutes of moderate intensity cardiorespiratory exercise per week (1). Previous RSS research did not assess %HRmax or %$\dot{V}O_2$max, although similar responses have been found with other RE modalities that include decreased rest times or continuous RE (3,32). This is a novel and relevant finding of this investigation, and the comparison of breathing kinetics can be seen in Figure 2. Although differences in energy expenditure between RSS and TRAD were not hypothesized, [BLa] and $\dot{V}O_2$ were used to calculate anaerobic and aerobic energy expenditures, respectively (Tables 3 and 4). Given the significantly greater %$\dot{V}O_2$max, [BLa], and %HRmax during RSSs compared with TRAD, both anaerobic and aerobic energy expenditures were significantly higher (Figure 2 and Table 3). When comparing men and women, anaerobic and aerobic energy expenditures were significantly higher in men than in women during RSSs, but not in TRAD (Table 4). The significantly greater %HRmax and %$\dot{V}O_2$max during RSSs are likely due to the training intensity and the decrease in rest time. Training intensity for modalities similar to RSSs, such as circuit weight training, has been shown to acutely increase $\dot{V}O_2$ and HR (2,3,11,34). It should be noted that long-term adaptations and increases in $\dot{V}O_2$max are largely reflective of initial training status (33). The decreased rest times between sets has been shown to be a key contributor to cardiorespiratory responses during RE (26,29) and may be a strong enough stimulus to increase $\dot{V}O_2$max over a prolonged training period (18). By contrast, other studies using shorter rest periods with a TRAD protocol observed no significant change in $\dot{V}O_2$max over 12 weeks (7). For now, it is unclear whether short rest intervals may lead to aerobic adaptations after acute bouts of exercise and long-term training studies.

Excess post-exercise oxygen consumption was significantly higher in RSSs when compared with TRAD (Table 3). Because more perturbations from homeostasis occur in RSSs when compared with TRAD (Figure 2), this likely explains the differences observed in EPOC, which are similar to findings in previous studies (5,19). Still, it is important to note that sex differences in EPOC are apparent. During RSSs, men had higher EPOC than women, although this difference was not seen in TRAD. This can likely be explained by the higher average [BLa], anaerobic energy expenditure, and aerobic energy expenditure exhibited by men (Table 4). To the author's best knowledge, this is the first study to compare sex differences in EPOC after RE with short rest times, and more specifically RSSs. The increase in EPOC in RSSs compared with TRAD is in line with previous research regarding SSs training (26). Kelleher et al. (26) assessed EPOC for 60 minutes after RSSs and found a significantly higher response when compared with TRAD. Similarly, DeGroot et al. (11) assessed EPOC during and after a 4-circuit training trial with either a 30- or 60-second rest between sets and found higher EPOC occurred after shorter rest times compared with longer rest times. Both of these studies displayed significantly greater EPOC after shorter rest periods between exercise sets, which supports the idea that less recovery during exercise may produce greater metabolic perturbations, which in turn appreciatively increase EPOC. Increases in EPOC would allow for greater caloric expenditure at rest and may help with weight management of clients or athletes.

A limitation of this study is that exercise tempo, or the time during concentric and eccentric muscle action, was not standardized in either RE trial. To increase practicality and to mimic a realistic training session, subjects were encouraged to lift at a tempo that they were accustomed. Furthermore, our subjects were young, resistance-trained, and aerobically fit individuals, which may mean the generalizability to other populations is not applicable. A final limitation for the study is that RSS and TRAD trials were not randomized or counterbalanced. As performed in previous studies (22,26), the RSS trial was performed first for all subjects to equate volume-load during the subsequent TRAD trial.

Practical Applications

The current study shows that the RSS produces an acutely higher metabolic and physiological demand on the body than volume-load equated TRAD. In addition, RSSs may provide a cardiorespiratory exercise benefit according to the ACSM's guidelines. The time-saving design of RSSs may provide a new and compelling method of training for some athletes and exercise enthusiasts seeking an effective time-saving exercise program. For other athletes, RSSs may be used to decrease training intensity while eliciting increased metabolic demands, thus increasing the work capacity while simultaneously acting as a deload. Similarly, the use of RSSs during a periodized hypertrophy or strength block can be used to evoke increases in muscular endurance as a secondary training focus.

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