THE METABOLIC COSTS OF RECIPROCAL SUPERSETS VS. TRADITIONAL RESISTANCE EXERCISE IN YOUNG RECREATIONALLY ACTIVE ADULTS

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ABSTRACT

Kelleher, AR, Hackney, KJ, Fairchild, TJ, Keslacy, S, and Ploutz-Snyder, LL. The metabolic costs of reciprocal supersets vs. traditional resistance exercise in young recreationally active adults. J Strength Cond Res 24(4): 1043–1051, 2010—An acute bout of traditional resistance training (TRAD) increases energy expenditure (EE) both during exercise and in the postexercise period. Reciprocal supersets (SUPERs) are a method of resistance training that alternates multiple sets of high-intensity agonist-antagonist muscle groups with limited recovery. The purpose of this study was to compare the energy cost of SUPERs and TRAD both during and in the postexercise period. We hypothesized that SUPERs would produce greater exercise EE relative to the duration of exercise time and greater excess postexercise oxygen consumption (EPOC) than TRAD of matched work. Ten recreationally active, young men each participated in 2 exercise protocols: SUPER, followed 1 week later by TRAD matched within using a 10-repetition maximum load for 6 exercises, 4 sets, and repetitions. Participants were measured for oxygen consumption and blood lactate concentration during exercise and 60 minutes postexercise after each exercise bout. No significant differences were observed in aerobic exercise EE between trials (SUPER 1,009.99 ± 71.42 kJ; TRAD 954.49 ± 83.31 kJ); however, when expressed relative to time, the exercise EE was significantly greater during SUPER (34.70 ± 2.97 kJ min⁻¹) than TRAD (26.28 ± 2.43 kJ min⁻¹). Excess postexercise oxygen consumption was significantly greater after SUPER (79.36 ± 7.49 kJ) over TRAD (59.67 ± 8.37 kJ). Average blood lactate measures were significantly greater during SUPER (5.1 ± 0.9 mmol L⁻¹) than during TRAD (3.8 ± 0.6 mmol L⁻¹). Reciprocal supersets produced greater exercise kJ min⁻¹, blood lactate, and EPOC than did TRAD. Incorporating this method of resistance exercise may benefit exercisers attempting to increase EE and have a fixed exercise volume with limited exercise time available.

KEY WORDS energy expenditure, agonist-antagonist, EPOC, weight training

INTRODUCTION

Energy expenditure (EE) includes the total number of kilojoules metabolized by the body at any given point in time (9). Exercise EE is the additional expenditure above baseline because of mechanical work and metabolic perturbation associated with physical activity. After exercise has ceased, EE can remain elevated while the body returns to homeostasis (5). Exercise mode, intensity, duration, and recovery (type and time) are all essential factors affecting the total quantity of kilojoules expended (exercise EE and postexercise EE) (2, 8, 11, 13, 26). One commonly adopted mode of exercise is resistance training, because of its capacity to increase muscle mass, strength, and endurance (3, 5, 7, 13, 17, 20–24). In this regard, aerobic-based exercise and low- to moderate-intensity resistance exercise are commonly recommended for weight loss (24, 26). In addition, high-intensity resistance exercise increases total EE, particularly by enhancing the postexercise EE (7, 21, 22, 24, 26). However, not all methods of resistance training (i.e., traditional, circuit, and superset) are likely to produce the same total EE.

Traditional resistance training (TRAD) involves completing a set of repetitions to failure followed by an adequate rest period before subsequent bouts of the same exercise. During rest periods, between sets of fatiguing contractions, increased EE is associated with repletion of muscular energy substrates, elevated body temperature, and altered hormone release (5). Circuit training is another method of resistance training that incorporates different exercises in succession with the same duration or shorter rest periods than commonly employed in TRAD (15, 22). Compared with TRAD, this method of training attempts to increase exercise intensity (defined by...
Reciprocal Supersets vs. Traditional Resistance Exercise

work per time) by shortening systemic rest duration between sets. However, because exercises are performed in succession, it typically extends recovery time per muscle by increasing the duration between subsequent sets of the same exercise. Reciprocal supersets (SUPERs), also known as agonist–antagonist superset training (19), consist of performing 2 consecutive exercises on opposing muscle groups while limiting the rest duration between the exercises. This method of training somewhat hybridizes the TRAD and circuit-training methods to increase exercise intensity with shortened rest periods, and greater fatigue ensues because of brief local muscle recovery.

Reciprocal supersets are likely to produce greater metabolic energy costs than TRAD training because of the reduced recovery time, which leads to greater metabolic perturbation and fatigue. Accordingly, studies by DeGroot et al. (11,12) and Haltom et al. (15) evaluated EE during and 1 hour after bouts of matched work, which included rest periods between sets of 30 vs. 60 seconds, or 20 vs. 60 seconds, respectively. Although absolute EE was greater during the longer exercise bouts, those bouts with shorter rest periods between sets produced greater exercise EE relative to the duration of exercise (kcal·min⁻¹), blood lactate, and excess postexercise oxygen consumption (EPOC). In a separate study by Epstein et al. (14), subjects walking on a treadmill for 120 minutes under a constant backpack load of 40 kg demonstrated a significant increase in EE across the 120 minutes. The increase in energy cost across time was attributed to physical fatigue, which altered locomotion biomechanics. Taken together, exercise methods, such as SUPER, which incorporate short rest periods between sets are likely to display elevated EE relative to the duration of exercise time (kJ·min⁻¹), blood lactate, and EPOC by reducing recovery time and inducing greater fatigue than traditional exercise methods.

Although previous research has used supersets as an exercise protocol to evaluate isometric strength, rate of force development, and muscle endurance (16,19), no previous study, to the authors’ knowledge, has evaluated the metabolic cost of SUPER. In one of these studies, contraction patterns of quadriceps and hamstrings were evaluated with and without prefatigued antagonist muscle groups (19). The results showed that prefatiguing the hamstrings reduced peak torque, power, and rate of force development in the quadriceps, and increased electromyogram (EMG) activity by 25% in the hamstrings during knee extension (19). The increase in EMG suggests that a greater number of motor units were activated, which would theoretically require greater energy expenditure, although this has not been empirically shown. Therefore, the EE in response to SUPER remains to be established.

Reciprocal supersets are a common method of resistance training, assumed to produce greater metabolic energy costs, but there is no scientific evidence to support this. The hypothesis for greater metabolic cost is based on observed increases in EE with fatigue, EE relative to the duration of exercise time, and EPOC when rest duration is limited during circuit training (8,11,14,15,19,22). Therefore, the purpose of this study was to compare the energy cost of SUPER and TRAD, both during and immediately after the exercise period. We hypothesized that SUPERs produce greater EE relative to the duration of exercise time and greater EPOC than TRAD.

**METHODS**

**Experimental Approach to the Problem**

All subjects participated in a 2-test, crossover research design. One repetition maximum (IRM) strength testing was performed 5–7 days before the first test. Participants then completed 2 testing sessions with a recovery period of 7 days between each. Seven days was chosen as an appropriate nonresistance exercise period between tests to wash out the effects of muscle recuperation on EE (13). Participants were asked to refrain from any supplementary exercise during the course of the study. Comparing the difference in EE between SUPER and TRAD, the experiment was designed to specifically focus on the effect of rest duration between exercise sets on EE because this is a distinguishing characteristic of SUPER from TRAD. Because it is already well known that EE is directly related to total work, it was necessary to match total work in the SUPER and TRAD test sessions. Thus, the SUPER and TRAD test sessions were matched for exercises, sets, load, repetitions, and repetition speed to isolate the method of resistance training (rest duration between exercise sets) as an independent variable on EE. Each participant completed the SUPER test day first, followed by matched sets, repetitions, and loads for the TRAD test 1 week later. Reciprocal supersets were always performed during the first test because pilot testing showed subjects to reach volitional fatigue after fewer repetitions associated with supersets compared with TRAD. Thus, the test attaining fewer repetitions had to be completed first in order to match work in the second test. Resting energy expenditure (REE) was assessed for at least 25 minutes, and resting breath-by-breath was assessed for at least 10 minutes before exercise to establish baseline EE. After baseline, participants completed a resistance exercise protocol while expired air was collected continuously and blood lactate samples were collected every 6 minutes. In the 60 minutes after the resistance exercise protocol, expired air was collected continuously for evaluation of EPOC, and blood lactate was sampled every 15 minutes (15,20). Dietary intake was monitored through journal records and matched between tests to confirm similar intake.

**Subjects**

Ten recreationally active men (21.7 ± 2.1 years; 175.4 ± 6.9 cm; and 75.3 ± 7.8 kg) participated in the study. Men were used exclusively for this study measuring EE, to control for potential differences between sexes because of hormonal
fluctuations with menstrual cycle that can influence REE. Recreationally active was defined as engaging in 45–90 minutes of traditional resistance training 2–4 times per week for at least the past 6 months before enrollment. None of the participants had trained using SUPER before this study. All research procedures were approved by the Institutional Review Board at Syracuse University, and all subjects signed an approved written informed consent form before participation.

Procedures

One Repetition Maximum Strength Testing. Five to 7 days before the first test session, participants underwent 1RM testing on each of the 6 exercises (bench press, bent over row, biceps curls, triceps extensions, leg extensions, and leg curls) in that order to mimic the exercise protocol used during testing. One testing session was deemed sufficient in determining 1RM because all subjects were familiar with the exercises. Before 1RM testing, all participants were asked to refrain from exercise for 72 hours. Testing was conducted according to the guidelines set forth by the National Strength and Conditioning Association (1) involving a warm-up set followed by appropriate incremental increases in load until reaching 1RM without fatiguing the participant (5 attempts or less). A research assistant determined the success and failure of each 1RM test.

Dietary Intake Journal. Dietary intake is known to affect metabolic rate (10); therefore, we attempted to minimize this variable by instructing subjects to follow their normal diet between testing sessions. No nutritional intervention was implemented, but to maintain consistent diets between trials, 3-day dietary journals were completed 2 days before and through the testing session. Participants were encouraged to keep their normal dietary habits and were educated on proper dietary recording, including listing the brand and serving sizes by a member of the research team. Participants were given the same dietary journals for the second test along with their journal entries from the first test to match intake.

Resistance Exercise Protocols. The final 1RM load achieved through testing was used to calculate 70% 1RM for exercise loads (1). All participants completed 4 sets to volitional fatigue of each exercise in the following order: bench press, bent over row, biceps curls, lying triceps extension, leg extension, and leg curl. The order was established by placing compound exercises before isolation exercises and all upper body exercises before lower body exercises to prevent blood pooling in the legs. Reciprocal supersets were grouped in exercise pairs of agonist–antagonist muscle groups (bench press and bent over row, biceps curls and lying triceps extension, and leg extension and leg curl). A reciprocal superset was conducted by completing a set of agonist muscle exercise followed immediately by a set of antagonist muscle exercise. Upon completion of 1 reciprocal superset (e.g., bench press and bent over row), each participant recovered for 60 seconds before beginning the second set of the same reciprocal superset pair. Upon completion of 4 supersets, 60 seconds was given before moving to the next exercise pair (Figure 1A). Traditional resistance training used the same 70% 1RM loads but completed 1 set for an exercise followed by 60 seconds before subsequent sets of the same exercise. Completing all 4 sets for an exercise, 60 seconds was given before beginning the first set of the next exercise (e.g., 4 sets bench press, 4 sets bent over row; Figure 1B). All work performed during the SUPER test to volitional fatigue was recorded and matched in the TRAD test. All repetitions for both exercise protocols were maintained at a speed of 2 seconds for both concentric and eccentric movements.

Resting Energy Expenditure. Resting energy expenditure was established using the procedures described by Compher
et al. (10) for indirect calorimetry. Resting energy expenditure was measured before each resistance training session (~1:30–7:00 PM) using a Sensormedics Vmax series metabolic cart (Anaheim, CA, USA) and hood. Before testing, participants were instructed to refrain from aerobic and resistance exercise for 72 hours, consuming alcohol for 24 hours and caffeine for 12 hours. All subjects self-reported little to no routine alcohol and caffeine consumption, and there were no reports of withdrawal experienced throughout the study. All participants were fasted for at least 5 hours before REE measurement; however, water intake was encouraged, and it is believed that all subjects entered the laboratory in a euhydrated state. For each REE test, the metabolic cart was calibrated with known gas concentrations and volume using a 3-L syringe. Each participant was asked to remain supine in a quiet, dark thermoneutral (20–24°C) environment for ~30 minutes. Resting energy expenditure was recorded as the mean of the median 10 minutes of measurement of steady state oxygen consumption ($\dot{V}O_2$).

Energy Expenditure during Exercise and Excess Postexercise Oxygen Consumption. After REE measurement, participants were fitted with a face mask attached to a Cosmed electronic metabolic cart with Quark b$^2$ breath-by-breath pulmonary gas exchange system (Rome, Italy). Participants sat quietly for at least 10 minutes to establish a baseline measurement for the metabolic cart before initiating any resistance exercise. The metabolic cart was calibrated for gas concentration and volume in the same manner as described above. Participants remained fitted to the metabolic cart throughout exercise to measure aerobic EE. Aerobic EE was calculated according to the total volume of oxygen consumed and respiratory exchange ratio values using the Weir equation for resting measurements, and exercise aerobic EE $= [ (4.210 (\dot{V}CO_2) - 2.962 (\dot{V}O_2)) (4.07 \text{ kcal}) + [(1.695 (\dot{V}O_2) - 1.701 (\dot{V}CO_2)) (9.75 \text{ kcal})]$ during moderate to high-intensity exercise (18). Both measurements were then converted to kilojoules by the conversion factor (1.00 kJ/0.239 kcal). Anaerobic EE could not be calculated during the exercise period. Postexercise lactate samples were converted to kilojoules using the equation (millimole increase in lactate $[0.02698 \text{ kcal kg}^{-1}\text{.body mass}]) (1.00 \text{ kJ/0.239 kcal})$ as outlined by Mazzetti et al. (20). Excess postexercise oxygen consumption measurements began immediately after completion of the exercise protocol after the participant was placed back under the REE hood. Excess postexercise oxygen consumption was continually collected for 60 minutes postexercise and converted to EE using the Weir equation

![Figure 2](image-url)

**Figure 2.** (A) Mean aerobic energy expenditure (EE) per minute measures averaged every minute during exercise. Reciprocal superset exercise (SUPER) depicted by the solid line represents the mean exercise aerobic (kJ min$^{-1}$) during reciprocal supersets. Traditional resistance exercise (TRAD) depicted as the dashed line represents measures taken during traditional resistance exercise. Mean exercise duration for the 2 protocols, SUPER: 31 minutes; TRAD: 40 minutes, mean ± SE. (B) Mean aerobic exercise EE corrected for time (kJ min$^{-1}$). #Significantly different (p < 0.05) between tests, mean ± SE.
equation (5,17,20,21). Sixty minutes of postexercise, $\dot{V}O_2$ was chosen for measurement because of consistent returns to baseline measures in pilot testing and in conjunction with the postexercise assessment period of other resistance training EE studies (15,20). Aerobic exercise EE, EE relative to the duration of exercise time, EPOC, and postexercise anaerobic EE were all compared between trials. Total EE was calculated by adding aerobic exercise EE and both the aerobic and anaerobic EEs during the 60 minutes postexercise. Aerobic exercise EE and EPOC were calculated by summing up the $\dot{V}O_2$ measurements per minute for the duration of the exercise and EPOC periods per subject per test. Mean exercise EE per time (kJ min$^{-1}$) was calculated by dividing aerobic exercise EE by the number of minutes. Subjects could not consume water during the exercise and EPOC periods but were given approximately 8–12 ounces of water transitioning from the end of exercise to the EPOC measuring period, because this does not significantly affect REE (10).

Lactate Concentration Sampling. $\dot{V}O_2$ alone does not provide a complete evaluation of total EE (20,25). Blood lactate concentration measurements taken during and after the exercise protocols were included as a reflection of anaerobic metabolism. After baseline was measured on the metabolic cart, a resting fingerstick blood lactate sample was obtained. Approximately 35 $\mu$L of blood was taken per sample and immediately transferred to BM-Lactate strips and analyzed using the Accutrend Lactate analyzer (Roche Diagnostics GmbH; Mannheim, Germany). Samples were taken every 6 minutes after the initiation of exercise, one immediately upon completing the exercise protocol and every 15 minutes during the postexercise period (Figure 1).

Statistical Analyses
Separate paired $t$-tests were used to compare SUPER with TRAD for exercise EE, EE relative to duration of exercise time, 1 hour EPOC, and exercise lactate measures.

Postexercise lactate measures were compared using a $2 \times 5$ repeated measures analysis of variance, followed up with 1 paired $t$-test per time point without alpha inflation. Total metabolic cost was determined by summing aerobic exercise EE, EPOC, and postexercise anaerobic EE in kilojoules (kJ) for both tests and compared using paired $t$-test. Statistical significance was determined by $p \leq 0.05$.

**Results**

**Exercise Aerobic Energy Expenditure**
Aerobic EE during SUPER was not significantly different between tests (SUPER 1,009.99 ± 71.42 kJ; TRAD 954.6 ± 83.31 kJ), $p = 0.371$, despite what appears to be a consistent elevation in oxygen consumption for SUPER above TRAD (Figure 2A). When expressed relative to duration of exercise
time, EE per minute was significantly greater during SUPER (34.70 ± 2.97 kJ/min⁻¹) compared with TRAD (26.28 ± 2.43 kJ/min⁻¹), $p < 0.001$ (Figure 2B).

**Excess Postexercise Oxygen Consumption**

Aerobic EE following SUPER was higher than TRAD (Figure 3A). Excess postexercise oxygen consumption converted to EE in kilojoules (Figure 3B) was 33.0% higher after SUPER compared with TRAD ($p \leq 0.001$). Analyzing the 60 minutes postexercise, aerobic EE was significantly greater between resistance exercise tests (SUPER 79.36 ± 7.49 kJ; TRAD 59.67 ± 8.37 kJ), $p < 0.001$.

**Blood Lactate**

Peak lactate during the exercise protocols was significantly greater in the SUPER (11.7 ± 1.2 mmol·L⁻¹) compared to TRAD (8.8 ± 1.1 mmol·L⁻¹), $p = 0.009$. Furthermore, mean elevations above baseline in blood lactate per measure during resistance exercise were significantly greater for SUPER (5.1 ± 0.9 mmol·L⁻¹) compared with TRAD (3.8 ± 0.6 mmol·L⁻¹), $p = 0.030$ (Figure 4). After exercise, a significant time by test effect was observed between postexercise measures, $p = 0.003$. Follow-up posthoc analysis revealed that SUPER (10.79 ± 1.49 mmol·L⁻¹) was greater than TRAD (6.75 ± 0.97 mmol·L⁻¹) immediately postexercise, $p = 0.002$ (Figure 5); however, no differences in lactate were observed between tests for the remainder of the postexercise period (15 minutes $p = 0.303$; 30 minutes $p = 0.390$; 45 minutes $p = 0.974$; and 60 minutes $p = 0.605$). Blood lactate concentration remained elevated above baseline

![Figure 4](image1.png)

Figure 4. Mean blood lactate measure sampled every 6 minutes during exercise. Reciprocal superset exercise (SUPER) depicted by the solid line with diamond points represents the mean blood lactate measures during reciprocal supersets. Traditional resistance exercise (TRAD) depicted as the dashed line with square points represents measures taken during traditional resistance exercise.

![Figure 5](image2.png)

Figure 5. Mean blood lactate measure sampled every 15 minutes postexercise during the 60-minute excess postexercise oxygen consumption (EPOC) period. Reciprocal superset exercise (SUPER) depicted by the solid line with diamond points represents the mean blood lactate after reciprocal supersets. Traditional resistance exercise (TRAD) depicted as the dashed line with square points represents measures taken after traditional resistance exercise. The dotted black line at the bottom represents pre-exercise baseline extrapolated across the EPOC period. #Significantly different ($p < 0.05$) between tests. ○Significantly different ($p < 0.05$) from baseline lactate measures.
measures up to 45 minutes postexercise for both tests ($p < 0.05$) and had returned to baseline measures at 60 minutes (SUPER $p = 0.333$; TRAD $p = 0.123$). Converting to kilojoules, SUPER expended an additional 76.20 ± 16.57 kJ postexercise because of anaerobic EE, whereas TRAD required an additional 71.39 ± 10.33 kJ postexercise because of anaerobic EE.

**Total Metabolic Cost**

The mean aerobic EE during SUPER was (13.47 ± 0.94 kJ·kg$^{-1}$; 1,009.99 ± 71.42 kJ) whereas the mean during TRAD was (12.75 ± 1.08 kJ·kg$^{-1}$; 954.49 ± 83.31 kJ). The mean 1 hour EPOC after SUPER was (1.05 ± 0.08 kJ·kg$^{-1}$; 79.36 ± 7.49 kJ), whereas the mean after TRAD was (0.80 ± 0.13 kJ·kg$^{-1}$; 59.67 ± 8.37 kJ). Using the equation provided by Mazzetti et al. (20), the mean postexercise anaerobic EE for SUPER was (1.00 ± 0.21 kJ·kg$^{-1}$; 76.20 ± 16.57 kJ), whereas the mean for TRAD was (0.96 ± 0.17 kJ·kg$^{-1}$; 71.39 ± 10.33 kJ). Summing up each of these measures above to compare total metabolic cost between groups, there were no significant differences between SUPER (15.52 ± 1.13 kJ·kg$^{-1}$; 1,165.57 ± 85.86 kJ) and TRAD (14.52 ± 1.17 kJ·kg$^{-1}$; 1,085.57 ± 86.78 kJ; $p = 0.265$; kJ; $p = 0.252$). The calculations for total metabolic cost did not include anaerobic EE during exercise, because we could not account for the production and clearance of lactate.

**DISCUSSION**

A number of studies have shown that resistance training increases EE both during (20) and immediately postexercise (5,7,24,26). Resistance exercise protocols vary considerably with regard to the specific exercises performed. Additionally, the intensity, speed, number of sets, and repetitions, in which the exercises are completed can influence EE. Energy expenditure has been assessed in traditional (5,26), circuit (8,15,22), and explosive resistance exercise (20), but SUPERs have not been previously evaluated. The premise of SUPER is to increase EE relative to the duration of exercise time by exercising to fatigue in a reduced exercise time. According to the literature on EE with matched work in shorter time periods (15), and with fatigue (14), it is reasonable to hypothesize that EE·min$^{-1}$ and EPOC would be higher for SUPERs. Thus, the purpose of this study was to quantify the EE of SUPER and compare it with that collected from matched work of TRAD.

The major finding of this study was that the EE between SUPER and TRAD was not significantly different; however, because of the SUPER being completed in a shorter time period, the EE relative to the duration of exercise time was significantly greater during SUPER compared with TRAD. This finding is in line with our hypothesis that SUPERs would produce greater EE relative to the duration of exercise time because of the EE associated with both mechanical work and metabolic perturbation. One may interpret this finding as being indicative that despite greater metabolic perturbations associated with SUPER, as evidenced by greater lactate concentrations and EE per time, this did not affect the absolute EE necessary to complete the work. This may in part be explained by this study controlling the speed at which each repetition was completed.

Similar aerobic exercise EE between SUPER and TRAD is in opposition to the results observed by DeGroot et al. and Haltom et al. (11,15) when comparing resistance training methods. In their studies using matched work with 30 vs. 60 seconds or 20 vs. 60 seconds between sets, respectively, they observed greater aerobic exercise EE·min$^{-1}$ with shorter recovery periods between sets, but aerobic exercise EE was greater during the longer protocols. The authors attribute greater aerobic exercise EE to longer exercise durations, which allows more time to sum elevated EE. However, despite longer exercise duration during TRAD, no significant differences in aerobic exercise EE were observed between these 2 different methods of resistance exercise.

In line with the hypothesis, EPOC after SUPER was significantly greater than TRAD. SUPERs include both greater aerobic exercise EE per unit time and greater metabolic disruption from homeostasis than traditional resistance exercise, which is likely to explain the greater EPOC observed (5,7,15,16). Mean $V_O_2$ began at the same value between protocols, but $V_O_2$ declined slowly to baseline after SUPER compared with TRAD.

Greater EPOC after SUPER compared with TRAD is in line with other resistance exercise studies. Murphy and Schwarzkopf (22) assessed EPOC after bouts of either standard set weight training at 80% 1RM with 120 seconds between sets or circuit training at 50% 1RM with 30 seconds between sets. Although work was not matched, this study lends support to greater EPOC after an exercise protocol with shorter recovery between sets. DeGroot et al. (11) assessed $V_O_2$ during and after 4 circuit-training trials with either 30- or 60-second rest between sets using loads of either 40 or 60% 1RM. In this study, 40% 1RM trials were matched for work, as were the 60% 1RM trials matched with each other. Haltom et al. (15) performed a similar study using matched work with either 20- or 60-second rest between circuit training sets at 41.4% 1RM. Both of these studies displayed significantly greater EPOC after those trials with shorter recovery periods between exercise sets, lending support to the notion that less recovery during exercise produces greater EE-associated metabolic perturbations, which in turn increase EPOC. In support of these studies and the hypothesis, SUPER as a method of resistance training incorporating fewer recovery periods within a work-out than TRAD produced greater EPOC.

Less recovery from supramaximal exercise during SUPER is likely to result in higher blood lactate concentrations because of greater anaerobic metabolism. At supramaximal exercise intensity, the accumulation of pyruvate is greater than the clearance of pyruvate via oxidative metabolism (4). After cessation of exercise, energy production falls within
aerobic metabolism capacity (9). Less recovery during SUPER is likely to produce greater blood lactate concentrations because of less time when energy production is low enough for aerobic metabolism alone to meet energy demand. Elevated lactate measurements during and after exercise were also the result of slow rates of blood lactate clearance, typically metabolized via the Cori cycle (4,6,9). These rates of blood lactate appearance and disappearance are important for quantifying kilojoules from lactate as an indication of anaerobic EE. According to the results, the imbalance between lactate accumulation and clearance is greater during SUPER, but exercise lactate measures could not be converted to kilojoules as a reflection of anaerobic EE without knowing the clearance rate. Blood lactate accumulation was measured because it is linked with exercise anaerobic EE (20,25). However, periodic fingertip samples during and after exercise do not provide accurate assessments of EE. Therefore, lactate measures were collected to compare between tests, but they could not provide a substantial contribution to assessing EE without knowing rates of appearance and disappearance.

\( \text{VO}_2 \) and lactate measures were both included to give a full analysis of total metabolic cost between SUPER and TRAD. The most important finding from this study was the observation of greater EE relative to the duration of exercise time after SUPER. Despite no differences in absolute exercise EE between exercise protocols of matched work, SUPER displayed greater exercise EE-min\(^{-1}\). Furthermore, EPOC was significantly higher after SUPER compared with TRAD. Blood lactate measures were higher during and immediately after SUPER compared with TRAD; however, these lactate measures could not accurately quantify anaerobic EE.

The implications of this study should be accepted with caution as there are limitations to the experiment. Energy expenditure was not measured using direct calorimetry. However, significant differences in EE have not been found between direct and indirect calorimetry methods (9). In addition, proportions of metabolic substrate use are known to change with increasing exercise intensity. To account for increased EE primarily from stored muscle glycogen stores with intense resistance training exercise, EE in kilojoules was calculated from collected expiratory gas ratios using a known equation for exercise above 75% VO\(_{2}\max\) (18). Periodic lactate samples provide only a kinetics of lactate changes throughout the exercise and postexercise periods. These measures provided for consistent lactate level comparison between tests. The postexercise measures allow for calculating postexercise anaerobic EE according to the protocol used by Mazzetti et al. (20). Finally, the subjects in this study were young, healthy, recreationally active men, and so the results may not be generalized to the entire population.

To isolate and evaluate the method of resistance training (how rest between sets of resistance exercise affects EE), the experimenters were forced to control for work between the exercise protocols. Although this analysis indicates that SUPERs produce higher EPOC and blood lactate measures than does matched work of TRAD, this study does not indicate whether SUPERs necessarily expend more energy in a practical context. Having more rest between sets in our TRAD protocol, meant that subjects did not reach volitional fatigue within each exercise set when work was matched with the SUPER protocol. Therefore, it is likely that greater increases in EE would be observed if these subjects were allowed to exercise to volitional fatigue in the TRAD protocol because of additional work performed with TRAD. With this in mind, it is important to note that the results of this study only apply to matched workloads of SUPER and TRAD for a carefully controlled comparison between these 2 resistance training methods. It should be understood that this experiment is the first to compare EE between multiple sets of SUPER and TRAD, and the purpose of this study was to provide an initial assessment of how the limited rest associated with SUPER affects EE.

**Practical Applications**

The implications of this study appeal predominantly to experienced exercisers looking to increase EE with a limited duration exercise session. Total kilojoules were not significantly different between trials, but SUPER metabolized more kilojoules relative to the duration of exercise time than did TRAD. Therefore, if more kilojoules can be metabolized within the same limited timeframe, SUPERs present a convenient form of resistance training for the exerciser looking to increase EE with limited exercise time. In particular, this form of training could appeal to lunch-break exercisers, personal training clients, or others who have a fixed period of approximately 30–40 minutes to exercise. However, the reader should be aware that these results only apply to matched-work comparisons between SUPER and TRAD. Although SUPER could potentially produce greater EE completing more total work in a fixed timeframe, this study did not measure EE when subjects exercised to volitional fatigue in both SUPER and TRAD protocols. Although this study did not evaluate the long-term training adaptations associated with SUPER and TRAD, it is likely that SUPER and TRAD would elicit different training adaptations. It is possible to speculate that SUPER training would elicit higher EE and enhance muscular endurance and TRAD would elicit greater increases in muscle strength. Additional studies would be required to confirm long-term training adaptations.

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