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Less time, same gains: Comparison of superset vs traditional set training on muscular adaptations

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ABSTRACT

The purpose of this study was to compare the effects of superset versus traditional resistance training (RT) on muscular strength, hypertrophy, body composition, and endurance. Forty-three young, resistance-trained male and female participants were randomly assigned to either a superset RT group (SS) or a traditional RT group (TRAD). The RT protocol targeted the upper and lower body musculature using six exercises (lat pulldown, Smith machine bench press, seated leg curl, leg extension, dumbbell biceps curl, and cable triceps pushdown). All exercises were performed in the same session, twice weekly for eight consecutive weeks. Participants performed four sets of each exercise to muscular failure with loads equivalent to 8-12 RM under supervision of research assistants. Participants in TRAD completed all sets for one exercise prior to performing a different exercise with two minutes of rest between sets. Participants in SS performed a set for one exercise followed immediately by a set for another exercise then two minutes of rest, which was repeated for a total of four sets per superset. Potential group differences were assessed within a Bayesian framework, with Bayes factors (BF) used to assess the strength of evidence. Consistent evidence was obtained that both groups generally experienced the same average increases in muscle thickness across all assessed muscle groups ($\underline{BF}$= 0.54, range: 0.23 to 1.3) as well as the same average changes in strength ($\underline{BF}$= 0.28, range: 0.14 to 0.41), power (BF= 0.22), local muscular endurance ($\underline{BF}$= 0.59, range: 0.54 to 0.63), and body composition outcomes ($\underline{BF}$= 0.19, range: 0.13 to 0.24). Despite similar estimates of between-group changes, SS completed sessions in 36% less time than TRAD. In conclusion, supersets appear to be a time-efficient alternative for eliciting muscular adaptations in a resistance-trained population.

Keywords: paired set; agonist-antagonist; time-efficient training; muscle hypertrophy; strength, perceived exertion

INTRODUCTION

Individuals of various populations engage in resistance training (RT) with the goal of gaining muscle mass (1,2). A typical RT session often involves completing all sets of a particular exercise before performing a different exercise with up to several minutes of rest between sets. Training in such a manner, however, may pose time-related issues for some, making it difficult to achieve sufficient weekly set volume necessary to maximize muscle growth. Although one can reduce inter-set rest intervals to shorten the duration of a training session, limiting inter-set rest to sixty seconds or less may limit performance in subsequent sets due to insufficient recovery, and consequently reduce muscle hypertrophy (1,3–6).

To counteract issues associated with limited training time and avoid compromising progress, some individuals seek to achieve greater training session density (i.e. accomplishing more exercise in less time) by implementing time-saving strategies such as superset RT. Specifically, superset RT involves the performance of two or more exercises consecutively with minimal to no rest between sets (7,8). Practitioners can employ various superset strategies such as pairing exercises targeting agonist muscles (e.g. leg extension and back squat), unalike muscle regions (e.g. bench press and back squat) or opposing muscle regions exhibiting an agonist-antagonist relationship (e.g. biceps curl and triceps pushdown). For the purpose of this paper, we define superset RT as performing two exercises for agonist-antagonist muscle groups in succession with minimal rest.

Current research indicates that when sets are performed to muscular fatigue, a RT session consisting solely of supersets can be completed in roughly half the time compared to traditional sets without reductions in total repetitions performed or volume load (i.e. sets x repetitions x load) (8–11). Moreover, some evidence suggests that pre-fatiguing the antagonist may acutely increase neural drive to the agonist, resulting in enhanced force production and the ability to perform more repetitions to fatigue during the second exercise in a superset pair (9,10). Based on these acute findings, it is reasonable to hypothesize that long-term adherence to superset RT may lead to greater total volume load, and thus superior gains in muscle hypertrophy compared to traditional RT. However, only two longitudinal studies have assessed changes in muscle hypertrophy when comparing superset to traditional RT (11,12). Both studies reported similar increases in muscle mass (11,12), with one study reporting no between-group differences in volume load (11), whilst the other equated volume load between conditions (12). Additionally, Fink et al. (11) observed greater increases in muscle endurance with superset compared to traditional RT over an 8-week study period, which has been purported to be attributed to the ability to tolerate greater levels of metabolic stress and fatigue induced by the condensed training time of a superset RT session (11,13,14).

The findings of Fink et al. (11) and Pringga et al. (12) are intriguing, especially given that they suggest superset RT is a time efficient strategy to augment muscular adaptations without compromising gains in muscle mass. It is important to note, however, that both Fink et al. (11) and Pringga et al. (12) employed relatively small sample sizes (n=23 and n=14) comprising untrained participants, making it difficult to draw strong inferences and extrapolate the findings to resistance-trained populations. Additionally, the RT protocols of both studies comprised only two single-joint exercises, with Fink et al. (11) including the biceps curl and triceps extension performed with resistance bands, and Pringga et al. (12) including the leg curl and extension. These protocols would generally not be considered ecologically valid, given most strength and hypertrophy-oriented RT programs include a combination of several multi- and single-joint weight-based exercises for different body regions. Interestingly, a longitudinal study by Robbins et al. (15) compared the effects of superset versus traditional RT on 1-RM strength in two multi-joint exercises (bench pull and bench press) in resistance-trained individuals and found similar between-group increases in maximal strength following the eight-week training period. However, the RT program employed by Robbins et al. (15) included only the bench pull and press exercises, and the authors did not assess changes in muscle mass.

To the authors' knowledge, no study to date has investigated the effects of a full-body superset RT program consisting of a combination of multi- and single-joint exercises on muscular adaptations in resistance-trained individuals. Given the paucity of research regarding chronic adaptations to superset RT, the purpose of this study was to compare the effects of paired superset versus traditional RT on muscular strength, hypertrophy, body composition, and endurance in resistance-trained individuals across an eight-week study period. We hypothesized that (a) superset and traditional RT would elicit similar increases in strength and hypertrophy in substantially less training time; and (b) superset RT would produce superior increases in local muscle endurance and acute volume load compared to traditional RT.

METHOD

Participants

Participants were fifty male and female volunteers recruited from a university population. *A priori* sample size determination was made using a Bayesian approach to match the final analysis framework and employed a modified version of the workflow suggested by Wang and Gelfand (16). First, prior predictive data for samples of size n were simulated using informative priors (sampling priors). These priors were based on results from a previous randomized controlled trial of resistance training conducted in our laboratory (17), and comprised a mean group difference $N(3,1.2^2)$, a heterogeneous response $N(0,1^2)$, and measurement error $N(0,1.5^2)$. The fitting priors to be used in the final analysis were applied across m=500 iterations. The 95% credible intervals (CrI) generated were used to determine sample size. For n=25 per group the estimated 95%CrI width was 2.6 (95%CrI: 2.1 to 3.2), which accounting for dropouts and a potential sample size of n=20 per group returned an estimated 95%CrI width of 3.0 (95%CrI: 2.3 to 3.7). Relative to the proposed mean difference this was judged to provide suitable precision and would likely be improved when fitting multiple outcome variables.

To qualify for inclusion in the study, the participants were required to be: (a) between the ages of 18-40 years; (b) free from existing cardiorespiratory or musculoskeletal disorders as assessed by the Physical Activity Readiness Questionnaire; (c) self-reported as free from consumption of anabolic steroids or any other illegal agents known to increase muscle size currently and for the previous year; and (d) considered as resistance-trained, defined as consistently lifting weights for both upper and lower body musculature at least three times per week (on most weeks) for at least one year. Participants were asked to refrain from consuming creatine products throughout the course of the study period, since creatine has been shown to augment muscle growth when combined with RT (18).

Participants were randomly assigned to one of two experimental, parallel groups: a superset RT group (SS: n = 25) or a traditional RT group (TRAD: n = 25). Randomization into groups was carried out using block randomization, with two participants per block, via online software (www.randomizer.org). Approval for the study was obtained from the college Institutional Review Board. Written informed consent was obtained from all participants prior to beginning the study. The methods for this study were preregistered prior to data collection (https://osf.io/sy2zk).

Longitudinal Study: Resistance Training Procedures

The RT protocol targeted the upper and lower body musculature using the following six exercises: lat pulldown, Smith machine bench press, seated leg curl, leg extension, dumbbell biceps curl, and cable triceps pushdown. All exercises were performed in the same session, twice weekly for eight consecutive weeks. Participants performed four sets of each exercise with loads equivalent to 8-12 RM under supervision of research assistants, who verbally encouraged participants to perform all sets to the point of momentary muscular failure (i.e. the inability to perform another concentric repetition while maintaining standardized form). Participants in the TRAD group completed all sets for one exercise prior to performing a different exercise with two minutes of rest between sets, while those in the SS group performed a set for one exercise immediately prior to a set for another exercise followed by two minutes of rest and repeated for a total of four sets per superset (Table 1). The transition time between exercises in each superset pair was approximately twenty seconds.

Exercises in the SS group were paired as follows: a) lat pulldown → Smith bench press, b) seated leg curl → leg extension, and c) dumbbell biceps curl → cable triceps pushdown. The order in which the exercises were performed within each superset remained constant for the entire study. However, the order in which supersets "a", "b", and "c" were performed in each session depended on equipment availability in the laboratory at a given moment. Because within-superset exercise order remained constant throughout the study, participants in the TRAD group consistently completed all sets for the exercise performed first in a superset pair prior to performing the latter (i.e. lat pulldown prior to the bench press; seated leg curl prior to leg extension; biceps curl prior to triceps pushdown).

All RT was directly supervised by the research team to monitor the proper performance of the respective routines and ensure participant safety. As previously described (17), the repetition tempo was carried out in a controlled fashion, with a concentric action of approximately one second and an eccentric action of approximately two seconds as visually monitored by the supervising researcher. To maintain the target repetition range, loads were adjusted from set to set within each session in addition to across the duration of the study period. Participants were instructed to abstain from performing any additional RT outside the study itself for the entire duration of the study. Training for both groups consisted of two weekly sessions performed on non-consecutive days for eight weeks. Prior to the eight-week training program, participants underwent ten repetition maximum (10RM) testing to determine individual initial loads for each exercise. The RM testing was consistent with recognized guidelines as established by the National Strength and Conditioning Association (19). Thereafter, participants proceeded to the acute training study (described below) in the next scheduled training session. Following completion of the acute study, participants began the 8-week training protocol.

Table 1: Overview of the RT protocols for TRAD and SS. The remaining exercises were performed in the same manner.

	Set 1		Set 2		Set 3		Set 4
Traditional sets	Lat pulldown	2 min rest	Lat pulldown	2 min rest	Lat pulldown	2 min rest	Lat pulldown
Supersets	Lat pulldown → Smith bench press	2 min rest	Lat pulldown → Smith bench press	2 min rest	Lat pulldown → Smith bench press	2 min rest	Lat pulldown → Smith bench press

*(→) signifies minimum allowable rest between exercises.

Acute Study: Resistance Training Procedures

Following a minimum of 48 hours after the 10RM testing session, an acute crossover design was employed where participants performed two separate training sessions under the TRAD and SS protocols on non-consecutive days. Participants originally allocated to the SS group performed the first training session under the TRAD protocol and the second training session under the SS protocol. Contrariwise, participants in the TRAD group performed the first training session under the SS protocol and the second training session under the TRAD protocol. Both training sessions included four sets of each exercise taken to momentary muscular failure using the 10RM loads arrived at during RM testing. As shown above (Table 1), the TRAD protocol included two minutes of rest between all sets, while the SS protocol included two minutes of rest between supersets.

The exercises in the TRAD protocol were performed in the following order: Lat pulldown, Smith bench press, seated leg curl, leg extension, dumbbell biceps curl, and cable triceps pushdown. The SS protocol was carried out in the following order with exercises paired as supersets: a) lat pulldown → Smith bench press; b) seated leg curl → leg extension; and c) dumbbell biceps curl → cable triceps pushdown. The number of repetitions performed across all sets, rating of perceived exertion for the entire training session (SRPE), and duration of the training session was recorded and compared between trials. Once the final acute session was completed, participants began the eight-week training program solely under their allocated condition (TRAD or SS).

Acute Study Measurements

Volume Load

To compare total work performed in a session between TRAD and SS protocols, the load used was multiplied by the total number of repetitions completed for each exercise, and all six exercises were summed to obtain a value for total volume load per participant.

Training Session Duration

To compare potential differences in training time between TRAD and SS protocols, training session duration was recorded solely during the acute study. The exact time was noted immediately prior to the initial set of the first exercise and immediately following the final set of the final exercise. Training session duration was reported in minutes.

Longitudinal Study Measurements

As previously described (17), the following measurements were conducted pre- and post-study in separate testing sessions. Participants reported to the lab having refrained from any strenuous exercise for at least 48 hours prior to baseline testing and at least 48 hours prior to testing at the conclusion of the study. Anthropometric and muscle thickness assessments were performed first in the session, followed by measures of muscle strength. Each strength assessment was separated by a ten-minute recovery interval to help ensure restoration of physical and mental resources.

Anthropometry

Participants were told to refrain from eating for 12 hours prior to testing, eliminate alcohol consumption for 24 hours, and void their bladder immediately before undergoing anthropometric testing. Participants' heights were measured using a stadiometer and assessments of body mass and changes in percent body fat and segmental lower limb lean mass were obtained by multifrequency bioelectrical impedance analysis (Model 770, InBody Corporation, Seoul, South Korea) as per the instructions of the manufacturer.

Muscle Thickness

As previously described (17), ultrasound imaging was used to obtain measurements of muscle thickness. A trained ultrasound technician performed all testing using a B-mode ultrasound imaging unit (Model E1, SonoScape, Corporation, Shenzhen, China). The technician applied a water-soluble transmission gel (Aquasonic 100 Ultrasound Transmission gel, Parker Laboratories Inc., Fairfield, NJ) to each measurement site, and a 4-12 MHz linear array ultrasound probe was placed perpendicular to the tissue interface without depressing the skin. When the quality of the image was deemed satisfactory, the technician saved the image to a hard drive and obtained muscle thickness dimensions by measuring the distance from the subcutaneous adipose tissue-muscle interface to either the aponeurosis or the muscle-bone interface. Measurements were taken on the right side of the body for the following muscle groups: (1) elbow flexors; (2) elbow extensors; (3) anterior mid-thigh (a composite of the rectus femoris and vastus intermedius); (4) anterior lateral thigh (a composite of the vastus lateralis and vastus intermedius); (5) posterior medial thigh; and (6) posterior lateral thigh. The anterior upper arm measurements were obtained at 60% distally between the cubital fossa of the elbow joint and the acromion process of the scapula; the posterior arm measurement used the same value obtained on the anterior aspect as measured from the tip of the olecranon process. The mid and lateral anterior quadriceps measurements were obtained at 30, 50, and 70% between the lateral condyle of the femur and greater trochanter; medial and lateral hamstrings measures were obtained at 40 and 60% between the popliteal fossa and gluteal fold.

To help ensure that swelling in the muscles from training did not obscure muscle thickness results, images were obtained at least 48 hours after the training sessions in both the pre- and post-study assessments. This is consistent with research showing that acute increases in muscle thickness return to baseline within 48 hours following a RT session (20,21) and that muscle damage is minimal after repeated exposure to the same exercise stimulus over time (22,23). To further ensure accuracy of measurements, three successive images were obtained for each site and then averaged to obtain a final value. The test-retest intraclass correlation coefficient (ICC) from our lab for muscle thickness measurements is excellent (>0.94) with coefficients of variation (CV) of ≤3.3%.

Lower Body Muscle Power

Participants performed a countermovement jump to assess lower body muscular power. As previously described (17,24), participants were instructed on proper performance of the countermovement jump as follows: the participant assumed a shoulder-width stance with the body upright and hands on hips. When ready, they descended into a semi-squat position and then forcefully reversed direction, jumping as high as possible before landing with both feet on the ground. Assessment of jump performance was carried out using a Just Jump mat (Probotics, Huntsville, AL), which was attached to a hand-held computer that records airtime and thereby ascertains the jump height. The participant stood on the mat and performed three maximal-effort countermovement jumps with a one-minute rest period between each trial. The highest jump was recorded as the final value.

Dynamic Muscle Strength

Dynamic upper body strength was assessed by 1RM testing in the bench press ($1RM_{BENCH}$) exercise performed on a Smith machine (Hammer Strength Equipment, Life Fitness, Rosemont, IL, USA). As previously described (17,24), participants reported to the lab having refrained from any exercise other than activities of daily living for at least 48 hours prior to baseline testing and at least 48 hours prior to testing at the conclusion of the study. Repetition maximum testing was consistent with recognized guidelines as established by the National Strength and Conditioning Association (19). In brief, participants performed a general warm-up prior to testing consisting of light cardiovascular exercise lasting approximately 5-10 minutes. Next, a specific warm-up set of the bench of 5 repetitions was performed at ~50% 1RM followed by one to two sets of 2-3 repetitions at a load corresponding to ~60-80% 1RM with one minute of rest between sets. Participants then performed sets of 1 repetition of increasing weight for 1RM determination. Three to five minutes rest was provided between each successive attempt. To successfully perform the $1RM_{BENCH}$, participants were required to maintain a supine position on the bench with a five-point body contact position (i.e. head, upper back, buttocks, and both feet firmly on the floor); grasp the bar at a comfortable width and distance; un-rack the bar with assistance from a research assistant; bring the bar down until it gently touched the chest; and attain a full lock out with no assistance. The ICC from our lab for the Smith machine bench press is 0.996 and the CV is 2.0%.

Isometric Muscle Strength

Isometric strength assessment was carried out using dynamometry testing (Biodex System 4; Biodex Medical Systems, Inc. Shirley, NY, USA). After familiarization with the dynamometer and protocol, the participant was seated in the chair and performed unilateral isometric actions of the knee extensors on their right limb.

During each trial, the participant sat with their back flush against the seat back pad and maintained a hip joint angle of 85-degrees with the center of their lateral femoral condyle aligned with the axis of rotation of the dynamometer. The dynamometer arm length was adjusted to allow the shin pad to be secured with straps proximal to the medial malleoli. The participant was strapped in across the ipsilateral thigh, hips, and torso to help prevent extraneous movement during performance and was instructed to hold onto handles for greater stability. Testing was carried out at a knee joint angle of 70-degrees of knee flexion (where 0-degrees is full extension) (25).

Each maximum voluntary contraction trial lasted 5 seconds, followed by a 30-second rest period, for a total of four trials. Participants were verbally encouraged to produce maximal force throughout each bout. The highest peak net extension moment from the four trials were used for analysis. The ICC from our lab for knee extension isometric dynamometry is 0.91 and the CV is 18.1%.

Muscle Strength-Endurance

Upper-body muscular strength-endurance was assessed by performing the bench press on a Smith machine using 50% of the 1RM acquired via upper body dynamic muscular strength testing. As previously described (26), successful performance was attained by maintaining a five-point body contact position (head, upper back, buttocks, and both feet firmly on the floor), and achieving a full lock-out for each repetition. The same load (50% of initial $1RM_{BENCH}$) was used for pre- and post-study testing sessions. Participants performed as many repetitions as possible while maintaining a constant cadence of 2-0-2 as monitored by a metronome. The test was terminated when a participant failed to complete a repetition in accordance with the required cadence.

Lower-body muscular strength-endurance was assessed by performing the leg extension exercise on a selectorized machine (Life Fitness, Westport, CT) using 60% of the participant's initial body mass. As previously described (27), participants sat with their back flat against the backrest, grasping the handles of the unit for support. The backrest was adjusted so that the anatomical axis of the participant's knee joint aligned with the axis of the unit. Participants placed their shins against the pad attached to the machine's lever arm. Participants performed as many repetitions as possible using a full range of motion (90 degrees of knee flexion to 0 degrees) while maintaining a constant cadence of 1-0-1 as monitored by a metronome. The test was terminated when the participant could no longer perform a complete repetition with proper form and tempo. Muscular endurance testing was carried out after assessment of muscular strength to minimize effects of metabolic stress potentially interfering with performance of the latter.

Session Rating of Perceived Exertion

To assess changes in SRPE in both the acute and longitudinal aspects of the study, values were obtained for all training sessions across acute and longitudinal interventions. SRPE has been considered a reliable assessment of overall fatigue of a training session in varying RT protocols (28). Following the cessation of each training session, participants passively rested for 10 minutes before being asked to provide a rating of perceived exertion for the entire training session. Participants received standard instructions on how to use the RPE scale during the 10RM testing session. As previously recommended (28), a member of the research team asked participants to choose a number on a 10-point omni scale that best described their perceived effort during the session, with 0 signifying sitting still during the entire session and 10 signifying maximal effort during the entire session.

Dietary Adherence

To avoid potential dietary confounding of results, participants were advised to maintain their customary nutritional regimen. Dietary adherence was assessed by self-reported five-day food records (including at least one weekend day) using MacroFactor (https://macrofactorapp.com/). Nutritional data were collected twice during the study including one week before the first training session (i.e., baseline) and during the final week of the training protocol. Participants were instructed on how to properly record all food items and their respective portion sizes consumed for the designated period of interest. Each item of food was individually entered into the program, and the program provided relevant information as to total energy consumption, as well as the amount of energy derived from proteins, fats, and carbohydrates for each time-period analyzed.

Blinding

To minimize the potential for bias, the researcher who obtained the outcome data was blinded to group allocation, and the statistician (PAS) performed blinded analyses for all outcomes. At the time of study entry, all participants and the lead investigator (RB) responsible for determining participant eligibility were blinded to group allocation. Additionally, a separate investigator, who was not involved in determining participant entry, carried out the randomization procedures.

Statistical Analyses

All analyses were conducted within a Bayesian framework enabling formal inclusion of information regarding likely differences between interventions based on knowledge from previous studies (e.g. through informative prior distributions), and presentation of inferences based on intuitive probabilities. Potential differences between groups were assessed using univariate analysis of covariances and multivariate multilevel regression models. The multivariate approach improves precision by modeling selected outcome variables simultaneously, taking advantage of the correlations between outcomes. Inferences were based on 1) posterior distributions of estimated group differences and their associated credible intervals; and 2) Bayes factors (BF) to quantify the strength of evidence for either no difference between groups (null hypothesis H_0) or a difference in either direction (alternative hypothesis H_1). Standard qualitative labels (“anecdotal” < “moderate” < “strong” < “very strong” < “extreme”) expressing the strength of evidence for the different hypotheses were adopted (29).

To enhance transparency of the analyses, the WAMBS-checklist (When to worry and how to Avoid Misuse of Bayesian Statistics) was used and incorporated sensitivity analyses of prior distributions which has been shown to be important in all cases including when diffuse priors are used (30). We also performed simulation-based calibration of BFs (31) using priors featured in the sample size determination to ensure these were likely to be stable and provide appropriate inferences. Information and checks on analyses plus ancillary results are presented in the supplementary files. We also conducted standard diagnostic checks of the convergence of the sampling algorithms and modeling assumptions. All analyses were performed using the R wrapper package brms interfaced with Stan to perform sampling (32) and BFs estimated via the bridge sampling algorithm (33).

Results

Of the fifty participants that initially volunteered for the study, forty-three completed the protocol (men = 34, women = 9; height = 170.2 ± 9.4 cms; weight = 77.7 ± 14.4 kgs; age = 21.3 ± 4.0 years; body fat% = 22.2 ± 9.3%; training experience = 3.2 ± 2.4 years). Four participants dropped out of the study for personal reasons and the other three were removed for non-compliance. The final group sizes included for analyses were SS = 22, TRAD = 21. Of those completing the protocol, average attendance was 95% and 96% of sessions for SS and TRAD, respectively. Adverse events included nausea (SS: n=17; TRAD: n=9), lightheadedness (SS: n=1; TRAD: n=1) and vomiting during/after a session (SS: n=3; TRAD: n=2). Descriptive summaries and analyses of nutritional data are presented in the supplementary files, with results providing no evidence of differences between groups.

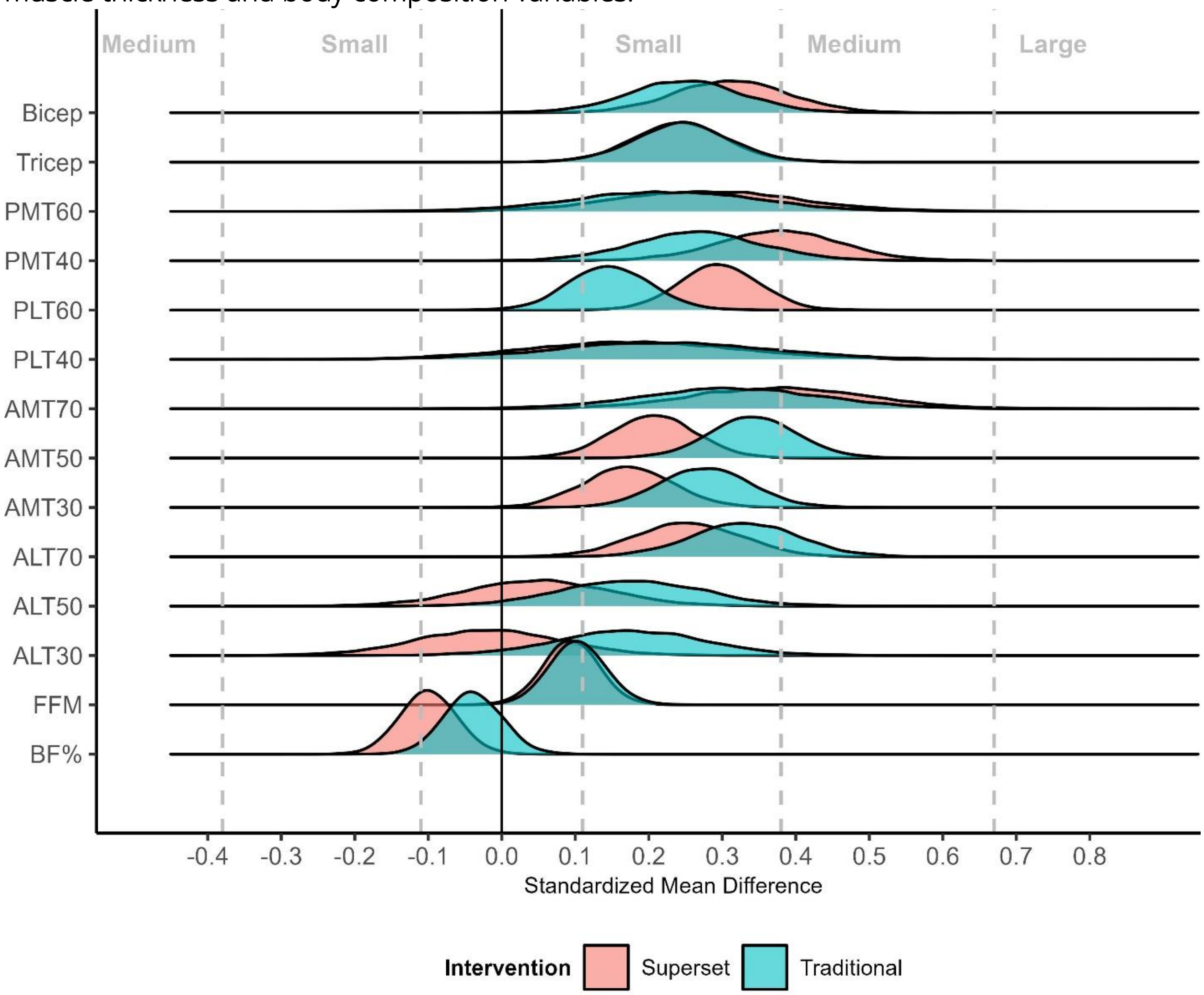
Acute Assessments

Total volume load was not appreciably different between SS and TRAD (8075 ± 2451 vs 7908 ± 2411 kgs, respectively). Participants session RPE was higher for SS compared to TRAD (8.1 ± 1.5 vs 7.2 ± 1.6, respectively). Total session time was substantially lower for SS compared to TRAD (44.4 ± 4.3 vs. 69.1 ± 5.6 min, respectively).

Muscle Hypertrophy and Body Composition

Within-group changes in muscle thickness and body composition outcomes are presented as standardized mean difference values in Figure 1. The results illustrate that both interventions were likely to create between small to medium increases in muscle thickness, and small increases in fat free mass and decreases in body fat percentage. Results for between group comparisons are presented in Table 2. The results provided consistent evidence in support of the null hypothesis; however, the strength of evidence was generally 'anecdotal'. Multivariate analyses generated point estimates close to zero and relatively wide credible intervals.

Figure 1: Distributions of within-group estimated standardized mean difference changes for muscle thickness and body composition variables.



Small, medium, and large thresholds for change are illustrated on the plot and based on strength and conditioning specific values (34). ALT: Anterior lateral thigh; AMT: Anterior mid-thigh; PLT: Posterior lateral thigh; PMT: Posterior mid-thigh; FFM: Fat free mass; BF%: Body fat percentage.

Table 2: Multivariate and univariate analyses of potential group differences for muscle thickness and body composition outcomes.

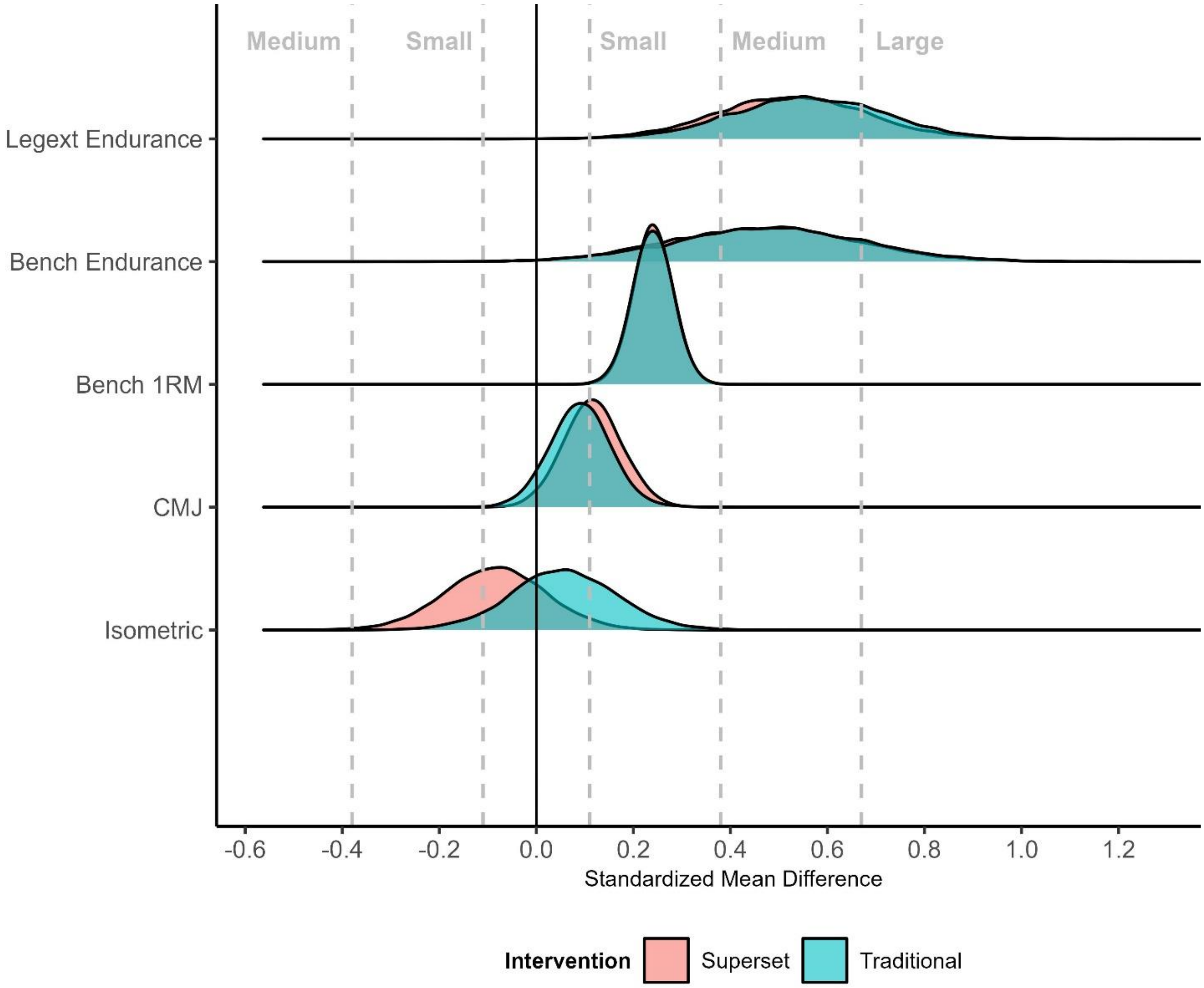
Outcome	Multivariate Group Difference (95%CrI) Standardized	Posterior probability favoring traditional intervention (Bayes Factor)	Univariate Group Difference (95%CrI) Absolute	Posterior probability favoring traditional intervention (Bayes Factor)
Anterior mid-thigh 30%	0.06 (-0.34 to 0.25)	*p* = 0.679 (0.66)	0.82 (-0.68 to 2.3 mm)	*p* = 0.867 (0.40)
Anterior mid-thigh 50%			1.1 (-0.24 to 2.4 mm)	*p* = 0.942 (0.70)
Anterior mid-thigh 70%			-0.81 (-3.4 to 1.7 mm)	*p* = 0.266 (0.50)
Anterior lateral thigh 30%	0.12 (-0.12 to 0.38)	*p* = 0.840 (0.76)	0.94 (-0.43 to 2.3 mm)	*p* = 0.912 (0.90)
Anterior lateral thigh 50%			0.62 (-0.67 to 1.9 mm)	*p* = 0.827 (0.51)
Anterior lateral thigh 70%			0.26 (-0.55 to 1.1 mm)	*p* = 0.738 (0.28)
Posterior medial thigh 40%	-0.10 (-0.39 to 0.23)	*p* = 0.254 (0.20)	-0.57 (-1.8 to 0.68 mm)	*p* = 0.181 (0.45)
Posterior medial thigh 60%			-0.62 (-3.1 to 1.8 mm)	*p* = 0.314 (0.49)
Posterior lateral thigh 40%	-0.11 (-0.36 to 0.30)	*p* = 0.259 (0.73)	-0.11 (-2.3 to 2.1 mm)	*p* = 0.459 (0.48)
Posterior lateral thigh 60%			-1.1 (-2.2 to 0.03 mm)	*p* = 0.028 (1.26)
Biceps brachii	-0.06 (-0.26 to 0.13)	*p* = 0.285 (0.08)	-0.47 (-1.7 to 0.80 mm)	*p* = 0.233 (0.32)
Triceps brachii			-0.26 (-1.6 to 1.1 mm)	*p* = 0.353 (0.23)
Body fat %	-	-	0.53 (-0.49 to 1.6 %)	*p* = 0.846 (0.24)
Fat free mass	-	-	0.13 (-2.7 to 2.9 kg)	*p* = 0.540 (0.13)

Positive values favor traditional intervention. *p* represents the probability that the group difference favors the traditional intervention based on the posterior distribution. Bayes factors >1 provide evidence for a group difference and values <1 provide evidence for the null hypothesis.

Performance

Within-group changes in performance outcomes are presented as standardized mean difference values in Figure 2. The results indicate that both interventions were likely to create between zero to small increases in jump performance and isometric strength, small to medium increases in 1RM bench press performance, and medium to large increases in endurance. Results for between group comparisons are presented in Table 3 and were similar to those obtained from muscle thickness and body composition outcomes. The results provided consistent evidence in support of the null hypothesis that was deemed to be 'anecdotal' in strength. Multivariate analyses generated point estimates close to zero and relatively wide credible intervals.

Figure 2: Distributions of within-group estimated standardized mean difference changes for performance variables.



Small, medium, and large thresholds for change are illustrated on the plot and based on strength and conditioning specific values (34). CMJ: Countermovement jump.

Table 3: Multivariate and univariate analyses of potential group differences for physical performance outcomes.

Outcome	Multivariate Group Difference (95%CrI)	Posterior probability favoring traditional intervention	Univariate Group Difference (95%CrI)	Posterior probability favoring

	Standardized	(Bayes Factor)	Absolute	traditional intervention (Bayes Factor)
Isometric	0.01 (-0.19 to 0.31)	*p* = 0.552 (0.08)	4.1 (-14.9 to 23.4 N·m)	*p* = 0.663 (0.41)
Bench press 1RM			-0.20 (-3.2 to 2.8 kgs)	*p* = 0.447 (0.14)
Bench press endurance	0.07 (-0.39 to 0.49)	*p* = 0.627 (0.28)	0.21 (-1.1 to 1.6 repetitions)	*p* = 0.628 (0.63)
Leg extension endurance			0.23 (-2.1 to 2.6 repetitions)	*p* = 0.575 (0.54)
Countermovement jump height	-	-	-0.06 (-0.79 to 0.66 cms)	*p* = 0.430 (0.22)

Positive values favor traditional intervention. *p* represents the probability that the group difference favors the traditional intervention based on the posterior distribution. Bayes factors >1 provide evidence for a group difference and values <1 provide evidence for the null hypothesis.

Discussion

This is the first study to investigate the effects of a full-body superset RT protocol on muscular adaptations in resistance-trained individuals. The findings from this study showed both protocols produced similar increases in muscle thickness across all assessed muscle groups as well as similar changes in strength, power, local muscular endurance, and body composition outcomes. Furthermore, SRPE values were greater for SS than TRAD during the acute study despite being similar between groups when averaged across the eight-week training intervention. Although the average training session duration was substantially lower for SS compared to TRAD, total acute volume load was similar between conditions. The subsequent sections discuss these findings in the context of the current body of literature as well as their implications for exercise prescription.

Time Efficiency and Perceived Exertion

Similar to other findings in the superset literature (9–12,35), the SS protocol was completed in 36% less time compared to the TRAD protocol (44.4 ± 4.3 vs. 69.1 ± 5.6 min, respectively). Additionally, average acute SRPE values were nearly 1-point greater for SS than TRAD (8.1 ± 1.5 vs 7.2 ± 1.6, respectively). From a practical standpoint, SRPE is considered an effective method for assessing internal training load (i.e. psychophysiological stress from a given workload), and higher SRPE values generally reflect greater levels of total fatigue accumulated during a bout of RT (36). Collectively, our findings for training time and acute SRPE are in accordance with existing literature suggesting that time efficient training, such as superset RT, is associated with greater perceived exertion due to the greater demands placed on body systems when completing the same work in less time than traditional RT (37–39).

Although both acute and longitudinal SRPE was greater in SS, values were more similar when averaged across the eight-week training intervention (SS: 8.1 ± 0.8; TRAD: 7.8 ± 0.9), calling into question the practical meaningfulness of this finding. Given the RT variables remained constant throughout the intervention (i.e. exercises, intensity of effort, number of sets, repetition range), it could be expected that participants would become more accustomed to the training regimen, leading to a decline in average SRPE throughout the longitudinal intervention compared to the initial values observed in the acute study. However, average SRPE remained constant in SS while modestly increasing in TRAD. Although the RT protocol remained unaltered throughout the study, participants performed all sets to momentary muscular failure, with additional load applied as needed to maintain the 8-12 repetition range throughout the longitudinal study. Therefore, it is possible that, on average, SRPE remained elevated throughout the study due to the high intensity of effort exerted in each set combined with progressive overload throughout the study period.

Volume Load

Despite the differences in training session duration, SS and TRAD accumulated similar values for total volume load (8075 ± 2451 vs 7908 ± 2411 kgs, respectively). These results agree with other acute research that reported either similar or greater total volume load in superset compared to traditional RT conditions (9,10,40–43). In our study, the SS protocol allowed for greater rest of the working muscles between sets compared to the TRAD protocol, due to a two-minute inter-set rest interval, transition time between exercises (~ 20 sec), and rest time allocated for the antagonist muscles during each opposing set in SS. Thus, the additional rest time between sets for the same exercise in the SS protocol may have allowed for sufficient recovery of the local muscles, enabling a similar total volume load as in the TRAD protocol.

Some research suggests that pre-fatiguing the antagonist muscle may acutely potentiate agonist force production and improve repetition performance during the latter half of a superset (7,9,10,41). Although the exact mechanisms are unclear, it has been purported that this phenomenon may be mediated by reduced muscle coactivation, increased elastic energy storage, or changes in the sensitivity of proprioceptors, such as Golgi tendon organs and muscle spindles (7,9,10,44). However, our volume load results show no indication of enhanced performance with supersets. Similarly, Fink et al. (11) and Paz et al. (41) reported no statistical differences in volume load for the biceps curl and triceps extension between superset and traditional conditions, suggesting that supersetting single-joint exercises for the elbow flexors and extensors may not alter performance in either movement. Additionally, other research suggests that performing the bench press prior to a row or pulldown movement acutely enhances repetition performance in the latter, while the inverse order has no effect on bench press performance during superset RT (10,39,41,42). Thus, our results may be partially explained by exercise order, as the lat pulldown preceded the Smith bench press.

As for the lower body, two previous studies by Maia et al. (9) and Antunes et al. (43) found statistically greater EMG activity in the quadriceps femoris, and improved repetition performance in the leg extension when preceded by the leg curl exercise in a superset compared to traditional set condition. However, these previous studies only included two total exercises while our RT protocol consisted of six exercises. Although speculative, it is possible that residual fatigue from the two prior exercises mitigated the performance-enhancing effects in the leg extension observed in previous studies. Nonetheless, the existing literature does not unanimously show greater volume load with superset compared to traditional RT, and the potential mechanisms responsible for enhancing performance during superset RT remain unclear. Future research should compare volume load between superset and traditional set conditions using multi-superset RT protocols.

Hypertrophy

Both groups experienced appreciable gains in muscle thickness throughout the study (~2-7%), with relatively similar between-group changes observed in all muscles assessed. Overall, these results suggest that superset RT can be a time-efficient way to augment increases in muscle size to a magnitude comparable to traditional RT. These findings largely parallel those of Pringga et al. (12) and Fink et al. (11), who found similar muscle growth in the lower- (12), and upper-body limbs (11) when comparing superset and traditional RT interventions. However, it should be noted that Pringga et al. (12) and Fink et al. (11) employed untrained participants with RT protocols consisting of only two single-joint exercises, making it difficult to extrapolate their findings to resistance-trained individuals who generally perform a combination of several multi- and single-joint weight-based exercises that target various muscle groups. Thus, our novel findings address an important gap in the literature, as no previous study has compared the effects of a full-body superset versus traditional RT protocol on muscle hypertrophy in resistance-trained individuals.

Strength Outcomes

Both SS and TRAD experienced similar increases in 1RM bench press across the study period (9.2% vs. 10.4%, respectively). These findings corroborate Robbins et al. (15), who found similar between-group changes in 1RM of the bench pull and bench press exercises in resistance-trained participants following eight-weeks of supersets versus traditional RT.

Collectively, these findings suggest that superset and traditional RT can induce comparable gains in upper body dynamic maximal strength. Both SS and TRAD experienced minimal changes in isometric strength (-2.6% vs. +1.6%, respectively), with a small effect in favor of TRAD by 4.1 N·m, and a broad CrI ranging from -14.9 N·m to 23.4 N·m. The negligible changes in isometric outcomes may be attributed to the reduced specificity between dynamic RT and isometric measures of strength, as some evidence suggests that strength gains improve to a greater degree during dynamic testing compared to isometric testing (17,45). Although the leg extension exercise and isometric knee extension test employed in this study require similar movement patterns, the difference between their dynamic and isometric nature may be large enough to reduce the transfer of strength between modalities.

Muscle Strength-Endurance

Both groups achieved similar increases in repetitions performed during the upper and lower body strength-endurance assessments. These results contrast with our initial hypothesis that long-term adherence to superset RT would enhance muscular endurance adaptations via the ability to tolerate greater levels of fatigue and metabolic stress (11,13). Interestingly, Fink et al. (11) observed roughly ~15-17% greater increases in assessments of local muscular endurance with supersets compared to traditional sets following an eight-week RT protocol consisting of resistance band biceps curls and overhead triceps extensions. However, it is important to note that the investigators used the close grip bench press as a proxy measure for local muscle endurance of the triceps brachii, which may not accurately assess local endurance of the triceps alone due to the additional involvement of other muscles, such as the anterior deltoid and pectoralis major. Overall, the relatively small sample size (n = 23) consisting of untrained participants, and lack of specificity between the endurance tests and the exercises employed in the training intervention make it difficult to draw strong inferences from that study (11).

The reduction in total rest time between exercises in an agonist-antagonist superset may increase the demands on systemic components such as the cardiovascular system that are unrelated to the working musculature (13), which may modestly affect local muscular endurance-related adaptations. Since muscular endurance may be best improved when rest intervals are reduced between traditional sets (8,46,47), agonist-agonist supersets (e.g. leg press and leg extension) might be the most effective superset strategy for increasing local muscular endurance. More research is required to better understand the effects of performing supersets with varying exercises and repetition ranges on local muscular endurance outcomes.

Lower Body Muscular Power

Both groups exhibited minimal increases in CMJ performance. To maximize lower body muscular power, it has been suggested that practitioners perform RT and plyometric exercises that largely involve the stretch shortening cycle (SSC), such as Olympic weightlifting exercises or box jump variations (19). Given that our study only targeted the lower body musculature via two single-joint machine-based exercises it follows that both groups experienced negligible changes in CMJ performance. Although speculative, it is possible that the inclusion of lower body plyometric and/or explosive RT exercises would have yielded greater changes in CMJ height.

Limitations

Our study has several limitations that warrant consideration when interpreting the findings. First, this study employed healthy males and females between the ages of 18-40 years old with at least one year of RT experience. Thus, the findings may not generalize well to other populations of different health conditions, ages, and training experiences. Second, the results can only be applied to the specific exercises employed, and the way in which they were performed in this study. For example, SS performed all six exercises in a superset fashion, which may not accurately reflect real-world scenarios where individuals perform some exercises as supersets and others as traditional sets. Moreover, there are numerous possible combinations of exercises and orders that can be paired as supersets, making it unclear how muscular adaptations would fare following the performance of other superset variations and RT protocols. Given that our study included only two single-joint exercises for the lower body musculature, more research is needed to determine the effects of supersets consisting of multi-joint lower body exercises, such as the back squat or leg press, on gains in muscle size and strength. Also, the superset protocol employed in this study included minimal rest between the first and second paired exercise. Thus, caution should be used when attempting to generalize these findings to other protocols that employ different exercises and inter-set rest periods within a superset. Third, volume load was only recorded during the acute study (two total sessions). Although the results showed that both conditions yielded similar total volume load, it is unclear whether there were any differences in volume load across the eight-week training period. Therefore, it is not entirely clear whether repetition performance and progression may have differed between groups. Fourth, participants performed all sets to the point of momentary muscular failure. Given that sufficient gains in muscle mass and strength can be made when traditional sets are performed with repetitions in reserve (RIR) (48–50), it is unclear if employing greater proximities to failure would have limited the reports of nausea and/or elicited different results in SS. Fifth, reports of nausea were assessed retrospectively by asking participants to recall whether they experienced any symptoms throughout the study period once it concluded. Consequently, these reports should be interpreted with caution, as their accuracy may be considered questionable due to the absence of a formal questionnaire to assess symptoms of nausea during the study period and the potential for recall bias. Lastly, the RT protocol consisted of a full-body routine, carried out only twice per week. Although current literature suggests that weekly training frequency does not meaningfully impact muscle hypertrophy when set volume is sufficient (51), the set volume and frequency demands of this study may be considered relatively low. Given the high SRPE values and abundance of adverse events in the SS group, it is unclear if or how the results would have fared with higher total set volumes and/or frequencies.

Conclusion

In conclusion, both superset and traditional RT yielded similar changes in muscular strength, size, power, and endurance. These findings are highly applicable to individuals with time constraints, as supersets offer the ability to improve training efficiency without compromising muscular adaptations. This has important implications for the general population, given that time constraints are considered a primary barrier to exercise adherence (52). Furthermore, given the existing literature suggests a dose-response relationship between weekly set volume and muscle hypertrophy (53), superset RT also can be a viable strategy for those looking to maximize gains in muscle mass while reducing time spent in the gym.

It is important to note that increasing training density via supersets likely increases the demands placed on the body, consequently resulting in a greater potential for training-induced nausea—although these symptoms generally subside after several consistent training sessions. Thus, when initially employing full-body superset routines, such as the one in this study, practitioners should consider performing sets shy of muscular failure or reducing the total set volume, then monitor symptoms of nausea before progressing toward closer proximities to failure over time. This approach may allow the body to sufficiently adapt to the demands of supersets, potentially reducing the likelihood of training-induced nausea. Future research should investigate the effects of superset variations with different exercise combinations, inter-set rest intervals and intensities of effort on muscular adaptations. Moreover, investigators should aim to determine if changing exercise order within a superset influences changes in muscular strength and size.

Contributions

RB and BJS conceived of the idea for the study. RB, MC, PAK, MW, PAS and BJS designed the methodology for the study. RB, TH, AP, AM, FA, MS, PAK and MW assisted with acquisition of data. PAS conducted the statistical analysis. All authors critically interpreted the data, drafted and/or revised the article, and approved the final version of the manuscript draft.

Conflict of interest

BJS formerly served on the scientific advisory board for Tonal Corporation, a manufacturer of fitness equipment. All other authors report no competing interests with the content of this manuscript.

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Data and Supplementary Material Accessibility

Data can be requested from the corresponding author. Supplementary material are available on the Open Science Framework project page: https://osf.io/kdgv3/

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