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Effects of Resistance Training Techniques on Metabolic Responses in Trained Males

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ABSTRACT

International Journal of Exercise Science 17(2): 576-589, 2024. This study investigated the effects of bi-set, drop-set and traditional resistance training (RT) techniques on metabolic responses in resistance-trained males. Fifteen trained males (age 29.7 ± 6.1 years; body mass 83.4 ± 7.6 kg; RT experience 11.4 ± 6.7 years; one-repetition maximum (1RM) barbell bench press: body mass ratio 1.4 ± 0.1 a.u.) were assigned to three experimental conditions, in a randomized crossover design. The experimental conditions were bi-set (3x10 repetitions at 70%1RM in barbell bench press followed by 10 repetitions at 60%1RM in incline bench press), drop-set (3x10 repetitions at 70%1RM followed by 10 repetitions at 50%1RM in barbell bench press) and traditional RT (3x20 at 60%1RM in barbell bench press). A portable gas analyzer was used to assess energy expenditure and maximal oxygen uptake during the experimental protocols. Blood lactate levels were assessed at baseline and 1, 3, and 5 minutes after the training session. There were no differences for total training volume ($p = 0.999$). Post hoc comparisons revealed that bi-set elicited higher aerobic energy expenditure ($p = 0.003$ vs. drop-set; $p < 0.001$ vs. traditional RT) and aerobic oxygen consumption ($p = 0.034$ vs. drop-set; $p < 0.001$ vs. traditional RT) than other RT schemes. There were no differences regarding anaerobic EE between-conditions ($p > 0.05$). There was a main effect of time and condition for blood lactate levels ($p < 0.001$). Post hoc comparisons revealed that drop-set training elicited higher blood lactate levels than traditional RT ($p = 0.009$). The results suggest that RT techniques may have a potential role in optimizing metabolic responses in resistance-trained males.

KEY WORDS: Strength training; energy expenditure; indirect calorimetry; drop-set; bi-set; lactate

INTRODUCTION

Resistance training (RT) is an effective intervention to increase lean mass and decrease body fat. It is widely known that decreasing body fat is mostly determined by a hypocaloric intake, however, RT is a viable strategy to avoid losses of lean mass and to increase total energy expenditure (EE) (3, 27). Indeed, energy expenditure is a key variable related to training routines to help practitioners achieve their body composition goals (3, 41). Coaches, physique athletes and fitness enthusiasts can manipulate RT variables (e.g. volume, intensity, rest interval, etc.) to increase the EE of a training session.

RT elicits distinct acute responses and chronic adaptations according to programming, and EE is an acute response that can be maximized by how RT variables are programmed (25). There is compelling evidence showing that number of sets, intensity, movement speed, exercise mode and rest interval can influence EE (15, 21, 26, 33, 38). Recently, João et al. (22) conducted a systematic review with meta-analytic data aiming to identify if the intensity in traditional and circuit RT sessions could alter EE; there was a trend towards indicating a dose-response relationship between intensity and EE in RT. Indeed, total training volume seems to be one of the determining variables affecting EE (22, 26). Thus, equating total training volume between conditions seems to reduce this confounding variable in the analysis of EE induced by RT.

Although traditional (TRAD; i.e. multiple sets performed until concentric failure with rest intervals between sets) RT is the most common form of RT practice, resistance-trained individuals commonly employ advanced RT techniques in their training programs; for example, bi-set and drop-set training are two commonly used advanced RT practices. RT techniques allow for manipulation of RT variables during a training session, enabling practitioners to manipulate volume, training density, exercise order, repetition duration and load using shorter duration training sessions (24, 35). Both bi-set and drop-set training are RT schemes that have their sets executed until concentric failure, followed by another exercise for the same muscle group (bi-set training) or a decrease in load (drop-set training) with a minimal (< ~5 seconds) rest interval to adjust the weight in drop-set training or to switch the exercise in bi-set training. These RT configurations can promote distinct training volume, training density, rating of perceived exertion, microvascular oxygenation levels and blood lactate compared to TRAD (2, 11, 12, 17, 23). In a crossover study design, Kelleher et al. (23) compared the metabolic cost of supersets and TRAD in ten recreationally active adults with matched-work comparisons. The authors observed that supersets produced greater kilojoules per minute, blood lactate and excess post-oxygen consumption compared to TRAD. However, it remains unclear if RT techniques promote higher metabolic responses than traditional RT in trained males, which deserves additional investigation.

Thus, the purpose of this investigation was to examine if the bi-set and drop-set training techniques would elicit greater metabolic responses and EE as compared to TRAD RT in trained males. Since the volume-load was equated, we hypothesized that the minimal rest interval and training density differences employed in bi-set and drop-set training would promote higher metabolic stress and energy expenditure than traditional RT.

METHODS

Participants

The sample power was calculated by the software G**Power* 3.1 for F family (ANOVA) repeated measures within interaction to determine the number of participants required for the study. For this, we adopted a priori power of 0.80, alpha = 0.05, and effect size of 0.36 for energy expenditure (6, 33). Prior power analysis indicated that fourteen individuals were sufficient to reduce the probability of type II error and to achieve sufficient statistical power. After three dropouts in the study for personal reasons, fifteen participants completed the experimental protocol. The inclusion criteria were as follows: a) trained males between 18-35 years of age; b) minimum barbell bench press strength of 1.25 x body mass; c) negative responses on all items of the Physical Activity Readiness Questionnaire; d) at least two years of RT experience (considered as the first time that they started RT practice, disregarding whether they stopped their RT routines within this period); e) self-report of no continuous use of any substance that could interfere in metabolic responses (e.g., anti-inflammatory drugs, anabolic androgenic steroids, and dietary supplements such as nitrates and citrulline). The following criteria were considered for exclusion: a) self-report of musculoskeletal injuries; b) not attending one of six lab visits.

All participants were oriented to have the same meal at least 2 hours prior to each training session and to maintain their normal eating habits. This study was approved by Federal University of Paraná Ethics Committee (protocol 3.735.414) and our procedures were in accordance with the Declaration of Helsinki. All participants were informed of the purpose and experimental procedures and all participants signed a written informed consent form prior to their participation. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (28).

Protocol

We used a randomized, crossover, repeated measures study design (Figure 1). Each participant visited the lab six times. During the first visit, resting EE and anthropometrics were assessed followed by a maximum dynamic strength test (1-RM) familiarization in the barbell bench press and incline barbell bench press. The familiarization session included explanations about the test and technical standards for both exercises such as full range of motion being considered moving the barbell down to the chest followed by a "touch and go" to full elbow extension. Additionally, the research team answered any questions from the participants. After explanations, participants performed a low-load warm-up procedure on the barbell bench press and then performed two sets of one repetition on the exercise; the same procedures were followed for the incline bench press. These one repetition sets were performed utilizing self-selected heavy loads, but not maximum loads. Forty-eight hours after the familiarization session, we conducted two 1-RM assessments performed 48–72h apart. Seven days after the 1-RM testing, the fourth, fifth and sixth visits were performed in random order with one of the training protocols (bi-set, drop-set or traditional RT) with 7-days between each condition. During the training protocols, EE was measured and blood lactate levels were assessed at pre-training and from 1, 3 and 5 minutes after the session was completed.

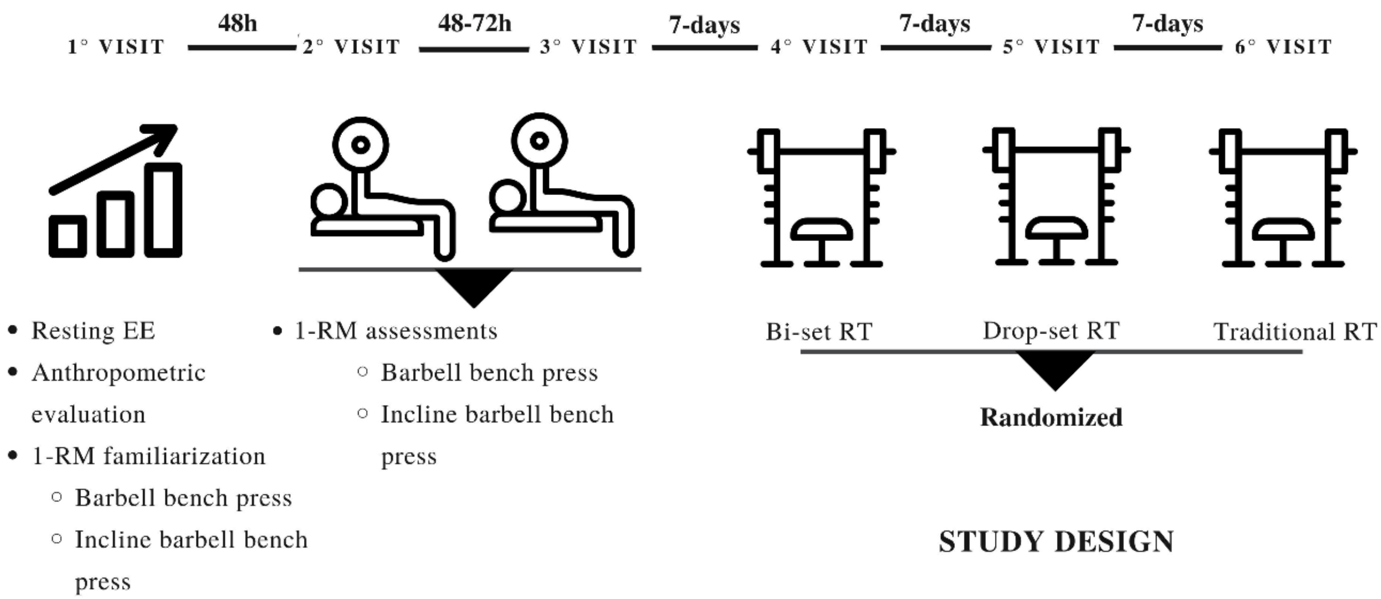

Figure 1. Study design.

Resting Energy Expenditure: Resting energy expenditure was measured using procedures previously described (14). Resting energy expenditure was assessed in the first visit in the lab before the anthropometric assessment (6:00 - 9:00 AM) using a portable gas analyzer COSMED K5b2 (COSMED, Rome, Italy). Before each test, the volunteers were instructed to not perform any endurance or resistance exercise at least 72h before testing and to not drink alcohol or caffeine beverages 24h before testing. All volunteers were in a fasted state for at least 5 hours before (considered nocturnal fasting) the resting EE measurement. Importantly, the fasted state condition was just for resting EE measurement. Before starting the energy expenditure measurement, the participants sat quietly for at least 30 minutes to establish a baseline measurement for the oxygen consumption ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$). Resting energy expenditure was measured for 30 minutes, where the initial and final 10 minutes were discarded. This method was adopted to maintain an accurate reading and a lower coefficient of variation. For each resting EE test, the gas analyzer was calibrated with known gas concentrations and volume using a 3L syringe. The volume of inspired and expired air was analyzed to provide the measurement of $\dot{V}O_2$; this allowed inference of resting energy expenditure (REE) (14, 23). Thus, the estimated REE was calculated according to the manufacturer's procedures using the equation proposed by Weir (36) with $\dot{V}O_2$ and $\dot{V}CO_2$ as parameters.

Anthropometric Assessments: Height was assessed with a stadiometer (SANNY®, São Bernardo do Campo, Brazil) to the nearest 0.1 cm. The body mass and body fat were evaluated with multifrequency bioelectrical impedance (InBody® 120, Biospace, USA). For the measures, volunteers wore light workout clothing and no shoes. Moreover, participants were instructed to follow a protocol provided according to the multifrequency bioelectrical impedance manufacturer. Participants were instructed to: a) consume no food and no water for at least 5 hours prior to testing; no consumption of drinks containing caffeine or alcohol for at least 24 hours before the evaluation, respectively; b) if possible, urinate 30 min before; c) no moderate to vigorous physical activity 12 hours before; d) water intake of at least 2 L on the previous day.

Maximum Dynamic Strength (1-RM): To ensure an accurate load prescription to the barbell bench press and incline barbell bench press according to percentages of one repetition maximum, 1-RM tests were conducted for each exercise on the second and third visits. We conducted 1-RM tests in the following exercise order: barbell bench press followed by incline barbell bench press. Before the 1-RM test, participants performed a general warm-up (5 min at 6km.h^{-1} on a treadmill), and subsequently, a specific warm-up of 2 sets of 8 and 3 repetitions at an estimated load for a 10 and 6 repetition maximum in the barbell bench press, respectively. 1-RM attempts were initiated 3 minutes after the specific warm-up. To ensure proper technique, each subject received specific instructions regarding exercise technique, as occurred during the familiarization session, following the guidelines established by Baechle and Earle (4). Load was increased by ~5% for each successful attempt, until a 1-RM load was found (within five attempts). Rest interval at warm-up sets and 1-RM attempts in each exercise was 3 to 5 mins (9). We defined the 1-RM as the highest value between the two 1-RM tests. The coefficient of variation (CV), typical error (TE), intraclass correlation coefficient (ICC) with the respective 95% confidence interval (95%CI) and standard error of mean (SEM) between two 1-RM sessions performed with a 48-72h interval between them were as follows: barbell bench press (CV = 0.9%; TE = 5.53 kg; ICC = 0.998 (95%CI = 0.993 - 0.999); SEM 5.541 kg), incline barbell bench press (CV = 1.4%; TE = 4.70 kg; ICC = 0.995 (95%CI = 0.986 - 0.998); SEM 4.535 kg).

Training Sessions: At the fourth, fifth and sixth visit, separated by 7 days between each of them, the RT protocols were performed in a randomized design. All training sessions were held at the same time of day in order to avoid influence of the circadian rhythm. In all training sessions, the same general and specific warm-up procedures of the 1-RM tests were adopted, and the resistance training techniques were performed in 3 sets. The drop-set training was performed with 10 initial reps at 70%1RM, followed by 10 additional reps at 50%1RM with a minimal intraset rest interval (< ~5 seconds) in the barbell bench press. The bi-set training was performed with 10 initial reps in the barbell bench press at 70%1RM, followed by 10 additional reps in the incline barbell bench press at 60%1RM, with a minimal intraset rest interval (< ~5 seconds). The TRAD was performed with 3 sets of 20 repetitions at 60%1RM for the barbell bench press. In order to maintain an equal training volume between the training protocols (to reduce the likelihood of this confounding variable influencing the results) and for participants to reach the repetition target, the load was decreased by 10% for the incline bench press (bi-set training) and the bench press (TRAD training). Rest intervals between each set in the three RT schemes were 120 seconds. If any participant reached concentric failure missing from 1-2 repetitions from the target, a researcher provided slight assistance in the sticking point for the participant to reach the targeted repetitions (note: this only occurred during the third set and was not a frequent occurrence). Participants were instructed to not perform any other training session during the intervention period. The total training volume was calculated by sets × reps × load (kg).

Metabolic Analysis During Training Sessions: As soon as the participants arrived at the lab, they were fitted with a face mask connected to a COSMED K5b2 (COSMED Rome, Italy) portable gas analyzer that continuously measured breath-by-breath pulmonary gas exchange. The participants then remained quiet for 10 minutes in a supine position on a stretcher. Afterwards, general and specific warm-ups were performed followed by the training protocol. The gas analyzer was turned on as soon as the training protocol started (i.e., without the warm-up period). The volume of inspired and expired air during the training protocol, without rest intervals, was analyzed to provide the measurement of oxygen consumption (VO2) to estimate the energy expenditure during exercise. The estimated aerobic EE during training sessions was calculated according to the manufacturer's procedures from VO2-derived data. The anaerobic EE was calculated based on blood lactate levels, where the difference between resting and peak blood lactate was considered and converted into an EE measurement as mL O2· (kg body mass·mmol blood lactate)$^{-1}$; to calculate anaerobic EE, 1L O2 = 20.9 kJ was used (36, 37).

Blood Lactate Analysis: Blood samples (0.7 µl) were collected from tip of the finger at baseline and 1, 3 and 5 minutes after the training protocols for lactate [La$^-$] determination in whole body blood. Before each blood collection, hygiene was performed on the site with an alcohol swab. The finger was punctured with the lancet after drying. This protocol was repeated, if necessary, for a second drop of blood. Blood lactate levels were assessed using an automatic blood lactate analyzer (Lactate Plus Meter; NOVA BIOMEDICAL®, Waltham, MA, EUA) (19).

Statistical Analysis

All outcome measures were reported as mean ± SD and were obtained using the software SPSS 25.0 (IBM Japan, Inc., Tokyo, Japan). The assumptions of normality were assessed by Shapiro-Wilks´ test. Initially, a coefficient of variation (CV%), typical error (TE), intraclass correlation coefficient (ICC) and standard error of mean (SEM) was applied between the measures of the 1RM. The ICC (α model) were determined by two-way mixed and absolute agreement analysis. The sphericity was verified by the Mauchly test, and when not met, the Greenhouse-Geisser correction was used. A repeated measures analysis of variance (ANOVA) model was used to compare the dependent variables between the RT schemes. When the F value was significant, a Bonferroni's post hoc test for multiple comparisons was applied to identify the differences. For lactate analysis, we had to perform a two-way repeated measures ANOVA (independent variables: RT schemes and time). The effect sizes were calculated through the partial eta squared ($_p n^2$), and classified as follows: .02 small, .13 medium, and .26 large effect (5). To identify the magnitude of differences between pairwise comparisons, the Hedge's g analysis (pooled SD model) and the 95% of confidence intervals for Hedge's g were reported (20). The Hedge's g estimates were classified as follows: < 0.15, trivial effect, 0.15 – 0.39, small effect, 0.40 – 0.74, medium effect, $\geq$ 0.75, and large effect. Statistical significance was considered when $p \leq 0.05$.

RESULTS

Table 1 shows general characteristics of participants. There were no between-condition differences for total training volume (bi-set training = 57001.01 ± 516.35 kg; drop-set training = 56887.88 ± 491.97 kg; traditional RT = 56975.25 ± 481.07 kg; $F_{(2,15)} = 0.022$ $p = 0.978$, $_{p}n^2 = 0.002$).

Table 1. General characteristics of participants.

Variable	Mean ± SD
Age (years)	29.7 ± 6.1
Body mass (kg)	83.4 ± 7.6
Height (cm)	176.6 ± 4.5
Body fat (%)	14.8 ± 3.6
REE (kcal/day)	2485.9 ± 296.1
RT experience (years)	11.4 ± 6.7
1RM barbell bench press (kg)	116.9 ± 21.1
1RM incline bench press (kg)	97.1 ± 17.8
1RM barbell bench press: body mass ratio (a.u.)	1.4 ± 0.2
1RM incline bench press: body mass ratio (a.u.)	1.2 ± 0.1

Abbreviations: kg = kilogram; cm = centimeters; kcal/day = kilocalories per day; a.u. = arbitrary units; SD = standard deviation.

The repeated measures analysis of variance (ANOVA) indicated a significant effect between the training protocols in aerobic EE (Figure 2A). The analysis suggest a protocol effect for aerobic EE in whole session (kcal) ($F_{(2,15)} = 41.431$; $p < 0.001$; $_{p}n^2 = 0.747$). Post hoc comparisons revealed that bi-set training (42.40 ± 6.02 kcal·min^{-1}) elicited higher aerobic EE ($p = 0.003$; $g_{Hedges} = -1.065$ [-1.83 – -0.3]) than drop-set training (36.53 ± 4.95 kcal·min^{-1}) and traditional RT (32.07 ± 4.43 kcal·min^{-1}) ($p < 0.001$; $g_{Hedges} = -1.955$ [-2.84 – -1.085]). In addition, the drop-set training elicited higher aerobic EE ($p = 0.002$; $g_{Hedges} = -0.95$ [-1.704 – -0.195]) than the traditional RT.

The absolute aerobic EE (kcal·min^{-1}) also indicated a significant effect ($F_{(1.452,15)} = 14.978$; $p < 0.001$; $_{p}n^2 = 0.517$) (Figure 2B). Post hoc comparisons showed that bi-set training (6.90 ± 0.99 kcal·min^{-1}) means were significantly different than TRAD (5.99 ± 0.82 kcal·min^{-1}) ($p < 0.001$; $g_{Hedges} = -1.001$ [-1.76 – -0.242]). In addition, there was a trend that drop-set training (6.36 ± 0.94 kcal·min^{-1}) promotes a higher relative aerobic EE than TRAD ($p = 0.069$; $g_{Hedges} = -0.419$ [-1.143 – 0.304]), but lower than bi-set training ($p = 0.068$; $g_{Hedges} = 0.559$ [-0.17 – 1.289]). The relative aerobic EE (kcal.kg^{-1}.min^{-1}) also indicated a significant effect ($F_{(1.447;15)} = 15.699$; $p < 0.001$; $_{p}n^2 = 0.529$) (Figure 2C). The bi-set training (0.083 ± 0.102 kcal.kg^{-1}.min^{-1}) elicited higher aerobic EE ($p < 0.001$; $g_{Hedges} = -0.152$ [-0.869 – 0.565]) that traditional RT (0.072 ± 0.010 kcal.kg^{-1}.min^{-1}), and there was a trend ($p = 0.058$; $g_{Hedges} = -0.097$ [-0.813 – 0.519]) to be greater than drop-set training (0.076 ± 0.009 kcal.kg^{-1}.min^{-1}).

Lastly, there was an effect of protocols on aerobic $\dot{V}O_2$ ($F_{(1.402,15)} = 19.029$; $p < 0.001$; $_{p}n^2 = 0.576$), in which the bi-set training (16.28 ± 2.15 ml.kg^{-1}.min^{-1}) was higher than drop-set training (14.73 ± 2.03 ml.kg^{-1}.min^{-1}) and traditional RT (13.75 ± 1.79 ml.kg^{-1}.min^{-1}) ($p < 0.034$, $g_{Hedges} = -0.756$ [-

1.496 – -0.015]; $p < 0.001$, $g_{Hedges} = -1.279$ [-2.064 – -0.493]; respectively). Additionally, there was a trend that drop-set training induces a higher aerobic $\dot{V}O_2$ than traditional RT ($p = 0.051$; $g_{Hedges} = -0.496$ [-1.223 – 0.230]) (Figure 2D).

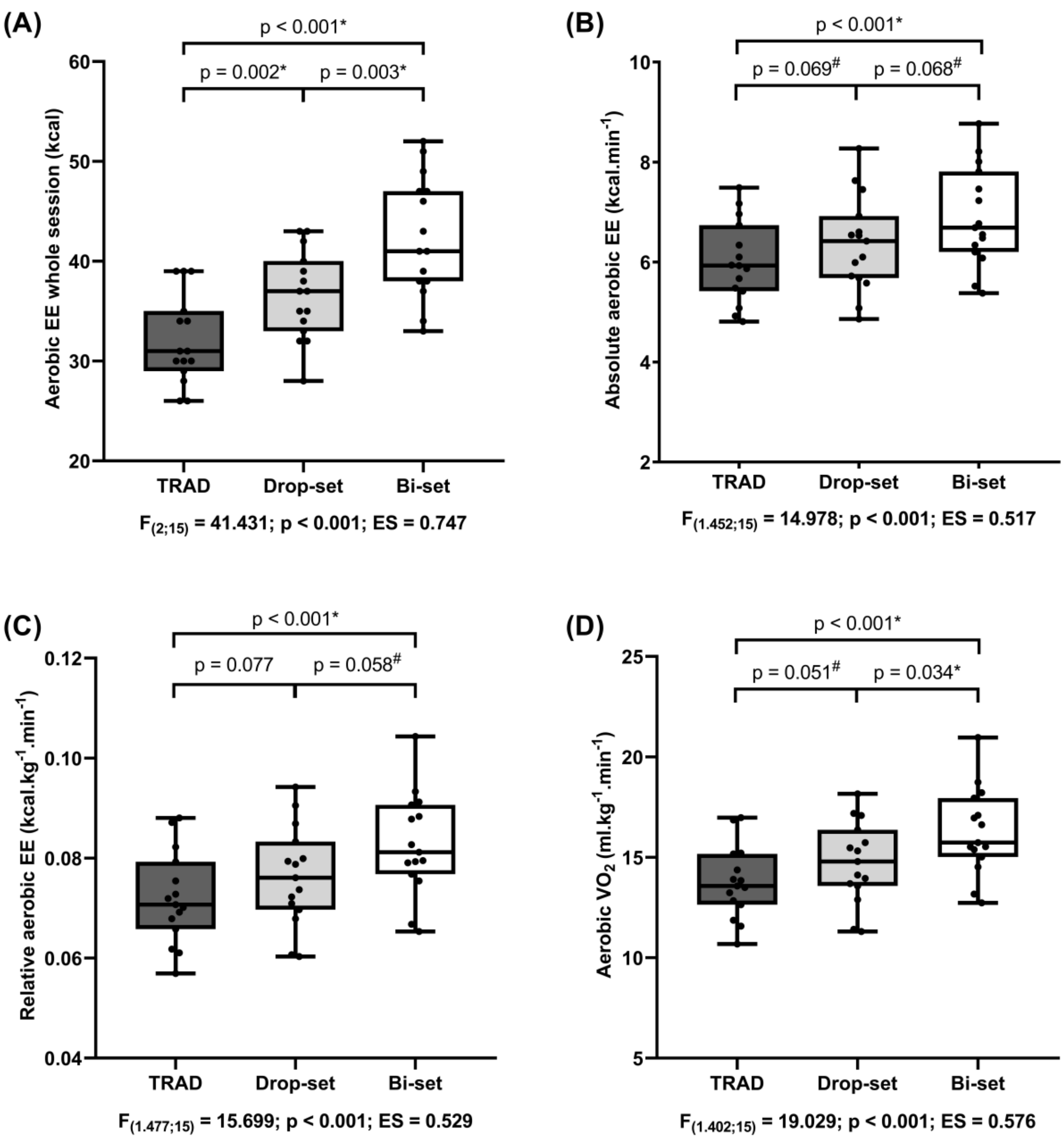

Figure 2. Aerobic EE whole session (A), absolute aerobic EE (B), relative aerobic EE (C) and aerobic $\dot{V}O_2$ (D) during different RT schemes. *significant difference ($p \leq 0.05$); #significant trend ($p \geq 0.05$ to ≤ 0.07). Abbreviations: EE = energy expenditure; TRAD = traditional resistance training; ES = effect size.

There were similar effects between the training protocols in anaerobic EE whole session (kcal) ($F_{(1.270,15)} = 0.220$; $p = 0.702$; $_p n^2 = 0.015$), absolute anaerobic EE (kcal·min^{-1}) ($F_{(1.394,15)} = 0.267$; $p = 0.688$; $_p n^2 = 0.019$), relative anaerobic EE (kcal.kg^{-1}.min^{-1}) ($F_{(1.329,15)} = 0.297$; $p = 0.657$; $_p n^2 = 0.021$)

and anaerobic $\dot{V}O_2$ (ml.kg^{-1}.min^{-1}) ($F_{(1.329,15)} = 0.297$; $p = 0.657$; $_p\eta^2 = 0.021$). Figure 3 shows the effects between the training protocols in anaerobic EE (Figure 3A to 3D; respectively).

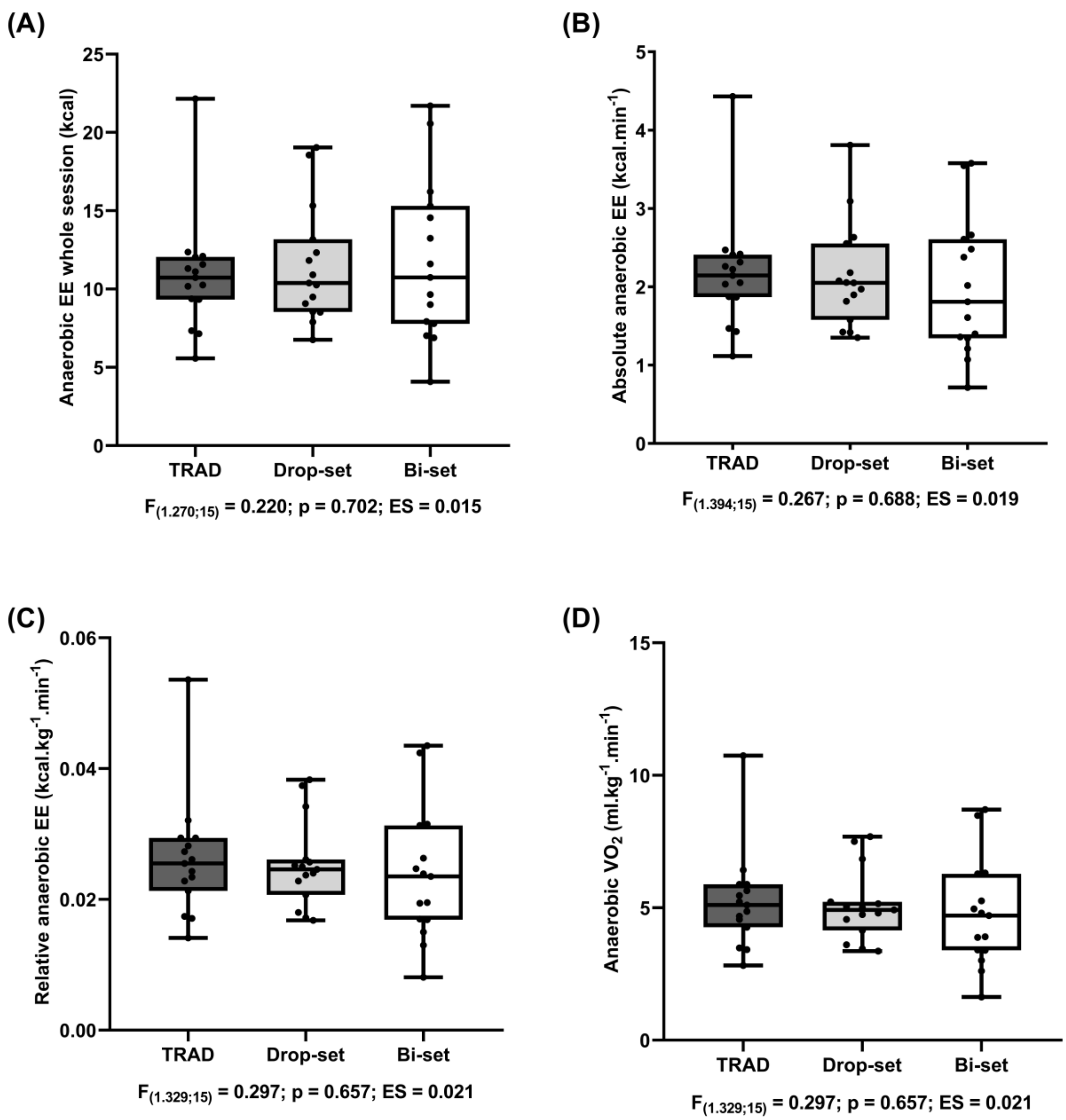

Figure 3. Anaerobic EE whole session (A), absolute anaerobic EE (B), relative anaerobic EE (C) and anaerobic $\dot{V}O_2$ (D) during different RT schemes. Abbreviations: EE = energy expenditure; TRAD = traditional resistance training; ES = effect size.

Repeated measures ANOVA indicated a main effect of time ($F_{(3,15)} = 117.294$; $p < 0.001$; $_p\eta^2 = 0.893$) and condition ($F_{(2,15)} = 4.349$; $p = 0.023$; $_p\eta^2 = 0.237$) for blood lactate levels (Figure 3). Post hoc comparisons suggest that blood lactate levels at pre-test (2.91 ± 1.08 mmol/L) were lower ($p < 0.001$) than at 1 (9.56 ± 1.69 mmol/L; $g_{Hedges} = 4.689$ [3.303 - 6.075]), 3 (10.74 ± 2.21 mmol/L; $g_{Hedges} = 4.502$ [3.156 - 5.847]) and 5 minutes (9.90 ± 1.65 mmol/L; $g_{Hedges} = 5.103$ [3.556 - 6.469]) after training sessions. In addition, drop-set training (8.80 ± 1.81 mmol/L) elicited higher blood lactate levels as compared to TRAD (7.43 ± 1.35 mmol/L; $p = 0.009$; $g_{Hedges} = -0.858$ [-1.606 - -0.110]), but were similar when compared to the bi-set training (8.60 ± 1.92 mmol/L; $p = 0.999$; $g_{Hedges} = -0.108$ [-0.824 - 0.608]). No significant time vs. condition interaction was found ($F_{(6,15)} = 0.388$; $p = 0.885$; $_{p}n^2 = 0.027$).

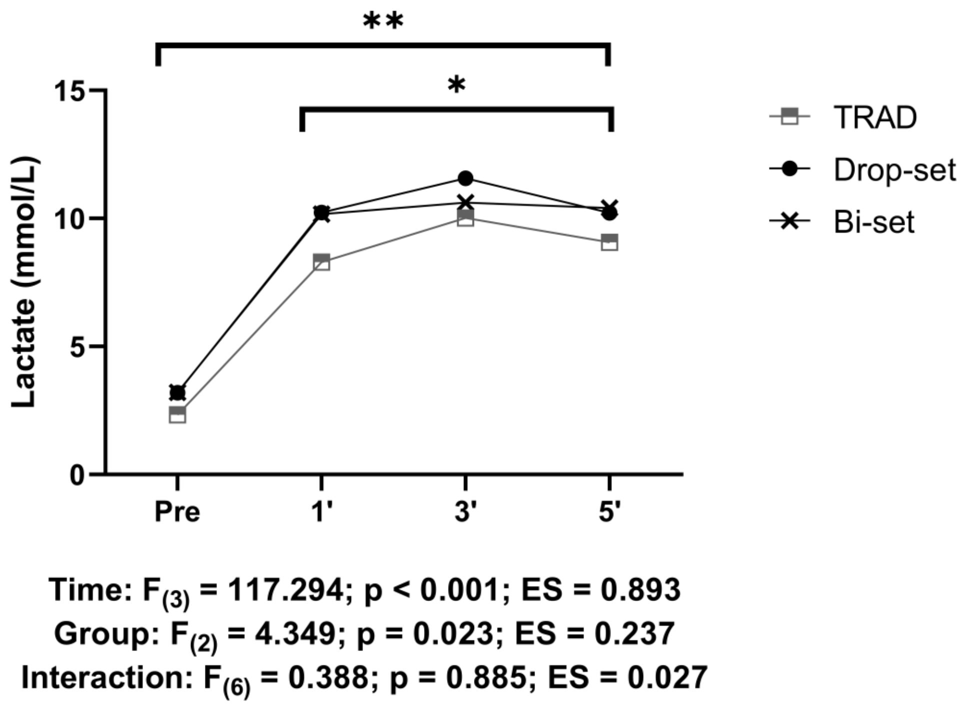

Figure 3. Blood lactate levels in the three RT schemes. *main effect of post-test (1′, 3′ and 5′ min) when compared to baseline ($p < 0.001$). **main effect of drop-set training when compared to traditional RT ($p = 0.009$). Abbreviations: TRAD = traditional resistance training; ES = effect size.

DISCUSSION

This study investigated the effects of RT techniques with total training volume equalized on metabolic responses in trained males. In accordance to the initial hypothesis, the bi-set and drop-set RT techniques elicited greater metabolic responses than traditional RT. The main findings were: a) bi-set training promotes higher aerobic but not anaerobic energy expenditure than drop-set and traditional RT; b) bi-set training has the highest oxygen consumption between RT schemes; c) drop-set training elicited higher energy expenditure and blood lactate levels than traditional RT, but not to bi-set training.

Aerobic EE was higher in RT using the bi-set and drop-set techniques as compared to traditional RT. To the author's knowledge, this is the first study to compare volume-equated bi-set and drop-set training to traditional RT on metabolic responses in trained males. This finding reinforces the initial hypothesis about the potential superiority of metabolic cost in RT using advanced RT techniques due to distinct acute responses compared to traditional RT. In accordance with the findings in this study, Kelleher et al. (22) found that supersets elicited prominent metabolic responses (i.e. higher relative EE and excess post-oxygen consumption) and blood lactate levels than traditional RT, which raises a potential role of RT techniques on metabolic responses. On the other hand, Brentano et al. (8) compared two superset configurations for the upper- and lower-limbs and observed that EE was similar between the conditions. However, Brentano et al. (8) did not compare EE to a traditional RT session, which may explain the lack of difference to any of the RT techniques.

The superiority of bi-set and drop-set training on aerobic EE may be partially explained by the absence of longer rest intervals between changing exercise/load and training density. It is plausible that the lack of longer rest intervals may promote greater hypoxia, ventilatory compensation, and limited resynthesis of muscular energy substrates (1, 7, 16, 23). Moreover, the addition of the incline bench press could contribute to distinct neuromuscular responses since performing exercises at different joint angles may contribute to more metabolic stress as compared to other training protocols (15, 32). However, bi-set training is a RT technique that combines distinct exercises and has been studied previously (8, 11, 29, 30). These differences on aerobic EE were not found regarding anaerobic EE data. In contrast to the results in this investigation, Realzola et al. (31) reported that reciprocal supersets elicited higher anaerobic energy expenditure than traditional sets. This conflicting result might be partially explained by RT techniques discrepancies and the training status of individuals. Some discrepancies in RT techniques could lead to distinct blood lactate levels, which was the data used to estimate anaerobic EE in both studies. Moreover, highly trained individuals would likely exhibit different blood lactate levels than moderately trained individuals. These potential explanations are only hypotheses, and further studies are needed to elucidate this.

Drop-set training elicited higher blood lactate levels than traditional RT, but not compared to bi-set training. This was an unexpected finding due to the equated conditions (i.e. concentric failure, repetitions number) among RT techniques. Intriguingly, contrary findings were observed by previous studies that investigated blood lactate levels comparing RT techniques to traditional RT. Paz et al. (30) found similar responses to blood lactate levels from baseline to 72h post-training between supersets, paired sets, circuit training and traditional RT in trained males. Another study observed no differences for blood lactate levels after performing a traditional RT program as compared to a pyramidal system in healthy males (12). To the author's knowledge, only Fink et al. (17) assessed blood lactate levels after RT bouts with drop-set and traditional schemes and reported no differences between them. Some variables can partially explain the different findings in this study with these previous studies such as the muscle groups and exercises involved, as well the rest interval length between sets. Additionally, the method in which the drop-set protocol was performed in this investigation could also contribute to the differences reported in this study as compared to other studies. For example, the load reduction in the drop-set condition may have allowed the participants to do a few high-velocity repetitions once the load was reduced; in turn, this may creates a shift in muscle fiber types recruitment and alterations on microvascular oxygenation (2, 10, 13, 18, 33). These factors might influence the glycolytic activity due to the specific mitochondrial content in each muscle fiber type and distinct microvascular oxygenation levels (i.e. concentrations of oxygenated and deoxygenated hemoglobin) that results in a higher lactate efflux from the sarcolemma to blood (2, 18, 34, 39). This hypothesis warrants further investigation given that we can only speculate explanations regarding blood lactate findings.

The results of this study must be interpreted with caution to avoid misinterpretations. Practitioners who want to reduce body fat need to be on a hypocaloric intake; RT is just a means to help increase total EE and may help maintain lean mass. The results of this study are specific to trained males, which should not be extrapolated to other populations such as women, older adults or untrained populations. Although the participants were oriented to have the same meal at least 2 hours prior to each training session and to maintain their normal eating habits, this was not specifically controlled; hence, it is not known what and how much participants ate before each experimental protocol. All of the mechanisms mentioned to attempt to explain the findings of this study are speculative since they were not specifically evaluated. RT techniques generally contribute to an increase in total training volume; however, in this study total training volume was equated between conditions to verify the effect of the RT technique and not total the training volume on metabolic responses. Importantly, although bi-set training standards combine two exercises, the addition of the incline bench press could influence the results since varying an exercise could lead to a different demand on specific muscles involved in the exercise. Moreover, although statistical differences were identified, the findings of this study are related for only a limited number of exercises of a muscle group. Since the VO2-measured values were relatively low, it may not have a strong practical meaning because it does not represent what occurs after a complete training session.

In conclusion, bi-set and drop-set resistance training techniques elicit prominent metabolic responses as compared to TRAD RT. It seems that using bi-set or drop-set training may be viable tools to maximize resistance training-induced aerobic energy expenditure to assist resistance-trained males and physique athletes improve their body composition. However, it is important to point out that these findings are related to only one/two exercises and the VO2-data were relatively low among the RT protocols. As such, this information may not transfer to what occurs after a complete training session.

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