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STRENGTH AND MUSCULAR ADAPTATIONS FOLLOWING 6 WEEKS OF REST-PAUSE VERSUS TRADITIONAL MULTIPLE-SETS RESISTANCE TRAINING IN TRAINED SUBJECTS

Running Head: Rest-pause method and resistance training

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ABSTRACT

The purpose of the present study was to compare the longitudinal effects of six weeks of *rest-pause* versus traditional multiple-set RT on muscle strength, hypertrophy, localized muscular endurance, and body composition in trained subjects. Eighteen trained subjects (mean ± SD; age = 30.2 ± 6.6 years; weight = 74.8 ± 17.2 kg; height = 171.4 ± 10.3 cm) were randomly assigned to either a traditional multiple-set group (n = 9; 7 males and 2 females; 3 sets of 6 repetitions with 80% of 1-RM and 2 min rest intervals between sets) or a *rest-pause* group (n = 9; 7 males and 2 females). The results showed no significant differences ($p > 0.05$) between groups in 1RM strength (*rest-pause*: 16 ± 11% for BP, 25 ± 17% for LP, and 16 ± 10% for BC versus traditional multiple-set: 10 ± 21% for BP, 30 ± 20% for LP and 21 ± 20% for BC). In localized muscular endurance, the *rest-pause* group displayed significantly greater ($p < 0.05$) repetitions, only for the LP exercise (rest pause: 27 ± 8% versus traditional multiple set: 8 ± 2%). In muscle hypertrophy, the *rest-pause* group displayed significantly greater ($p < 0.05$) thickness, only for the thigh (*rest-pause*: 11 ± 14% versus traditional multiple-set: 1 ± 7%). In conclusion, resistance training performed with the *rest-pause* method resulted in similar gains in muscle strength as traditional multiple-set training. However, the *rest-pause* method resulted in greater gains in localized muscular endurance and hypertrophy for the thigh musculature.

Keywords: training method, rest interval, hypertrophy, muscle strength

INTRODUCTION

The manipulation of resistance training (RT) variables has been widely used to achieve training goals, such as muscle hypertrophy, maximal strength, power, and localized muscular endurance (2, 13, 15). Additionally, RT methods that combine the manipulation of inter-set rest intervals and repetition failure sets might be important for continued muscle strength and hypertrophy adaptations in resistance-trained individuals (11, 14, 15).

Recreationally trained subjects and bodybuilders often use repetition failure sets with short inter-set rest intervals as in the *rest-pause* method. This method involves lifting a fixed load with an initial set to failure (typically 10–12 repetitions), followed by subsequent sets to failure using short (e.g., 10-20 s) inter-set rest intervals (14). However, the initial training status of an individual affects the magnitude of neuromuscular adaptations (7), so that those with a higher training status exhibit a lower rate of gain over time.

Although relatively few studies have investigated long-term responses to different RT methods (such as the *rest-pause* method) in trained individuals, it was found recently in untrained individuals (23 ± 6.6 years) that performing repetition failure sets for 12-weeks, induced similar adaptations in the elbow flexors as two other RT protocols that did not involve repetitions failure sets. This suggests that repetition failure sets are not critical to elicit significant neural and structural changes to skeletal muscle in untrained individuals (21). However, the effects of repetition failure sets might differ as training status changes.

Thus, the inclusion of RT methods, such as *rest-pause* could be productive to increase time under tension and metabolic stress, especially in recreationally trained subjects and bodybuilders, already adapted to traditional training. Possibly, the metabolic stress manifested by accumulation of metabolites, muscle hypoxia, cellular swelling and alterations in local myogenic factors, would increase hypertrophic adaptations and/or muscle strength (22). Consistent with these findings, six weeks of drop-set hypertrophy type training and four weeks of strength mixed with drop-sets were effective to increase muscle cross-sectional area, muscular endurance and one-repetition maximum (1-RM) for the leg press in resistance trained subjects (11).

Alternatively, the long-term findings on the use of short rest intervals, as in the *rest-pause* method have been contradictory. Fink *et al* (9) compared the long-term effects (8-week) of different rest intervals (30 s vs. 150 s with the same intensity of 40% 1RM) carried out to muscular failure on muscle strength and cross-sectional area (CSA) of the upper arm and thigh muscles in untrained individuals (18 – 22 years) not involved in RT for at least 2 years. The results confirmed that for untrained individuals, different rest interval lengths in low-load RT lead to similar strength and hypertrophy adaptations, independent of the greater total training volume achieved in the longer rest interval group. This confirms that current findings from untrained subjects cannot be generalized to resistance-trained individuals (23).

So, for resistance-trained individuals (RT experience = 3.4 years) Schoenfeld *et al* (23), compared the effects of low- versus high-load resistance training on muscle strength and muscle thickness in the elbow flexors and extensors. Although there were no significant between-group differences, the high-load RT routine resulted in a greater effect size for bench press strength, back squat strength, elbow extensor thickness, and quadriceps thickness versus the low-load RT. These results were in spite of the low-load group performing a higher total training volume. Thus, for maximizing hypertrophy and muscle strength in resistance-trained individuals, the heavier loading (e.g. 80% of 1 RM) coupled with shorter rest intervals (as in the *rest-pause* method) could be as productive as a traditional multiple-set RT program.

Marshall *et al* (14) evaluated the acute fatigue responses to the *rest-pause* method in trained subjects performing three different protocols in random order for the squat exercise with an intensity of 80% 1-RM (Protocol A: consisted of 5 sets of 4 repetitions with 3 min inter-set rest intervals; Protocol B: consisted of 5 sets of 4 repetitions with 20 sec inter-set rest intervals; and Protocol C, the *rest-pause* method consisted of an initial set to failure with subsequent sets performed with a 20 sec inter-set rest interval). All protocols resulted in a total of 20 repetitions. The results demonstrated greater electromyographic activity (EMG) and similar fatigue behavior during the *rest-pause* method versus the other protocols.

Furthermore, Paoli *et al* (16) found that when resistance trained subjects performed the *rest-pause* method in the leg press, bench press and lat pull-down that they exhibited significantly higher basal energy expenditure and VO_2 for up to 22 hrs. post-exercise as compared to traditional RT. Taken together, these results clearly show the importance of using training methods, in this case *rest-pause*, to disrupt homeostasis in trained subjects and potentially promote further adaptation. The increase in EMG and energy expenditure in trained subjects might lead to further longitudinal adaptations. However, there is no current study investigating the longitudinal effects of the *rest-pause* method on muscle strength and hypertrophy. To note, trained subjects commonly use more exercises in daily training and methods that promote time-efficiency such as *rest-pause* might be desirable.

Thus, the purpose of the present study was to compare the longitudinal effects of six weeks of *rest-pause* versus a traditional multiple-set RT on muscle strength, hypertrophy, localized muscular endurance, and body composition in trained subjects. Our initial hypothesis was that RT with the *rest-pause* method would increase muscle mass and strength to a greater extent versus traditional multiple-set training, with no differences between protocols in altering body composition.

METHODS

Experimental Approach to the Problem

The aim of the present study was to compare the muscle strength, hypertrophy, localized muscular endurance, and body composition alterations between *rest-pause* and traditional multiple-set RT over a 6-week period of training in trained subjects. The study followed a previous acute design proposed by Marshall *et al* (14) and was adapted to a chronic intervention, with each participant randomly assigned to a *rest-pause* or traditional multiple-set RT group (control). The main difference between the Marshall *et al* (14) study and the present study was that microcycles for both methods lasted 1 week; the training intervention lasted 6-weeks; tested exercises included the bench press, leg press, and free weight standing biceps curl; a higher ecological validity; and the use of B-mode ultrasound to investigate hypertrophic changes. All subjects were required to undergo the same exercise sequences, but the *rest-pause* group performed an initial set with 80% of 1-RM until failure with subsequent sets performed with a 20 sec inter-set rest interval until completing a total of 18 repetitions; while the traditional multiple-sets group completed 3 sets of 6 repetitions with 80% of 1-RM and a 2 min inter-set rest interval. Measures of body composition, strength, localized muscular endurance and hypertrophy were collected by a blinded researcher before and after the 6-week training period. To note, symptoms of fatigue and tiredness were not reported by subjects from the *rest-pause* method group during this study.

Subjects

Twenty-two subjects volunteered to participate in the present study. Four subjects were excluded due to not completing 75% of the training sessions. Eighteen subjects (14 males and 4 females) were randomly assigned to a *rest-pause* group (n = 9; 30.3 ± 6.5 years; 82.2 ± 17.9 kg; 174.9 ± 8.2 cm; > 1 year of training experience) or a traditional multiple-set group (n = 9; 30.1 ± 7.2 years; 67.4 ± 13.4 kg; 167.9 ± 11.5 cm; > 1 year of training experience). The subjects were accustomed to training 3-5 days per weeks with split-body training routines and 3-4 sets of 8-12RM per exercise with the objective of muscle hypertrophy. The study was approved by Catholic University of Brasilia Research Ethics

Committee for Human Use (protocol No. 030/09). Study design and ethical procedures were in accordance with ethical standards and the Declaration of Helsinki. Besides, subjects were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study.

1-RM testing and local muscle endurance

One-repetition maximum test and retest sessions were performed on different days with 72 hrs between tests. The tested exercises included the bench press, leg press, and free weight standing biceps curl (JOHNSON, Landmark Drive, Cottage Grove, USA). The protocol consisted of 5 min low intensity walking on a treadmill followed by eight repetitions with 50% of an estimated 1-RM (according to the subjects' perceived capacity) as described previously (26). After a rest of 1 min, three repetitions were performed with 70% of an estimated 1-RM. Following 3 min of rest, subjects completed three to five 1-RM attempts with progressively heavier weights (~5%), interspersed with 3–5 min rest intervals until a 1-RM was determined. The range of motion and exercise technique were standardized according Brown & Weir (3). The 1-RM tests (test-retest) were conducted on two non-consecutive days (minimum of 72 hr. between tests). The intraclass correlation coefficient was = .97 for all exercises, thus confirming the test-retest reliability. Once the 1-RM was determined, 60% of this value was calculated for the localized muscular endurance test. After a sufficient recovery period (4-5 min), the subjects performed as many repetitions as possible with 60% of 1-RM until failure for each exercise (5). All tests and training were performed during the summer period.

Muscle thickness and circumference

Muscle thickness and circumference of the arm, thigh and chest were tested before and after the six-week RT period. All tests were conducted at the same time of day, subjects were instructed to hydrate normally 24 hrs before the tests. Measures were taken 3–5 days after the last training session to prevent any residual effects (i.e. swelling) that could interfere with the validity of the muscle thickness measurements (6). Subjects were instructed to avoid any other type of exercise or intense activity. Muscle thickness was measured using B-Mode ultrasound (Philips-VMI, Ultra Vision Flip, model BF). A water-soluble transmission gel was applied to the measurement site and a 7.5-MHz ultrasound probe was placed perpendicular to the tissue interface while not depressing the skin. Muscle thickness of the arm, thigh and chest muscles from the dominant limb were measured according to the recommendations of Abe *et al* (1). Once the technician was satisfied with the quality of the image produced, the image on the monitor was frozen. With the image frozen, a cursor was enabled in order to measure muscle thickness, which was taken as the distance from the subcutaneous adipose tissue-muscle interface to muscle-bone interface (1). A trained technician performed all analyses.

Body Composition

Body composition was assessed using skinfold thickness measurements taken with a Lange skinfold caliper. The equation of Jackson *et al* (12) for women (18–55 years old) was used to estimate body fat percentage. In this equation, the sum of triceps, suprailiac, and thigh skinfolds is used. After this procedure, body density was estimated from which percentage body fat, fat mass (kg), and fat-free mass (kg) were estimated.

Resistance training program

The 6 week RT program for each group consisted of four sessions per week in a split routine, that included: Routine A (Monday and Wednesday, day 1 and 3) with three exercises for the pectoralis major (barbell bench press, dumbbell incline press, and cable cross), two exercises for the deltoids (military press and lateral raise), and two exercises for the triceps brachii (triceps pulley and barbell triceps extension); and Routine B (Tuesday and Thursday, day 2 and 4) with three exercises for the thigh musculature (squat, 45^{o} leg press and leg curl), three for the latissimus dorsi (front lat pull-down, seated row and dumbbell lateral row), and two for the biceps brachii (standing barbell elbow curl and preacher curl). All equipment was from JOHNSON (Landmark Drive, Cottage Grove, USA). The training sessions lasted around 57 and 35 minutes for the traditional and *rest-pause* methods, respectively. Each experimental protocol involved performance of 18 repetitions, at an intensity of 80% of 1 RM, with similar volume-loads and exercises chosen based on their common inclusion in RT programs. For the traditional multiple-set program, exercises were performed for three sets of 6 repetitions with 80% of 1-RM and 2-3 min of rest between sets and exercises; for the *rest-pause* group an initial set with 80% of 1-RM was performed until failure with subsequent sets performed with a 20 sec inter-set rest interval until a total of 18 repetitions were completed; and with 2-3 min of rest between exercises.

All training sessions were carefully supervised by a certified strength and conditioning professional, and adherence to the training program was ~90% for both groups. Also, during microcycles no reduction in training intensity or assistance was provided for the *rest-pause* group as recommend by Marshall *et al* (14) . The resistance training protocol is presented in Table 1.

Insert table 1 here.

Statistical analysis

The data are expressed as the mean value, standard deviation (SD) and 95% confidence interval (CI). The Shapiro-Wilk test was applied to check for normality distribution of study variables. ANCOVA was used to determine the effect of two different exercise-training programs on post-intervention strength and anthropometric variables after controlling for pre-intervention variables. The power of the sample size was determined using G*Power version 3.1.3 (8), based on the effect of different exercise-training programs on post-intervention variables. Considering the sample size of this study and an alpha error of 0.05, the power (1 – β) achieved was 1.00 for 1RM, body composition, circumferences and thickness variables, 0.61, 0.84 and 1.00 for bench press, leg press and biceps curl maximal repetitions, respectively. The effect size calculation (ES = difference between pre- and post-intervention divided by pre-intervention SD) and the ES strength training (18) were used to evaluate the magnitude of training effects. The level of significance was $p \leq 0.05$ and SPSS version 20.0 (Somers, NY, USA) software was used.

RESULTS

There was no difference in carbohydrate, protein, lipid, and calorie intake between groups pre- versus post-training ($p > 0.05$; data not shown). Figure 1 presents the 1-RM values for BP, LP and BC exercises pre- and post-training for each group. After adjustment for pre-intervention 1-RM values, there was no statistically significant difference ($p > 0.05$) at the post-training point between groups for any of the exercises. However, the ES was higher for *rest-pause* group, for the BP (*rest-pause*: ES = 0.39 – small; multiple-set: ES = 0.19 – trivial) and BC (*rest-pause*: ES = 0.59 – small; multiple-set: ES = 0.34 – trivial). The training effect was high for the LP exercise, both for the *rest-pause* group (ES = 0.94 – moderate) and traditional multiple-set group (ES = 0.92 – moderate). The 1-RM increase in the rest- pause group was 16 ± 11% (8 – 25%) for BP, 25 ± 17% (12 – 37%) for LP and 16 ± 10% (8 – 24%) for BC. The traditional multiple-set group presented an increase of 10 ± 21%

(-6 – 26%) for BP, 30 ± 20% (14 – 45%) for LP, and 21 ± 20% (5 – 37%) for BC. No statistically significant differences ($p > 0.05$) were observed between groups.

Insert Figure 1 here.

For localized muscular endurance, after adjustment for pre-training repetition values, the *rest-pause* group presented significantly greater repetitions ($p < 0.05$) post-training, only for the LP exercise (see Figure 2). For both the BP and BC there were no statistically significant differences ($p > 0.05$) at post-training between groups. The training effect was similar between groups (small ES), except in the case of the LP exercise for the *rest-pause* group (large ES). The percentage increase in repetitions for the rest-pause group was significantly greater ($p < 0.05$) only for the LP exercise [27 ± 8% (21 – 33%) for rest-pause versus 8 ± 23% (-9 – 25%) for traditional multiple-set].

Insert Figure 2 here.

Body composition parameters pre- and post-training for the traditional multiple-set and *rest-pause* groups are shown in Table 2. After adjustment for pre-training body composition, the traditional multiple-set group presented significantly lesser ($p < 0.05$) fat mass post-training, even with a trivial ES. No significant differences were observed ($p > 0.05$) in body mass and lean mass post-training between groups. After adjustment for pre-training body circumferences, there were no statistically significant differences ($p > 0.05$) at post-training between groups for any of the evaluated circumferences (see Table 3). Considering the ES, training effects for the arm, thigh and chest circumferences were trivial for both groups. No statistically significant differences ($p > 0.05$) were observed in the percentage change of circumferences and body composition between groups. The arm, thigh and chest thickness pre- and post-training for the traditional multiple-set and *rest-pause* groups are shown in Figure 3. After adjustment for pre-training muscle thickness, the *rest-*

pause group presented significantly greater ($p < 0.05$) thickness at post-training only for the thigh. The percentage increase in thigh thickness was also significantly greater ($p < 0.05$) in the *rest-pause* group [11 ± 14% (0 – 22%)] versus the traditional multiple set group [1 ± 7% (-5 – 7%)]. No significant differences were observed ($p > 0.05$) in the arm [8 ± 10% (0 – 16%) for the rest-pause and 4 ± 15% (-8 – 17%) for the traditional multiple set] and chest [6 ± 11% (-4 – 15%) for the rest-pause and 1 ± 12% (-10 – 10%] for the traditional multiple set) thickness at post-training between groups. The training effect, represented by the ES, was trivial for the arm, thigh and chest thickness in the traditional multiple-set group; and trivial for arm thickness in the *rest-pause* group; and small for thigh and chest thickness in the *rest-pause* group.

Insert Table 2 here.

Insert Table 3 here.

Insert Figure 3 here.

DISCUSSION

To the author's knowledge, this was the first study to evaluate long-term muscular and strength adaptations with the *rest-pause* method versus traditional multiple-set RT in resistance-trained individuals. The key findings were that *rest-pause* method was superior to the traditional multiple-set method for gains in localized muscular endurance (27% vs. 8%, respectively) and hypertrophy (11% vs. 1%, respectively) in the thigh musculature. However, there were no significant differences in strength gains and body composition changes between groups.

Localized muscular endurance is reflected in the ability to continuously produce submaximal muscle actions (15). Since the *rest-pause* approach in the current study required that subjects rest only 20 secs between succeeding sets (following the initial set), this may have elicited adaptations within the muscles to enable greater performance of submaximal muscle actions. However, it bears repeating that the difference was only significant for the lower body musculature during the leg press exercise. Why the same finding was not evident in the upper body musculature cannot be determined from the present methodology, but may have been due to training with higher repetitions per set for the lower body exercises versus the upper body exercises, albeit at the same percentage of 1-RM (24).

It is also plausible that adaptations in the lower body muscles to enable more leg press repetitions may have involved greater intramuscular buffering capacity to delay metabolic acidosis (20). The traditional multiple-set method allowed for 2 min rest between sets and allowed for more complete recovery between sets in series. Therefore, it appears that to develop localized muscular endurance in the lower body muscles, performing the next set in series prior to when complete recovery has taken place is especially important.

Another intriguing possibility for eliciting lower body muscle adaptations was demonstrated in a related study by Goto *et al* (10) that involved 26 recreationally trained men divided into three groups; a "no rest" group; a "rest within set" group; and a control group that did not train. Both training groups performed two workouts per week for 12 weeks that incorporated the lat pulldown, shoulder press, and knee extension. Prior to and following the training period, measurements included: shoulder press and knee extension 1-RM; cross-sectional area of the thigh via magnetic resonance imaging; and shoulder press and knee extension repetitions at 70% of 1-RM. The "no rest" group performed three to five sets of each exercise, with a 10-RM load for 10 repetitions per set, and with 1 min of rest between sets. Conversely, the "rest within set" group instituted a 30-sec pause between the 5th and 6th repetition each set, to limit the development of fatigue. The results showed the following:

significantly greater gain in 1-RM knee extension for the "no rest" group versus the "rest within" group (66% versus 39% gain); significantly greater gain in thigh cross-sectional area for the "no rest" group versus the "rest within" group (13% versus 4% gain); and significantly greater gain in knee extension muscular endurance for the "no rest" group versus the "rest within" group (42% versus 8% gain). These results suggest that creating greater fatigue through multiple repetition maximum sets and short rest intervals between sets could be critical to optimize strength, hypertrophic and localized endurance adaptations in the lower body muscles.

The metabolic stress of *rest-pause* training and the relative emphasis on the Phosphogen and Glycolytic Energy Systems might be different versus traditional multiple-set training. For example, with the *rest-pause* protocol utilized in the current study, an initial repetition maximum set was performed with 80% of 1-RM for a given lift; this was followed by subsequent sets performed at 20 sec intervals until a total of 18 repetitions were performed. The initial set at 80% of 1-RM to muscular failure would have involved approximately 8 to 12 repetitions (24), and placed emphasis on both the Phosphogen and Glycolytic Systems to meet the energy demand. Since phosphocreatine levels in muscle can regenerate relatively quickly (25), the 20-sec interval following the initial set would have allowed for partial resynthesis of phosphocreatine to contribute to performance of additional repetitions over a series of *rest-pause* style sets. These additional repetitions (up to a total of 18) would have also increased the degree of metabolic stress (induced from the initial set), and stimulated expression of hypertrophic and localized muscular endurance characteristics in the lower body muscles (22). This hypothesis requires further study.

To our knowledge, the present study was the first to assess site-specific changes in muscle size between different RT training programs using resistance-trained subjects. Results indicated a significant difference in growth for the thigh muscles. Marshall *et al* (14) conducted one of the few acute studies to date that specifically examined the *rest-pause* method versus the traditional multiple-set training. Fourteen resistance trained men performed three squat protocols at 80% of 1-RM, including: "Protocol A" which consisted of 5 sets of 4 repetitions with 3 min inter-set rest intervals; "Protocol B" which consisted of 5 sets of 4 repetitions with 20-sec inter-set rest intervals; and the *rest-pause* protocol involved performance of an initial set to failure with subsequent sets performed at 20-sec intervals. For all protocols, a total of 20 repetitions were performed. Maximal squat isometric force output and rate of force development (RFD) were measured before, immediately following, and 5 min following each protocol. Muscle activity from six different thigh and hip muscles was measured with surface electromyography (EMG) at each time point, and during every squat repetition.

Marshall *et al* (14) showed similar and significant decreases ($p < 0.05$) in maximal force and RFD immediately following each protocol, with full recovery at the five-minute time point following each protocol. However, significantly greater motor unit recruitment was observed during the *rest-pause* protocol compared to both Protocols A and B for all muscles measured ($p < 0.05$). Although muscle activity was not measured in the current study, the *rest-pause* protocol may have elicited great muscle activation in the lower body muscles with repeated workouts over time, as evidenced by the significantly greater longitudinal change in muscle hypertrophy in our study.

In another acute study, Paoli *et al* (16) compared high intensity interval resistance training (HIRT) versus traditional resistance training (TT) on resting energy expenditure at 22 hrs. post-exercise. The HIRT protocol consisted of performing three blocks of sets with a 6-RM load of the leg press, bench press, and dorsal machine exercises. Each block consisted of three sets, with an initial set to muscle failure and then two succeeding sets (usually 2 to 3 repetitions each) with 20 second rest intervals between sets and 2 min 30 secs between blocks. Conversely, the TT protocol consisted of 4 sets of 8 different exercises (bench press, leg press, dorsal machine, leg curl, biceps curl, military press, triceps extension, and sit-ups), at 70-75% of 1-RM. Subjects were instructed to perform as many repetitions as possible on each set with a 1-min rest between sets of single joint exercises and 2-min rest between sets for multiple-joint exercises. Despite the significantly lower volume (HIRT = 3872.4 ± 624 kg versus TT = 7835.2 ±1013 kg) and time commitment (HIRT = 32 mins versus TT = 62 mins), the blood lactate (HIRT = 10.5 ± 2.1 $mmol\cdot L^{-1}$ versus TT = 5.1 ± 1.2 $mmol\ L^{-1}$) and resting energy expenditure at 22 hours (HIRT = 2362 ± 118 Kcal/d versus TT = 1999 ± 88 Kcal/d) were significantly greater for the HIRT protocol. Despite these findings, the current study did not find differences in the change in percent body fat and circumferences between the *rest-pause* group and the traditional multiple-set group. Significant differences in these parameters may require greater than six weeks of training. However, this hypothesis requires further study.

Strength gains for both *rest-pause* and traditional multiple-set RT methods in recreationally trained individuals were consistent with meta-analyses for recreationally trained non-athletes (17, 19). These studies have identified that peak gains in strength occur with a training intensity of 80% 1 RM for recreationally trained individuals as used in this study. Furthermore, the length of rest intervals between RT methods did not to affect strength gains, demonstrating that strength increases are load dependent for recreationally trained individuals. This is consistent with a previous research with recreationally trained subjects, where after a 10-week training period, no differences for strength gains between groups were observed when using different rest intervals between sets (4).

This study had some limitations that should be noted. First, the study period lasted 6 weeks and it is not clear whether results between protocols would be different over a longer RT program. Second, muscle thickness was measured only at the middle portion of the muscle, and there is evidence that hypertrophy occur at the proximal and distal regions too (27). So, we cannot discard different changes in proximal or distal muscle thickness promoted by different RT methods. Finally, our subject population consisted of young recreationally RT men and women, and findings cannot be generalized to other populations (untrained, athletes, and the elderly).

Practical Applications

In conclusion, our findings indicate the viability of the *rest-pause* method in recreationally-trained individuals to achieve greater gains in muscle strength for the upper and lower limb musculature. The gains in muscle strength from *rest-pause* method were equal to that achieved with multiple-set RT method. As strength coaches usually vary training methods in a RT program for continued muscle strength and muscle mass enhancement, the *rest-pause* method elicited superior gains in localized muscular endurance and hypertrophy in the thigh musculature. Thus, if maximizing muscular endurance, hypertrophy, and time efficiency (14) are of primary importance, then the *rest-pause* method should be used at the exclusion of the traditional multiple-set RT method. These findings suggest a potential benefit to incorporating a wide spectrum of RT methods in a strength and hypertrophy oriented RT program.

Conflict of Interest

The authors have no financial, consultant, institutional, or other relationships that might lead to bias or a conflict of interest. The results of the present study do not constitute endorsement of the product by the authors or the NSCA. All the authors contributed to the study design, data collection, and article preparation.

REFERENCES

1. Abe T, DeHoyos DV, Pollock ML, and Garzarella L. Time course for strength and muscle thickness changes following upper and lower body resistance training in men and women. Eur J Appl Physiol 81: 174-180, 2000.

2. Assumpcao CO, Tibana RA, Viana LC, Willardson JM, and Prestes J. Influence of exercise order on upper body maximum and submaximal strength gains in trained men. Clin Physiol Funct Imaging 33: 359-363, 2013.

3. Brown LE and Weir J. ASEP Procedures Recommendation I: Accurate Assessment of Muscular Strength And Power. Journal of Exercise Physiologyonline 4: 1-21, 2001.

4. Buresh R, Berg K, and French J. The effect of resistive exercise rest interval on hormonal response, strength, and hypertrophy with training. J Strength Cond Res 23: 62-71, 2009.

5. Campos GE, Luecke TJ, Wendeln HK, Toma K, Hagerman FC, Murray TF, Ragg KE, Ratamess NA, Kraemer WJ, and Staron RS. Muscular adaptations in response to three different resistance-training regimens: specificity of repetition maximum training zones. Eur J Appl Physiol 88: 50-60, 2002.

6. Chilibeck PD, Stride D, Farthing JP, and Burke DG. Effect of creatine ingestion after exercise on muscle thickness in males and females. Med Sci Sports Exerc 36: 1781-1788, 2004.

7. Deschenes MR and Kraemer WJ. Performance and physiologic adaptations to resistance training. Am J Phys Med Rehabil 81: S3-16, 2002.

8. Faul F, Erdfelder E, Lang AG, and Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 39: 175-191, 2007.

9. Fink JE, Schoenfeld BJ, Kikuchi N, and Nakazato K. Acute and Long-term Responses to Different Rest Intervals in Low-load Resistance Training. Int J Sports Med, 2016.

10. Goto K, Ishii N, Kizuka T, and Takamatsu K. The impact of metabolic stress on hormonal responses and muscular adaptations. Med Sci Sports Exerc 37: 955-963, 2005.

11. Goto K, Nagasawa M, Yanagisawa O, Kizuka T, Ishii N, and Takamatsu K. Muscular adaptations to combinations of high- and low-intensity resistance exercises. J Strength Cond Res 18: 730-737, 2004.

12. Jackson AS, Pollock ML, and Ward A. Generalized equations for predicting body density of women. Med Sci Sports Exerc 12: 175-181, 1980.

13. Kraemer WJ, Adams K, Cafarelli E, Dudley GA, Dooly C, Feigenbaum MS, Fleck SJ, Franklin B, Fry AC, Hoffman JR, Newton RU, Potteiger J, Stone MH, Ratamess NA, and Triplett-McBride T. American College of Sports Medicine position stand.

Progression models in resistance training for healthy adults. Med Sci Sports Exerc 34: 364-380, 2002.

14. Marshall PW, Robbins DA, Wrightson AW, and Siegler JC. Acute neuromuscular and fatigue responses to the rest-pause method. J Sci Med Sport 15: 153-158, 2012.

15. Opdenacker J, Delecluse C, and Boen F. The longitudinal effects of a lifestyle physical activity intervention and a structured exercise intervention on physical self-perceptions and self-esteem in older adults. J Sport Exerc Psychol 31: 743-760, 2009.

16. Paoli A, Moro T, Marcolin G, Neri M, Bianco A, Palma A, and Grimaldi K. High-Intensity Interval Resistance Training (HIRT) influences resting energy expenditure and respiratory ratio in non-dieting individuals. J Transl Med 10: 237, 2012.

17. Peterson MD, Rhea MR, and Alvar BA. Applications of the dose-response for muscular strength development: a review of meta-analytic efficacy and reliability for designing training prescription. J Strength Cond Res 19: 950-958, 2005.

18. Rhea MR. Determining the magnitude of treatment effects in strength training research through the use of the effect size. J Strength Cond Res 18: 918-920, 2004.

19. Rhea MR, Alvar BA, Burkett LN, and Ball SD. A meta-analysis to determine the dose response for strength development. Med Sci Sports Exerc 35: 456-464, 2003.

20. Robergs RA, Ghiasvand F, and Parker D. Biochemistry of exercise-induced metabolic acidosis. Am J Physiol Regul Integr Comp Physiol 287: R502-516, 2004.

21. Sampson JA and Groeller H. Is repetition failure critical for the development of muscle hypertrophy and strength? Scand J Med Sci Sports 26: 375-383, 2016.

22. Schoenfeld BJ. Potential mechanisms for a role of metabolic stress in hypertrophic adaptations to resistance training. Sports Med 43: 179-194, 2013.

23. Schoenfeld BJ, Peterson MD, Ogborn D, Contreras B, and Sonmez GT. Effects of Low- vs. High-Load Resistance Training on Muscle Strength and Hypertrophy in Well-Trained Men. J Strength Cond Res 29: 2954-2963, 2015.

24. Shimano T, Kraemer WJ, Spiering BA, Volek JS, Hatfield DL, Silvestre R, Vingren JL, Fragala MS, Maresh CM, Fleck SJ, Newton RU, Spreuwenberg LP, and Hakkinen K. Relationship between the number of repetitions and selected percentages of one repetition maximum in free weight exercises in trained and untrained men. J Strength Cond Res 20: 819-823, 2006.

25. Stull GA and Clarke DH. Patterns of recovery following isometric and isotonic strength decrement. Med Sci Sports 3: 135-139, 1971.

26. Tibana RA, Prestes J, Nascimento Dda C, Martins OV, De Santana FS, and Balsamo S. Higher muscle performance in adolescents compared with adults after a resistance training session with different rest intervals. J Strength Cond Res 26: 1027-1032, 2012.

27. Wakahara T, Miyamoto N, Sugisaki N, Murata K, Kanehisa H, Kawakami Y, Fukunaga T, and Yanai T. Association between regional differences in muscle activation in one session of resistance exercise and in muscle hypertrophy after resistance training. Eur J Appl Physiol 112: 1569-1576, 2012.

FIGURE LEGENDS

Figure 1. Mean ± SD, 1-repetition maximum (1-RM) bench press, leg press and biceps curl pre- and post-training multiple-set (MS) and rest-pause (RP) groups. ES, *effect size.*

Figure 2. Mean ± SD, Maximal repetitions (RMs – 60% of 1RM) for bench press, leg press and biceps curl pre- and post-training traditional multiple-set (MS) and rest-pause (RP) groups. ES, *effect size*. * $p \leq 0.05$ for traditional multiple-set group.

Figure 3. Mean ± SD, Arm, thigh and chest thickness pre- and post-training multiple-set (MS) and rest-pause (RP) training methods. ES, *effect size*. *$p \leq 0.05$ for traditional multiple-set group.

Table 1. Resistance training protocol during 6 weeks of the rest-pause and traditional multiple-sets methods RT program. *

Routine A (Sessions 1 and 3)	Routine B (Session 2 and 4)
Barbel Bench Press	Squat
Dumbbell Incline Press	45º Leg Press
Cable Cross	Leg Curl
Military Press	Front Lat Pull-Down
Lateral Raise	Seated Row
Triceps Pulley	Dumbell Lateral Row
Barbell Triceps Extension	Standing Barbell Elbow Curl
	Preacher Curl

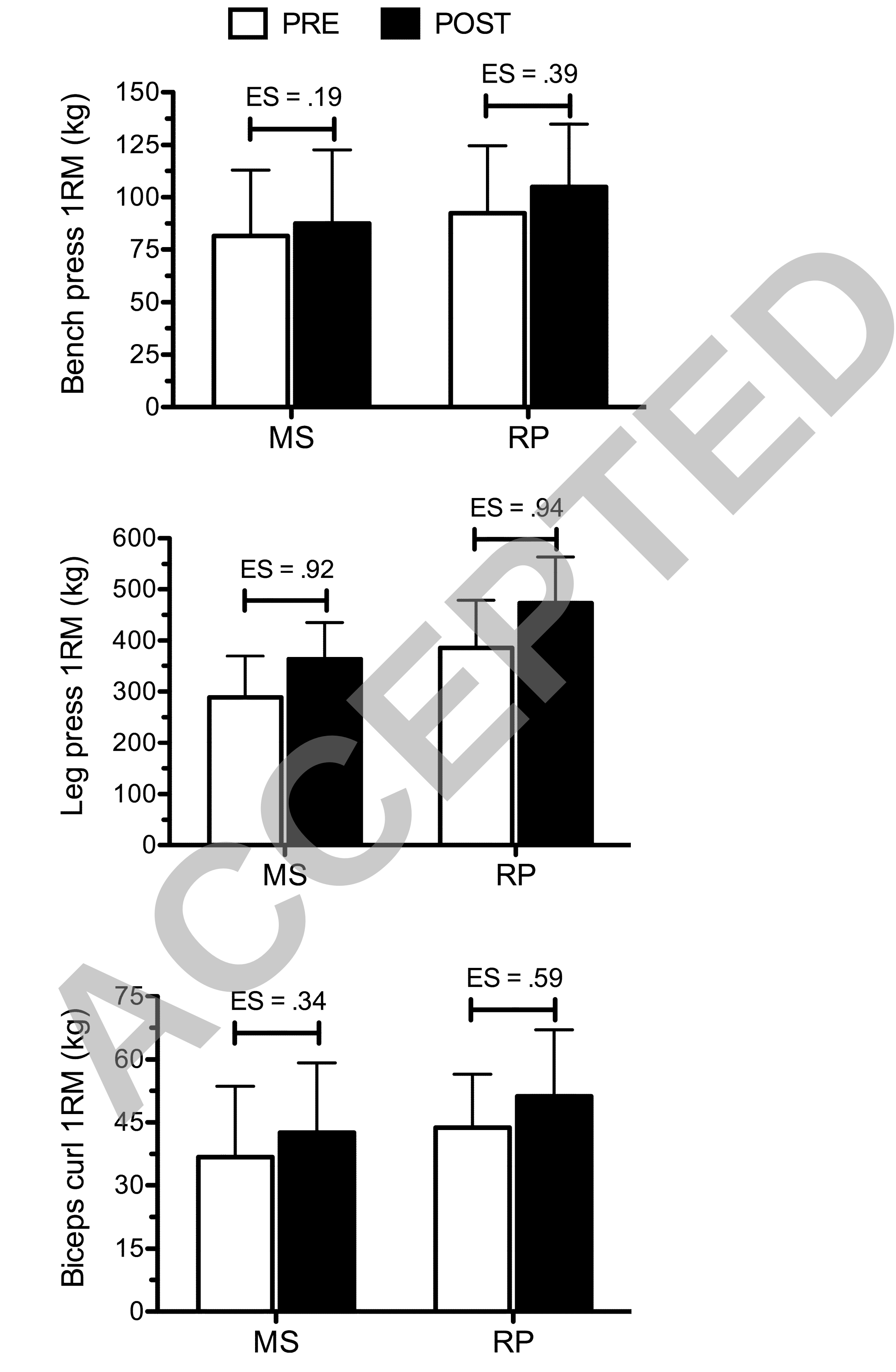
*Four weekly sessions, routine A was performed 2 days per week (Monday and Wednesday) and routine B was performed 2 days per week (Tuesday and Thursday).

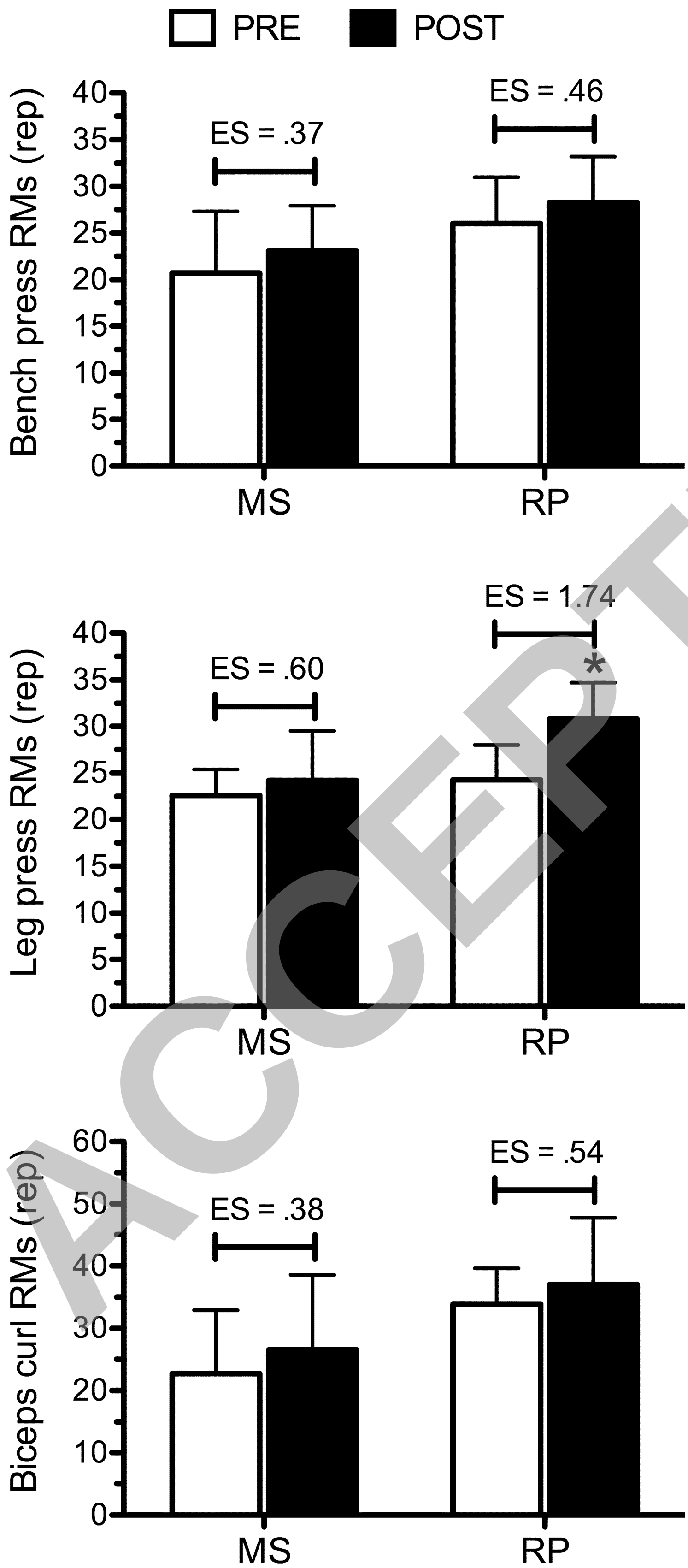
Table 2. Mean ± SD (95% CI), percentage change and effect size (ES) for body composition pre- and post-training traditional multiple-set and rest-pause groups.

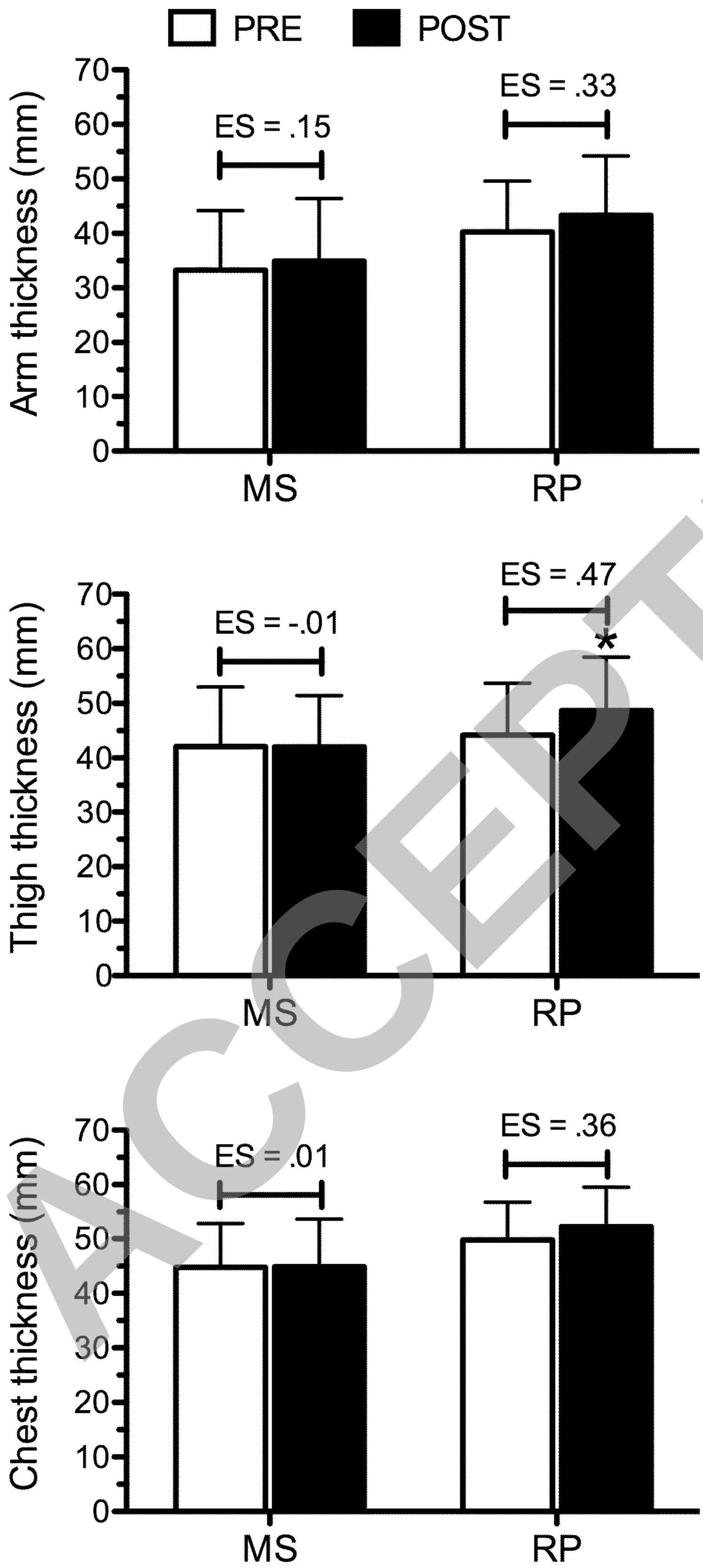
	Pre	Post	Change (%)	ES
Body mass, kg				
Multiple-set	67.4 ± 13.4 (57.1 – 77.7)	67.9 ± 14.7 (56.5 – 79.2)	0 ± 3	0.04 (trivial)
Rest-pause	82.2 ± 17.9 (68.4 – 96.0)	82.9 ± 16.2 (70.4 – 95.3)	1 ± 3	0.04 (trivial)
Lean mass, kg				
Multiple-set	57.9 ± 13.1 (47.8 – 67.9)	59.8 ± 14.7 (48.4 – 71.2)	3 ± 6	0.15 (trivial)
Rest-pause	70.0 ± 13.7 (59.4 – 80.5)	71.0 ± 12.4 (61.5 – 80.5)	2 ± 4	0.08 (trivial)
Fat mass, kg				
Multiple-set	9.5 ± 3.4 (6.9 – 12.1)	8.1 ± 2.2 (6.3 – 9.8)	-11 ± 17	-0.43 (trivial)
Rest-pause	12.2 ± 8.0 (6.1 – 18.4)	11.8 ± 6.9* (6.5 – 17.2)	0 ± 10	-0.05 (trivial)

Table 3. Mean ± SD (95% CI), percentage change and effect size (ES) for body circumferences pre- and post-training multiple-set and rest-pause groups.

	Pre	Post	Change (%)	ES
Arm, cm				
Multiple-set	33.5 ± 6.2 (28.7 – 38.3)	34.1 ± 6.4 (29.2 – 39.0)	2 ± 2	0.09 (trivial)
Rest-pause	36.6 ± 4.6 (33.1 – 40.1)	37.3 ± 4.6 (33.7 – 40.8)	2 ± 2	0.15 (trivial)
Thigh, cm				
Multiple-set	51.9 ± 4.7 (48.3 – 55.6)	53.2 ± 4.7 (49.6 – 56.9)	3 ± 2	0.28 (trivial)
Rest-pause	55.6 ± 5.8 (51.1 – 60.1)	57.5 ± 5.5 (53.4 – 61.8)	4 ± 2	0.34 (trivial)
Chest, cm				
Multiple-set	92.3 ± 9.5 (84.9 – 99.6)	92.3 ± 9.9 (84.8 – 99.9)	0 ± 1	0.01 (trivial)
Rest-pause	100.6 ± 9.5 (93.2 – 107.9)	100.2 ± 9.6 (92.8 – 107.6)	0 ± 2	-0.04 (trivial)


PRE
POST
ES = .19
ES = .39
Bench press 1RM (kg)
150
125
100
75
50
25
0
MS
RP
ES = .94
ES = .92
Leg press 1RM (kg)
600
500
400
300
200
100
0
MS
RP
ES = .34
ES = .59
Biceps curl 1RM (kg)
75
60
45
30
15
0
MS
RP


PRE
POST
Bench press RMs (rep)
40
35
30
25
20
15
10
5
0
ES = .37
ES = .46
MS
RP
Leg press RMs (rep)
40
35
30
25
20
15
10
5
0
ES = .60
ES = 1.74
*
MS
RP
Biceps curl RMs (rep)
60
50
40
30
20
10
0
ES = .38
ES = .54
MS
RP


PRE
POST
Arm thickness (mm)
ES = .15
ES = .33
MS
RP
Thigh thickness (mm)
ES = -.01
ES = .47
*
Chest thickness (mm)
ES = .01
ES = .36
0
10
20
30
40
50
60
70