IMPACT OF TWO HIGH-VOLUME SET CONFIGURATION WORKOUTS ON RESISTANCE TRAINING OUTCOMES IN RECREATIONALLY TRAINED MEN

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ABSTRACT

The present study compared the effects of two weekly-equalized by volume, loading zone and frequency resistance training designs, performed to failure (RTF) or not to failure (NTF), on body composition, strength and mechanical power. Based on individual baseline maximal strength, eighteen recreationally resistance-trained men were pair-matched and consequently randomly assigned to an RTF (n=9) or an NTF (n=9) protocol. Participants trained for 6 weeks using two different routines performed once per week (2 workouts per week). The RTF protocol comprised 4 sets of 10 repetitions per exercise with 2 min rest and the NTF involved 8 sets of 5 repetitions per exercise with 1 min rest. Participants were tested pre- and post-intervention for maximal strength, upper and lower body power, fat-free mass, limb circumferences and muscle thickness. Compared to baseline, both groups improved ($p<0.01$) the maximal loads lifted in the bench press (RTF +9.44 ± 3.00 kg; NTF +7.22 ± 4.41 kg) and the squat (RTF +9.44 ± 4.64 kg; NTF +11.1 ± 10.33 kg) exercises but only the NTF group increased ($p<0.05$) upper body power (+15.73 ± 12.59 W). Conversely, only the RTF group showed significant ($p<0.05$) increase of the elbow flexors (+3.44 ± 5.11 mm) and vastus medialis (+3.28 ± 2.32 mm) thickness while both groups enhanced anterior deltoid thickness (RTF +1.84 ± 1.68 mm, $p<0.05$; NTF +2.76 ± 2.63 mm, $p<0.01$). Although both training strategies improved strength, the RTF group elicited better hypertrophic outcomes while the NTF protocol resulted in more favorable improvements for upper body power.

Keywords: Strength, Power, Body Composition, Muscle Mass, Muscular Thickness, Work-To-Rest Ratio.

INTRODUCTION

Resistance training (RT) through neural and morphological adaptations is fundamental to induce positive changes in muscle function (11) and as a training modality RT promotes hypertrophy, strength gains, power increases and muscular endurance adaptations. The related metabolic, endocrine, neural and mechanical adaptations can be controlled by the manipulation of the training variables namely intensity, volume, rest interval between sets, the selection and order of exercises, movement velocity and training frequency (29). Even though the optimal interaction of the aforementioned variables is essential for obtaining the desired training outcomes, one of the most common used criteria for designing RT is the repetition maximum continuum-zone, i.e., 2–5, 6–12, or >12 repetitions for strength gains, gaining muscle mass and increasing muscular endurance respectively (34). Although repetition-to-failure training might not always be the optimum approach for athletic performance development (40), how close to failure each set is performed is a highly influential aspect in RT and it is associated with differentiated acute metabolic and long term training outcomes (21). Indeed, performing repetitions to failure using light and moderate loads causes a marked disruption of cellular homeostasis, with a considerable increase in protons (H^+), a concomitant decrease in intracellular pH and depletion of muscle purines resulting in the requirement for longer recovery times between training sessions (25). For athletes of different sports, this metabolic effect needs to be considered when integrating RT into a periodized plan (27). Furthermore, recent investigations indicated that similar strength gains and likely greater improvements in power related performances can be obtained when RT is composed of sets that are performed with maximal movement velocity, without reaching muscle failure (19,32). In this context and as an effective neuromuscular adaptation for increasing mechanical power in athletes, the National Strength and Conditioning Association advises to train with the maximal movement velocity ending each set with only half of the corresponding repetition-to-failure range (34). Conversely, completing every set near or at muscular failure increases both mechanical and metabolic stress which provides an optimal stimulus for increasing muscle mass but with a concomitant decline in movement velocity, a training setting which can be detrimental in sports involving fast actions (8). Different set configuration alternatives in RT, such as breaking sets into small groups of repetitions, e.g. cluster set schemes (14) have been used to reduce the metabolic stress while maintaining a high mechanical loading across a large number of repetitions (15). Compared to traditional RT training and for the development of lower-body power, Hansen et al. (14) proposed cluster set training to represent a superior option when maximizing the outcomes of ballistic training. This notion was recently confirmed by Arazi et al. who observed significantly greater improvements in vertical jump performance when employing a cluster vs. a traditional continuous set protocol in female volleyball players (1). However, improvements in strength and increases in limb circumferences were similar between the cluster set and the traditional training groups. Furthermore, Morales-Artacho et al. (24) showed that cluster set training is more efficient to enhance velocity related adaptions over a 3-week short-term intervention protocol.

Research comparing muscular hypertrophy and performance (strength and power) outcomes using similar loading zones with different set configurations is highly relevant for coaches. Therefore, the purpose of the present study was to compare the effects of two weekly-equalized (i) volume, (ii) loading zone and (iii) frequency RT programs on body composition, strength and mechanical power gains using two different set configuration protocols. A protocol designed for increasing strength and hypertrophy, with repetition-to-failure sets (RTF), and a protocol designed to improve strength and mechanical power using a not-to- failure set design (NTF) were implemented. Based on previous research we hypothesized: (i) Superior muscular mechanical power improvements for the NTF, (ii)

Higher hypertrophic gains for the RTF and (iii) Similar strength improvements in both groups.

METHODS

Experimental Approach to the Problem

The study utilized a two parallel group randomized controlled trial design. Participants were randomly allocated into one of the two intervention groups: (i) RTF (n = 9) and (ii) NTF (n = 9). Before and after the intervention period body composition and muscle thickness were measured and strength and power performance were assessed. Both groups trained for a total of 6 weeks using two different high-volume routines performed once per week (2 workouts per week). Groups were equalized in volume, intensity and frequency but they differentiated in the set configuration including different rest intervals between sets. Nonetheless, both conditions however had similar work to-rest-ratios. The RTF training comprised 4 sets of 10 repetitions per exercise with 2 min rest and the NTF comprised 8 sets of 5 repetitions per exercise with 1 min rest. As the objective of the present study was to compare the effect of two different RT routines and assuming that regardless of the workout configuration, RT interventions induce changes in body composition and performances the inclusion of a control non-training group was not considered.

Before the start of the intervention, participants were familiarized with the exercises (e.g. bench press, squat, etc.) and testing procedures during a one-week period. Strength and body composition assessments were performed during the week after the familiarization period. Thereafter and based on individual baseline maximal strength, participants were assigned to the individual treatments by block randomization, using a block size of two.

Subjects

Presented as mean ± SD the final groups characteristics were as follow: RTF: age: 24 ± 4 years, height: 174.6 ± 9.6 cm, and body mass: 78.37 ± 24.27 kg; 1 RM Squat: 87.22 ± 25.26 kg; 1 RM Bench Press: 71.11 ± 26.78 kg. For NTF: age: 23 ± 5 years, height: 176.7 ± 7 cm, and body mass: 76.04 ± 13.84 kg; 1 RM squat: 102.22 ± 28.52 kg; 1 RM bench press: 90 ± 29.15 kg.

To be eligible, participants had to be RT experienced with a 2 to 3 weekly training frequency and over a minimum of two and a maximum of five years, using a whole-body routine including squat and bench press exercises. Only recreationally RT individuals with no regular participation in other sports, such as bodybuilding and power or weight lifting were considered. Participants also had to be free of any existing or residual musculoskeletal injury within the last three months prior to the intervention. Additionally, only individuals not having ingested ergogenic aids or any type of nutritional supplements affecting muscular performance for 12 weeks or longer prior to the start of the study were eligible. Participants were instructed not to change their nutritional habits. All declared to ingest between four and five meals per day (e.g. breakfast, snack, lunch, snack and dinner) with no restriction of any food group. Additionally, all participants committed to report any meaningful change in their feeding pattern (i.e. becoming a vegetarian, restricting calories, taking nutritional supplements, etc.). If any relevant change was identified participants' data would have been excluded from the analysis. The University Research Ethics Committee approved the study. All procedures were in accordance with the Helsinki declaration. Prior to signing written informed consent, participants were fully informed of the nature and risks of the study.

Procedures

Familiarization: Even though experienced in RT, the study aimed to decrease learning effects by familiarizing participants over a one-week period. After that, both routines were once more explained and demonstrated during the first training session. To ensure that both training routines were performed in accordance with the designed protocol all participants regardless of their allocated group had one follow-up session during the second workout.

Assessments: Participants refrained from heavy exercise in the 48 h prior to all tests. Baseline values of all relevant variables were tested within one day. Body composition was examined first followed by limb circumferences and muscular thickness measurements. The strength and power assessments were performed as follow: (i) Vertical jump test (VJ), (ii) 1RM bench press, (iii) 1 RM parallel squat, (iv) bench press power at 50% of the previously determined 1 RM. A passive recovery period of 15 min was provided between individual tests.

Body Composition: The standard measurements were performed in accordance with the recommendations for anthropometric assessment (31). To eliminate interobserver variability only one investigator consistently performed all measures. Height was measured in a stretched stature to the nearest 0.01 m using a wall mounted stadiometer (Seca GmbH, Hamburg, Germany) and body mass was measured to the nearest 0.1 kg using a digital scale (Seca GmbH, Hamburg, Germany).

Fat mass (FM) and fat-free mass (FFM) were estimated from whole body densitometry using air displacement via a Bod Pod® (Life Measurements, Concord, CA) and followed the manufacturer's instructions as detailed elsewhere (7). Briefly, participants were tested wearing only tight-fitting clothing (swimsuit or undergarments) and an acrylic swim cap. For all body composition tests participants wore the exact same clothing. Using a predictive equation integral to the Bod Pod® software the thoracic gas volume was estimated. To estimate body composition, the calculated value for body density was taken from the Siri equation. The body composition measurements were performed twice. If the percentage of body fat was within 0.05%, the two tests were averaged. A third test was performed and the average of the three trials was used for all body composition variables, if the two tests were not within that agreement. The test-retest intra-class reliability for the two tests was excellent with R >0.980 (95% confidence intervals of 0.985 to 0.996).

Limb Circumferences: The circumferences of the right arm and right thigh were measured using a constant tension tape measure during maximal elbow extension or standing position respectively. Mid-arm circumference was measured midway between the tip of the acromion and the olecranon process and the thigh circumference was determined at a point situated two thirds between the edge of the iliac crest and the proximal border of the patella (upper knee) (2). Three measurements were made for both circumferences and averaging was performed to obtain mean values. The intra-rater reliability of both arm and thigh circumferences measurements performed by the trained investigator was excellent with an intra-class correlation coefficient of >0.970 (95% confidence intervals of 0.960 to 0.994). Therefore, the circumferences measured at pre- and post- intervention could be compared confidently.

Muscle thickness: All participants underwent cross-sectional images at three sites (dominant side) of the body (elbow flexors, anterior deltoid, and vastus medialis) using a real time B-mode ultrasound system (Dynamic Imaging, Livingston, Scotland UK). A trained researcher performed all the measurements in a standardized manner and according to the protocol described by Bradley and O´ Donnell (3). Each participant was placed in a semi-recumbed and relaxed position with knees fully extended and arms held straight alongside the torso with a supination position of the lower arms. The measurement sites were accurately located and marked at 60% distal to the lateral humerus epicondyle from the scapular acromial process of biceps brachialis muscle; at the acromion anterolateral edge for the anterior deltoid muscle; and at 80% distal from the greater trochanter to the lateral femur condyle for the vastus medialis muscle. A 7.5-MHz linear transducer together with watersoluble transmission gel (Aquasonic 100 Ultrasound Transmission gel), which provided acoustic contact without depressing the dermal surface, was placed in the transversal plane perpendicular to the skin surface at each of the marked sites. Distortion of tissue due to excessive compression was eliminated by resting the transducer lightly on the skin surface, by visually monitoring the image on the ultrasound screen and by asking participants to provide verbal feedback on the amount of pressure experienced on the skin. The interfaces between subcutaneous adipose tissue and muscle and between muscle and bone were identified from the ultrasonic image and the distance from the adipose tissue-muscle interface to the muscle-bone interface was measured as representative of muscle thickness.

The location of the probe was recorded onto acetate paper and pre and post intervention images were compared during the measurements to ensure that the location was the same based on identifiable markings (moles and small angiomas) viewed in the muscle fascicles as reference points. This was done to increase the reliability of repeated measures. Three images of each location were obtained, and the average of the measurements was calculated. Furthermore, to ensure the intra-observer reliability of the muscle thickness, the same researcher evaluated all participants. Images were obtained at least 48 hours before and after the training intervention to avoid any intra-muscle swelling. The intra- and inter-rater reliability of muscle thickness measurements performed by a single trained investigator on the same scans in a preparatory study was excellent (>0.99), therefore the thickness measurements on the three analyzed muscle at pre- and post- intervention could be compared confidently.

Countermovement Jump (CMJ): From a standing erect position, the participants descended to a self-selected depth and immediately jumped upward as high as possible. To exclude the influence of arm swing, participants were instructed to keep their hands on their hips (17). The CMJ was performed on a Kistler force platform (928B, 3 component force platform; Kistler, Hook, United Kingdom; dimensions: 900 x 600 x 100 mm) with a sampling rate of 2000 Hz where vertical forces were recorded. Jump height was calculated from the difference between maximum height of the centre of mass (apex) and the last contact of the toe on the ground during the take-off. Test-retest reliability coefficients (ICCs) for the day-to-day reproducibility of the dependent performance measures were recorded at ICCs $\geq$ 0.90 and the coefficients of variation (CV) ranged from 1.0 to 2.5%.

1 RM Strength: The 1RM value for both the bench press (BP) and parallel squat (SQ) using free weights was determined according to the methodology described by McGuigan (22). To avoid any specific muscle group interaction, the order of testing for BP and SQ was randomized. Briefly, participants performed a specific warm-up set of 4 repetitions at ~50% of their predicted 1RM followed by another set of 3 repetitions at ~75% of their perceived 1RM. Subsequent lifts were single repetitions of progressively heavier weights until reaching the 1RM. All participants achieved their maximal lift in less than five attempts. The test-retest intra-class reliability for the two exercises test was R >0.93 to <0.98.

Upper body mechanical power: Upper body mechanical power was measured for the BP exercise using 50% of the previously determined 1 RM value. Participants were required to perform 5 repetitions with correct form and with the maximal possible movement velocity. Mechanical power was determined from the repetition that produced the maximal average value of the mechanical power (calculated from the accelerative portion of the concentric phase, during which the acceleration of the barbell was $\geq$ -9.81 m.s^{-2}). A portable single optoelectronic infrared camera system (Velowin) with a fixed sampling frequency of 500 Hz was used to track a retroreflective strip placed at the center of the bar during the five BP repetitions. The device was connected to a computer through a USB interface and the proprietary software (Velowin 1.6.314, Deportec, Spain). Numeric and graphical real-time information after each repetition was obtained. All data were filtered using a low pass 10 Hz cut-off filter prior to calculating the displacement, velocity force and consequently estimating the average mechanical power in watts achieved during the BP performed with 50% of the previously determined 1 RM.

The test-retest reliability coefficients (ICCs), coefficient of variation (CV) and standard error of measurement (SEM) for the 1 RM BP; 1 RM SQ and BP power at 50% were 0.95 (2.1%; SEM 3.12) 0.92 (1.1%; SEM 2.11) and 0.92 (2.0%; SEM 20.10) respectively.

Training Intervention: The two intervention groups (RTF and NTF) underwent a 6-week RT program. Both groups trained twice (two sessions) per week using two different routines targeting 3 muscle groups involving 3 exercises per group, resulting in 9 exercises for both routines. Routine 1 was designed to target the pectorals, anterior deltoid, and arm flexors while routine 2 focused on back, arm extensor, and lower body. Each routine was performed on non-consecutive days with 48 h of recovery between routines (e.g. Monday and Wednesday or Tuesday and Thursday) (Table 1).

Table 1. Exercises performed in the two training routines

Training program 1 (chest, arm flexors and shoulders)	**Training program 2 (back, arm extensors and lower body)**
Bench press	Lateral pull-down
Dumbbell fly	Dumbbell reverse fly
Chest press	Barbell pullover
Barbell curl	Barbell lying arm extension
Seated dumbbell curl	Barbell close grip press on bench
Reverse grip bent-over row	Cable pushdowns
Dumbbell deltoid raise	Parallel squat
Barbell shoulder press	Dead lift
Barbell shoulder front raise	Machine leg curl

As both routines were completed once per week over 2 sessions using the same relative load (~75% 1 RM), both groups completed the same number of total repetitions per exercise and routine per week (Table 2). The RTF group trained with 4 sets of 10 RM self-determined maximum repetitions (35) using 2 min recovery period between sets. If a participant could not reach the desired number of repetitions, an additional ~30 sec of rest was allowed until the total number of prescribed repetitions was completed for every set. Conversely, a minimum amount of load (2.5 kg) was added to the subsequent set if participants felt that they could perform more than 10 repetitions per set.

The NTF group performed 8 sets of 5 reps with a 1-min recovery period between sets. Participants were instructed to use a load of the self-estimated 10 RM (~50% of the maximum possible number or repetition per set). Load was adjusted adding or removing a minimum amount of 2.5 kg based in participant's perceptual response.

The OMNI-RES scale (0-10) (30) was used to select and adjust the load during the training program. An initial OMNI-RES value > 4 and < 6 was recommended for starting a set (5,6). Furthermore, in order to avoid an excessive drop in movement velocity during the NTF workouts, a final perceptual value not higher than 7 was considered to end each set (5,6). Consequently, when participants reported an OMNI-RES value higher than 7, they were instructed to decrease the load by ~2.5 kg in subsequent sets. In both groups the participants were instructed to perform the concentric phase of every exercise with their maximal movement velocity from the beginning of each set and during the entire session.

All training sessions were supervised and instructed by a qualified research assistant. To improve the quality of supervision a ratio of one instructor to three participants was maintained during all the sessions. All participants completed the 6 weeks of intervention with a full compliance to both training routines. All sessions were completed within 120 min for both groups.

Table 2 summarizes the workout design (volume and intensity) per session and week for the both (RTF and NTF) intervention protocols.

Table 2. Acute program variables for the intervention groups

Variable	RTF (n= 9)	NTF (n= 9)
Reps per set and estimated relative load	10 (~75%1RM)	5 (~75%1RM)
Training sessions per week	2	2
Number of exercises per session	9	9
Exercises per muscle group	3	3
Sets per exercise	4	8
Total sets per muscle group	12	24
Total sets per training session (workout volume)	36	72
Sessions per each routine (training frequency)	1	1
Total sets and (reps) per week by Exercise Muscle group Routine	 4 (40) 12 (120) 36 (360)	 8 (40) 24 (120) 72 (360)

Statistical Analysis

A descriptive analysis was performed and subsequently the Kolmogorov-Smirnov and Shapiro-Francia tests were applied to assess normality. Sample characteristics at baseline were compared between groups using an independent means Student`s t-test. All pre- and post- intervention data were summarized and reported as mean (standard deviation) unless stated otherwise. Raw changes in all outcome variables were calculated by subtracting pre from post assessment values. Under the assumptions that both conditions would promote changes from baseline values and that the amount of change would be also dependent on each individual's baseline performance levels, one-way Analysis of Covariance (ANCOVA) models were used to compare differences in raw change between groups, using the pre-assessment values as covariates. Confidence intervals (CI) of the adjusted differences were calculated and plotted. Those CIs not crossing zero were considered statistically significant.

Additionally, two-tailed one sample student's tests were used to test for a null effect hypothesis. Cohen's d standardized effect sizes of the adjusted differences between intervention groups were calculated from the ANCOVA F tests, and compared to common benchmarks (small d = 0.2; moderate d = 0.5; and large d = 0.8). Significance level was set to $p < 0.05$, but p values between 0.05 and 0.1 were considered indicative of a trend. Stata (version 20.0, Statistical Package for the Social Sciences SPSS IBM Corporation) was used for statistical analysis.

RESULTS

The pre- and post- values of the analyzed variables, including changes and adjusted 95% CI for each of the intervention groups are presented in Table 3.

Table 3. Mean (M) ± standard deviation (SD) of the pre, post and changes values measured in. all the analysed variables for the two intervention groups

	RTF (n=9)			NTF (n=9)			Groups comparisons	
	Pre	Post	Changes	Pre	Post	Changes	p-value	ES
Body mass (kg)	78.4 ± 24.3	78.3 ± 23.1	-0.06 ± 1.9	76.0 ± 13.8	76.1 ± 13.7	0.07 ± 1.41	0.867	0.07
Fat Mass (%)	23.4 ± 11.7	21.8 ± 11.8	-1.54 ± 2.4[T]	15.1 ± 8.4	14.8 ± 9.7	-0.23 ± 1.8	0.207	0.54
Fat mass (kg)	18.6 ± 15.4	18.4 ± 15.6	-1.17 ± 1.9[T]	11.8 ± 8.0	11.7 ± 9.4	-0.09 ± 1.8	0.240	0.56
Fat-free mass (%)	76.6 ± 11.7	77.6 ± 11.4	0.97 ± 1.8	84.9 ± 8.4	85.2 ± 9.7	0.23 ± 1.8	0.392	0.41
Fat-free mass (kg)	58.8 ± 13.6	58.5 ± 12.5	0.71 ± 1.9	64.2 ± 11.5	64.4 ± 11.6	0.16 ± 1.3	0.485	0.29
Arm circumference (cm)	31.1 ± 4.5	31.5 ± 4.5	0.06 ± 0.7	32.1 ± 3.4	31.9 ± 3.7	-0.12 ± 0.9	0.635	0.26
Thigh circumference (cm)	46.3 ± 7.7	45.7 ± 6.9	-0.52 ± 2.2	45.0 ± 4.5	45.0 ± 4.4	0.01 ± 1.4	0.550	0.24
Vastus medialis Thickness (mm)	55.4 ± 8.1	58.7 ± 8.2	3.28 ± 2.3**	60.1 ± 5.9	60.5 ± 6.92	0.38 ± 2.7	0.026*	1.25
Elbow flexors Thickness (mm)	40.0 ± 11.5	43.4 ± 13.2	3.44 ± 5.1*	42.5 ± 7.9	44.6 ± 8.30	2.16 ± 0.9	0.468	0.25
Ant. deltoid thickness (mm)	22.9 ± 6.2	24.8 ± 6.6	1.84 ± 1.7*	23.7 ± 6.3	25.9 ± 6.55	2.76 ± 2.6**	0.394	0.54
1RM Bench press (kg)	71. ± 26.8	80.6 ± 29.2	9.44 ± 3.0**	90.0 ± 29.1	97.2 ± 28.6	7.2 ± 4.4**	0.229	0.74
1RM Squat (kg)	87.2 ± 25.3	96.7 ± 25.9	9.44 ± 4.6**	102.2 ± 28.5	113.3 ± 26.7	11.1 ± 3.3**	0.394	0.36
Vertical jump height (m)	0.36 ± 0.1	0.37 ± 0.1	0.01 ± 0.1	0.40 ± 0.2	0.42 ± 0.2	0.01 ± 0.1	0.895	0.08
Bench press power (W) at 50% 1 RM	347 ± 97	351 ± 102	4.09 ± 20.5	429 ± 198	445 ± 207	15.7 ± 12.6*	0.166	0.57

Notes: **p < 0.01, *p < 0.05, [t]p <0.10 respect to baseline levels; p-value of the difference in change was adjusted for the pre-value using ANCOVA; ES is the standardized effect size presented as Cohen`s d.

Differences from the baseline

Both groups improved in upper 1 RM bench press ($p=0.001$; $d>0.80$) and squat performances ($p=0.001$; $d>0.80$). However only the NTF group increased upper body power ($p=0.003$; $d=0.83$), while no effect was observed for the VJ height under the both treatment conditions.

As shown in Table 3, the RTF group showed moderate ES to reduce both fat ($p=0.059$; $d=0.48$) and fat percentage ($p=0.063$; $d=0.47$) along with statistically significant increased muscle thickness for vastus medialis ($p=0.003$; $d=0.82$), elbow flexors ($p=0.016$; $d=0.64$) and anterior deltoid ($p=0.031$; $d=0.59$). In contrast, the NTF group increased only anterior deltoid thickness ($p=0.003$; $d=0.83$). No other differences from baselines values were observed.

Comparison between groups

No significant differences were observed at test 1 (pre-intervention). After adjusting by the pre-intervention values, main significant differences between groups were determined for fat-free mass percentage ($p=0.04$; $d=4.51$; Figure 1B). Furthermore, the significant after intervention difference observed for the vastus medialis thickness ($p=0.026$, Table 3) disappeared after being adjusted for the pre-intervention values (Figure 1D). Nonetheless, it is worth noting that the effect sizes of the adjusted values revealed that compared to the NTF, the RTF group produced larger post intervention fat reduction (kg, $d=1.16$; percentage, $d=1.13$); increase fat-free mass (kg, $d= 3.21$, percentage, $d=4.51$, Figure 1 A); enlarged vastus medialis thickness ($d=1.48$, Figure 1C), as well as an improvement in the 1 RM bench press performance ($d=2.48$, Figure 1E). Conversely the NTF group showed larger post intervention increases for the 1 RM squat performance ($d=2.52$, Figure 1E) and the anterior deltoid thickness ($d=1.15$, Figure 1F).

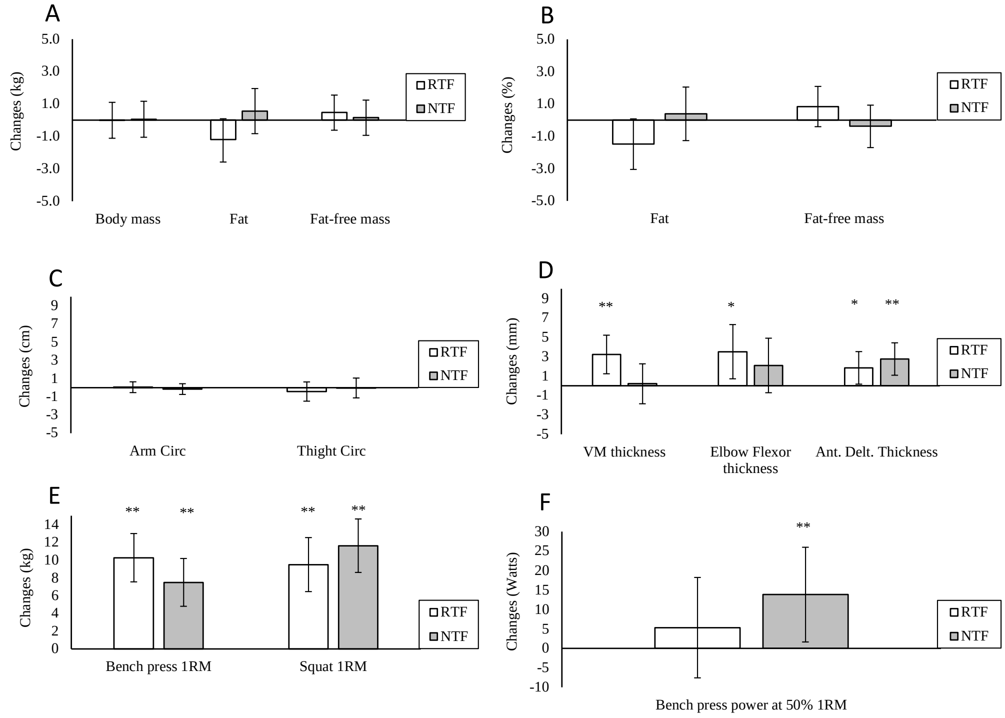

Figure 1. Estimated marginal means and 95% confidence intervals of changes in body composition (A and B) anthropometric and muscle thickness variables (C and D) and performance variables (E and F). Analysis of covariance (ANCOVA) models were used to compare differences in raw change between groups, using the pre-assessment values as covariates. *, $p < 0.05$; **, $p < 0.01$ from the baseline values. 1 RM, 1-repetition maximum; RTF, repetition-to-failure group; NTF, non to failure group.

DISCUSSION

To the best of the authors' knowledge, this is the first study that compared the effects of weekly-equalized volume, intensity and frequency RT programs using two different set configurations. Findings show evidence of superior improvements with respect to body composition and strength gains for the RTF protocol while favorable outcomes for upper body power and anterior deltoid thickness were observed for the NTF group. We can therefore accept our hypotheses of favorable power improvements for the NTF group but only for upper body and superior hypertrophic effects for the RTF group, along with similar strength gains within the groups.

As supported by Denton and Cronin the observed results consequently suggest that for recreationally trained men, exercising to failure for 6 weeks may be a preferred approach to gain muscle mass, to reduce body fat and to elicit general increases in strength (8). In contrast and supported by pertinent research (1,15,32), short sets involving half of the maximum number of repetitions needed to reach failure and performed with the maximal movement velocity can be suggested as a superior training design when targeting mechanical power improvements.

Nonetheless it is worth noting that even though the NTF increased upper body power, none of the protocols produced a change in VJ performance. Different from the bench press power test that was assessed with 50% of the 1 RM resistance, the jump test involved no external resistance other than the imposed participants’ body mass. Regardless of the exercise the relative training load for all exercises was ~75% 1 RM, which in case of the bench press power test was only 25% heavier than the relative load. However, when squatting with 75% of the external 1 RM load, a typical 80 kg participant with a 1 RM squat of 100 kg was training with an additional load of 75 kg resulting in an overall load of ~155 kg. Even though in squatting exercises shanks and feet are relatively static and should not be quantified as resistance, about 90% of the total body mass is vertically displaced (10). Consequently, the total training overload can be estimated as ~83% higher than the one used for the VJ test. The lack of specific fast lower body exercises performed with light resistances (≤ 50%) such as jumps, or other plyometric exercises in the present study can be suggested as the cause for the overserved VJ performance outcomes (1).

We have used a twice per week training design involving two different high-volume time-consuming routines each one performed once per week. This training scheme demonstrated to be a good option to improve strength, and to induce hypertrophic effects and overall positive changes in body composition in male recreationally trained individuals. Our findings are supported by Yue et al. (39) who recently demonstrated superior upper body hypertrophy and body composition outcomes using this low weekly frequency, high-volume training approach.

The observed trend of superior improvements in body composition in the RTF group could be associated with higher hormonal (20) and metabolic changes (4) elicited by RT designs using 6 to 12 repetitions to failure sets along with high volume workouts (39). As the number of repetitions approaches the set end in the RTF protocol, the fatigue-induced decrease in movement velocity reduces the mechanical power output (13,16), consequently resulting in a longer overall time under tension and an increased myoelectrical activity (38). These subsequent events, in addition to the associated optimal hypertrophic response, are also compatible with enhancements in strength (36). Nonetheless, it is important to highlight that previous research has revealed that faster movement velocities during resistance exercises have the potential to stimulate similar or even superior gains in strength and hypertrophy compared with slower concentric movements (26). Even though the NTF group achieved very similar improvements in strength, the lack of significant hypertrophic response observed in the elbow flexors and vastus medialis could be explained by a lower metabolic stress (33) along with a controlled workout volume that was limited to 40 repetitions per exercise and 120 repetitions per muscle group. Consequently, it is not possible to evaluate whether using not-to failure sets with short rest-pauses aimed to maintain higher loads with a larger number of repetitions and higher volumes per workout would have maximized hypertrophic effects. As both the workout and weekly volume in RT have demonstrated to be of relevant importance in the achievement of a meaningful muscular anabolic stimulus (28), the potential benefit of using NTF designs to optimize muscle accretion remains to be elucidated.

Similarly, RTF protocols using 10 RM sets have been associated with a larger decrease in muscle phosphocreatine content, higher blood lactate concentrations and lower peak power output values compared to performing 5 repetitions using the 10 RM load (12). Moreover, to maximize strength and mechanical power output values in resistance exercises other researchers (5,6,18) advocate the use of maximal movement velocities. Therefore, shortening the sets, providing more frequent rest periods to favor recovery via a greater maintenance of phosphagen stores and increased metabolite clearance (8) represent an effective strategy for improving performance with limited hypertrophic effects. Resistance training designs aimed to limit the typical metabolic fatigue-induced reductions in movement velocity seen during continuous sets to failure or near to failure could therefore represent an attractive option for body weight categorized sports such as boxing or martial arts where a high power to body mass ratio is desirable (9).

The present study has several limitations that must be considered when attempting to draw evidence-based inferences. The small sample size of 9 participants included in each experimental group could have increased the risk of a type 2 error. Nonetheless, the presented effect size analysis reduces this risk of misinterpretation. Additionally, the study period was 6 weeks and although it was enough to elicit significant changes in performance and muscle thickness for both groups, it is possible that some between groups differences could have diverged with a longer intervention. The measurement of muscle thickness was obtained only at the middle portion of the muscles. Although this region is often used as a proxy of overall muscle growth, research indicates that hypertrophy manifests itself in a regional specific manner, with greater gains sometimes seen at the proximal and/or distal aspects (37). Proposed mechanisms for this phenomenon include exercise-specific intramuscular activation and/or tissue oxygenation saturation (23). The possibility therefore exists that different changes in proximal or distal muscle thickness may have occurred in one condition versus the other, which might have gone undetected. The daily food ingestion was not recorded but participants were instructed to maintain their diet habit. Although nutritional changes were consistently monitored, providing a prepared and prepacked diet to participants during the intervention would have offered an ideal scenario to standardize and control the influence of diet on the present results. In summary, over a 6-week period, both weekly-equalized high workout volume protocols, RTF and NTF were similarly effective to improve strength. However, the RTF design eliciting general better hypertrophic outcomes whereby the NTF protocol resulted in a more favorable improvement for upper body power.

PRACTICAL APPLICATIONS

Although performing continuous sets to failure is a popular design for muscle mass gain, using short sets, involving half of the maximum number repetitions for a given load, and appropriate rest-pause (e.g. 1 min for a 5 repetition set using a ~10 RM load) provides a different stimulus that may benefit other training goals such as the enhancement of mechanical power output (5,6) along with a reduced emphasis on muscle mass accretion. With this is mind, it is important for coaches to determine the way in which fatigue is managed during the workout by allocating the length and frequency of intra-set rest intervals based on the desired training outcomes. For example, to increase strength and mechanical power output while limiting muscle mass accretions, multiple not to failure set involving 5 to 6 repetitions using moderate to high overloads (~60 to 85% 1 RM) alternated with appropriate inter-set rest periods performed with a maximal possible movement velocity can be recommended. Conversely, a more traditional continuous set design using incomplete rest periods aimed to maintain a load despite the consequent loss in movement velocity, can be an appropriate strategy to increase muscle mass and strength with no specific emphasis on changes in muscular power performance.

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