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ORIGINAL ARTICLE

## High-frequency resistance training does not promote greater muscular adaptations compared to low frequencies in young untrained men

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### Abstract

The aim of the study was to compare the effect of resistance training (RT) frequencies of five times (RT5), thrice- (RT3) or twice- (RT2) weekly in muscle strength and hypertrophy in young men. Were used a within-subjects design in which 20 participants had one leg randomly assigned to RT5 and the other to RT3 or to RT2. 1 RM and muscle cross-sectional area (CSA) were assessed at baseline, after four (W4) and eight (W8) RT weeks. RT5 resulted in greater total training volume (TTV) than RT3 and RT2 ( $P = .001$ ). 1 RM increased similarly between protocols at W4 (RT5:  $55 \pm 9$  Kg, effect size (ES): 1.18; RT3:  $51 \pm 11$  Kg, ES: 0.80; RT2:  $54 \pm 7$  Kg, ES: 1.13;  $P < .0001$ ) and W8 (RT5:  $62 \pm 11$  Kg, ES: 1.81; RT3:  $57 \pm 11$  Kg, ES: 1.40; RT2:  $60 \pm 8$  Kg, ES: 1.98;  $P < .0001$ ) vs. baseline (RT5:  $45 \pm 9$  Kg; RT3:  $42 \pm 11$  Kg; RT2:  $46 \pm 7$  Kg). CSA increased similarly between protocols at W4 (RT5:  $24.6 \pm 3.9$  cm<sup>2</sup>, ES: 0.54; RT3:  $22.0 \pm 4.6$  cm<sup>2</sup>, ES: 0.19; RT2: ES: 0.25;  $23.8 \pm 3.8$  cm<sup>2</sup>;  $P < .001$ ), and W8 (RT5:  $25.3 \pm 4.3$  cm<sup>2</sup>; ES: 0.69; RT3:  $23.6 \pm 4.2$  cm<sup>2</sup>, ES: 0.58; RT2:  $25.5 \pm 3.7$  cm<sup>2</sup>; ES: 0.70;  $P < .0001$ ) vs. baseline (RT5:  $22.5 \pm 3.8$  cm<sup>2</sup>; RT3:  $21.2 \pm 4.0$  cm<sup>2</sup>; RT2:  $22.9 \pm 3.8$  cm<sup>2</sup>). Performing RT5, RT3 and RT2 a week result in similar muscle strength increase and hypertrophy, despite higher TTV for RT5.

**Keywords:** Resistance exercise, total load, one-repetition maximum, muscle cross-sectional area

### Highlights

- Resistance training frequency of five times a week in which the same muscle group is exercised does not induce greater gains in muscle strength and hypertrophy compared to a frequency of three or two times a week in untrained young men.
- With approximately half of the resistance training sessions performed during the same period (i.e., 8-weeks), low training frequencies induced similar increases in muscle strength and mass than a high one.
- Lower resistance training frequencies may enable a greater number of people engaging in resistance training practice and contribute to increase exercise adherence.

### Introduction

Resistance training (RT) promotes increases in muscle strength and mass (i.e. muscle hypertrophy) (American College of Sports, 2009; Damas et al., 2016). However, the most appropriate RT scheme to maximize muscular adaptations remains elusive. Among several possible RT variables to be manipulated, training frequency (i.e. number of RT sessions in which the same muscle group is trained within a period) has been

considered as a critical variable to maximize RT-induced adaptations (American College of Sports, 2009; Wernbom, Augustsson, & Thomee, 2007). For example, a recent meta-analysis showed that training a muscle group once a week induced lower muscle hypertrophy than training twice or thrice a week (Schoenfeld, Ogborn, & Krieger, 2016); but it seems to be no differences between the last two RT frequencies in untrained individuals (Candow & Burke, 2007;

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Carneiro et al., 2015; Lera Orsatti et al., 2014). However, it is not clear if further increases in RT frequency would result in even greater RT-related outcomes gains than twice or thrice a week (Schoenfeld et al., 2016).

The rationale behind using higher RT weekly frequencies can be based on the acute increase in myofibrillar protein synthesis observed after each RT session (Damas et al., 2016), which was recently proposed (Dankel et al., 2017). For instance, after only a brief adaptation period (i.e. five RT sessions), we demonstrated that the myofibrillar protein synthetic response was increased above baseline 24 h post-RT session, but returned to basal levels 48 h post-RT bout session (Damas et al., 2016). Thus, it is plausible to consider that exposing the same muscle group to higher RT frequencies could induce more frequent periods of elevated protein synthesis, which would enhance muscle hypertrophy gains. Additionally, higher RT frequencies can result in greater weekly total training volume (TTV, i.e. sets  $\times$  repetitions  $\times$  load) and RT-related outcomes. Two recent meta-analyses showed that higher weekly RT sets (which directly influences the TTV) produced greater increases in muscle strength (Ralston, Kilgore, Wyatt, & Baker, 2017) and hypertrophy (Schoenfeld, Ogborn, & Krieger, 2017). On the contrary, it is reasonable to assume that very high training frequencies (e.g. five times per week) may not be beneficial to RT-related outcomes as one could expect a level of residual fatigue between training sessions that could negatively impact exercise performance and volume.

The aim of the present study was to compare the effect of RT frequencies of five times (RT5), thrice (RT3) or twice (RT2) weekly in muscle strength and hypertrophy in young men at the middle (i.e. week 4, W4) and at the end of a 8-week (W8) of RT. We hypothesized that the RT5 would produce greater TTV, thus resulting in larger muscle strength and hypertrophy gains than RT3 and RT2, at W4 and at the end (W8) of the RT programme, with no difference between the last two RT frequencies.

## Methods

### Participants

Twenty untrained males were selected for the study ( $23 \pm 4$  years;  $174 \pm 6$  cm;  $72.3 \pm 8.2$  kg). Participants were recreationally active, but did not partake in any structured RT for at least 6-mo prior to study initiation. The study was approved by the University's Ethics Committee and each participant gave informed consent prior to participation. All procedures performed herein were in accordance with the Declaration of Helsinki.

### Experimental design

Prior to any testing, participants visited the laboratory for a familiarization session with the equipment and testing procedures. Forty-eight hours after familiarization, maximum dynamic strength was assessed by one-repetition maximum (1 RM) test on the leg extension machine. To minimize the learning effect, 1-RM tests were performed every 72 hours until a variation  $<5\%$  was obtained between testing days. Each participant performed at least two 1-RM tests. The 1 RM value of the last testing day was considered for the actual experimental sessions. After 72-h, muscle cross-sectional area (CSA) was assessed using ultrasound. In order to reduce inter-subjects variability, a unilateral design was used. Each participant's leg was considered as an experimental unit and randomly allocated in one of three experimental conditions in a counterbalanced way. Experimental conditions were as follows: RT five times a week (RT5), RT three times a week (RT3), and RT two times a week (RT2). Considering the muscle myofibrillar protein synthesis time course (Damas, Phillips, Vechin, & Ugrinowitsch, 2015; Tang, Perco, Moore, Wilkinson, & Phillips, 2008), we adopted RT5 as a positive control assuming that weekly protein synthetic response would be maximized using this RT frequency. Thus, legs were allocated in the RT5 condition ( $n=20$ ; 10 dominant and 10 non-dominant legs). The contralateral legs were then randomized to either RT3 ( $n=10$ ; five dominant and five non-dominant legs) or RT2 ( $n=10$ ; five dominant and five non-dominant legs) (Angleri, Ugrinowitsch, & Libardi, 2017). Besides baseline measures, 1 RM and muscle CSA evaluations were performed after four and eight weeks of RT (i.e. W4 and W8, respectively).

### Maximal dynamic strength test

1 RM tests were performed according to Brown and Weir (2001) recommendations. All tests were carried out unilaterally using a leg extension machine (Effort NKR; Nakagym, São Paulo, Brazil). Prior to the strength test, participants warmed-up in a cycle ergometer (Ergo 167 Cycle; Ergo Fit, Pirmasens, Germany) at  $20 \text{ km h}^{-1}$  for 5-min. Next, participants were properly positioned in the knee-extension machine and a specific warm-up was carried out. First, participants performed eight repetitions at 50% of the estimated 1 RM value. After a 2-min rest, three repetitions at 70% of the estimated 1 RM value were performed. Following a 3-min rest, participants were allowed up to five attempts to achieve their highest 1 RM value, and a 3-min rest interval was

adopted between attempts. 1 RM tests were performed 72 h after the last training session on the W4 and W8. A coefficient of variation (CV) and typical error (TE) of 3.64% and 1.56 kg were obtained between two repeated measures with 72-h intervals among testing sessions.

### Muscle CSA

Vastus lateralis muscle CSA was assessed using a B-mode ultrasound with a 7.5 MHz linear probe (MySono U6, Samsung, SP, Brazil). For image acquisition and CSA calculation, procedures validated by Lixandrao et al. (2014) were utilized. Participants were instructed to abstain from vigorous physical activities for at least 72-h prior to image acquisition. Immediately before the test, participants were placed in supine position and asked to remain still for 15-min. Transmission water soluble gel was applied on the skin allow acoustic coupling without causing dermal compression. CSA was assessed at 50% of thigh length, determined as the middle point between the femur's greater trochanter and the lateral epicondyle, identified by manual palpation. Images were acquired in the sagittal plane parallel to the long axis of the femur with participants laying in supine. The skin was ink-marked transversely in 2-cm intervals toward the medial and lateral aspects of the thigh to guide probe displacement. The probe was aligned with the skin marks and sequential images were acquired by moving the probe medial-laterally on the thigh. Images were opened in *Power point* (Microsoft, USA) in the same sequence they were acquired, rotated and aligned in order to reconstruct whole muscle fascia. Muscle CSA was then circulated using the fascia as reference for the muscle boundaries, and CSA value was calculated using computerized planimetry. The evaluators were blinded for the analyses. Each muscle CSA was reconstructed three times, and the mean value was assumed as the true muscle CSA value. A CV and TE of 1.38% and 0.33 cm<sup>2</sup> were obtained between two repeated measures with 72-h intervals among them for these procedures.

### Resistance training

All RT protocols were performed in a leg extension machine (Effort NKR; Nakagym, SP, Brazil). Training protocol consisted of three sets of 9–12 RM to muscular failure at ~80% 1 RM. Sets were interrupted if participants failed to maintain proper range of movement (~90°). Training load was adjusted whenever participants performed more than 12 RM to maintain the number of repetitions in the desired range. A 2-min

rest interval was allowed between sets. TTV was calculated as sets × repetitions × load (Kg). Accumulated TTV was calculated considering the whole RT programme and progression considering the TTV at W1, W4 and W8.

### Data analysis

Following visual inspection, data normality was assessed through Shapiro–Wilk test. The eight-week accumulated TTV was compared between RT frequencies using a repeated measure one-way ANOVA. To analyse TTV progression of RT frequencies from W1 to W4 and W8, we applied an analysis of covariance (ANCOVA) for repeated measures using the TTV at W1 as a covariate to correct for baseline differences. A mixed model was used to compare 1 RM and CSA absolute values over time between RT protocols, assuming RT frequencies (RT5, RT3 and RT2) and time (Pre [W1 for TTV], W4 and W8) as fixed factors and participants as a random factor. As a result of our experimental design, 20 legs were allocated to RT5 (i.e. positive control condition), while RT3 and RT2 remained with 10 legs each. Thus, we opted to run 10 simulations in which 10 legs were randomly removed from the RT5 condition in order to test if different statistical results would be found when all 20 legs were considered vs. when only 10 legs were considered. No statistical differences were found between simulations for any dependent variable. One subject had to be excluded from the analyses, as he could not finish the experiment for personal reasons. Thus, the statistical analyses were carried out using  $n = 19$  for RT5,  $n = 10$  for RT3 and  $n = 9$  for RT2. In case of significant  $F$  values, Tukey adjustment was implemented for multiple comparisons. Significance was established as  $P < .05$  for all data analyses. Effect sizes (ES) were calculated for TTV using the changes from W1 to W4 and from W4 to W8. For 1 RM and muscle CSA, ES were calculated using the changes at W4 and W8 compared to baseline. ES were classified as “small” if lower than 0.2, “medium” if between 0.2 and 0.5, and “large” if higher than 0.8 (Cohen, 1988).

## Results

### Total training volume

RT5 showed higher eight-week accumulated TTV ( $P = .001$ ) compared to RT3 and RT2 ( $54,375 \pm 12,810$  Kg;  $30,936 \pm 8391$  Kg and  $21,386 \pm 3825$  Kg, respectively), with no difference between RT3 and RT2 ( $P > .05$ ).

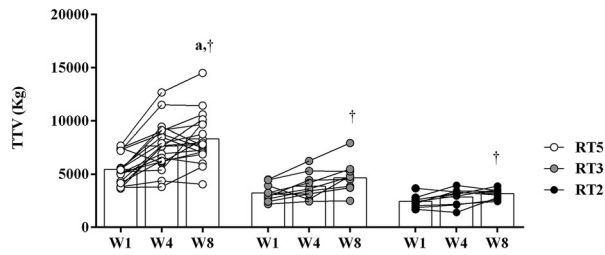


Figure 1. Total training volume for each training frequency at week 1 (W1), week 4 (W4) and week 8 (W8) of RT. Bars are means and circles are individual values. RT5: RT performed five times per week; RT3: RT performed three times per week; RT2: RT performed two times per week. †: Significantly different from W4 within RT frequency protocol (interaction effect;  $P < .0001$ ); a: Significantly different from RT3 and RT2 at the respective time-point (interaction effect;  $P < .01$ ).

#### Progression total training volume

RT5 showed significantly greater TTV values ( $5430 \pm 1383$  Kg) at W1 compared with RT3 ( $3243 \pm 801$  Kg,  $P < .0001$ ) and RT2 ( $2436 \pm 593$  Kg,  $P < .0001$ ), with no difference between RT3 and RT2 ( $P > .05$ ). When W1 differences in TTV values were taken into account (repeated measures ANCOVA), a significant protocol vs. time interaction ( $P < .0001$ ) was found (Figure 1), with significantly ( $P < .02$ ) higher TTV values in W8 (RT5:  $8328 \pm 2339$  Kg, RT3:  $4659 \pm 1450$  Kg and RT2:  $3160 \pm 476$  Kg) compared to W4 (RT5:  $7657 \pm 2217$  Kg, RT3:  $3861 \pm 1202$  Kg and RT2:  $2854 \pm 794$  Kg) for the all protocols (Figure 1). Between-protocol comparisons revealed significantly higher TTV for RT5 compared to RT3 and RT2 at W8 ( $P < .01$ , Figure 1), with no difference between RT3 and RT2 ( $P > .05$ , Figure 1). ES of TTV progression were constant for RT3 and RT2 considering the first half (W1–W4: 0.61 [medium] and 0.60 [medium], respectively) and the second half (i.e. W4–W8: 0.60 [medium] and 0.47 [medium], respectively) of the RT period. However, RT5 showed a trend to decrease the rate of TTV progression at the second half of the RT period (W1–W4: 1.21 [large]; W4–W8: 0.29 [small]).

#### Maximal dynamic muscle strength

Figure 2 depicts muscle strength measured by 1 RM test for all tested RT frequencies at W1, W4 and W8. No difference was found between training frequencies at baseline (RT5:  $45 \pm 9$  Kg; RT3:  $42 \pm 11$  Kg; RT2:  $46 \pm 7$  Kg,  $P > .05$ ). The analysis showed that all three training frequencies similarly increased muscle strength compared to baseline at W4 (RT5:  $55 \pm 9$  Kg, ES: 1.18 (large); RT3:  $51 \pm 11$  Kg, ES: 0.80 (large); RT2:  $54 \pm 7$  Kg, ES: 1.13 (large); main time

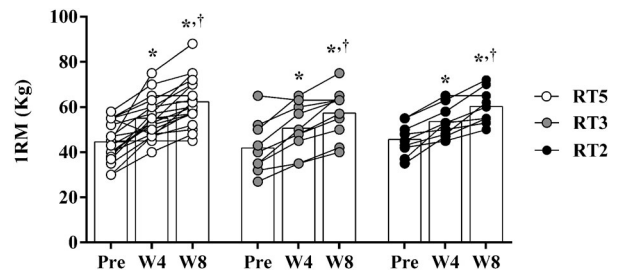


Figure 2. Maximal dynamic muscle strength measured by one-repetition maximum (1 RM) test for each training frequency at baseline (Pre), week 4 (W4) and week 8 (W8) of RT. Bars are means and circles are individual values. RT5: RT performed 5 times per week; RT3: RT performed three times per week; RT2: RT performed two times per week. \*: Significantly different from Pre (main time effect;  $P < .0001$ ); †: Significantly different from W4 (main time effect;  $P < .0001$ ).

effect:  $P < .0001$ ) and at W8 (RT5:  $62 \pm 11$  Kg, ES: 1.81 (large); RT3:  $57 \pm 11$  Kg, ES: 1.40 (large); RT2:  $60 \pm 8$  Kg, ES: 1.98 (large); main time effect:  $P < .0001$ ). In addition, values at W8 were greater than at W4 (main time effect:  $P < .0001$ ).

#### Vastus lateralis muscle cross-sectional area

Similar muscle CSA was found across training frequencies at baseline (RT5:  $22.5 \pm 3.8$  cm<sup>2</sup>; RT3:  $21.2 \pm 4.0$  cm<sup>2</sup>; RT2:  $22.9 \pm 3.8$  cm<sup>2</sup>,  $P > .05$ ). All three training frequencies increased similarly muscle CSA compared to baseline at W4 (RT5:  $24.6 \pm 3.9$  cm<sup>2</sup>, ES: 0.54 (medium); RT3:  $22.0 \pm 4.6$  cm<sup>2</sup>, ES: 0.19 (small); RT2:  $23.8 \pm 3.8$  cm<sup>2</sup>, ES: 0.25 (small); main time effect:  $P < .001$ ), and at W8 (RT5:  $25.3 \pm 4.3$  cm<sup>2</sup>, ES: 0.69 (medium); RT3:  $23.6 \pm 4.2$  cm<sup>2</sup>, ES: 0.58 (medium); RT2:  $25.5 \pm 3.7$  cm<sup>2</sup>, ES: 0.70 (medium); main time effect:  $P < .0001$ ; Figure 3). Muscle hypertrophy values at W8 were greater than at W4 (main time effect:  $P < .001$ ).

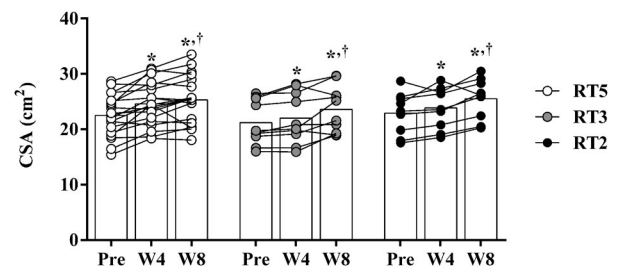


Figure 3. Muscle CSA for each training frequency at baseline (Pre), weeks 4 (W4) and 8 (W8) of RT. Bars are means and circles are individual values. RT5: RT performed five times per week; RT3: RT performed three times per week; RT2: RT performed two times per week. \*: Significantly different from Pre (main time effect;  $P < .001$ ); †: Significantly different from W4 (main time effect;  $P < .001$ ).

## Discussion

This is the first study to our knowledge that directly compared the effect of RT frequencies of five times (RT5), thrice- (RT3) or twice- (RT2) weekly, in which the same muscular group is exercised, on muscle strength and hypertrophy in young men. Our main findings suggest that higher RT frequencies are not superior to lower ones to induce gains in muscle strength and hypertrophy in healthy untrained men.

Only a few randomized controlled trials have investigated the effects of RT frequency on muscle adaptations (Schoenfeld et al., 2016). For example, Gentil, Fischer, Martorelli, Lima, and Bottaro (2015) showed similar muscle strength gains and hypertrophy for a single vs. twice-weekly RT sessions after 10-weeks of RT in untrained young men. In addition, Candow and Burke (2007) showed no difference in muscle strength and mass increases between three vs. two times per week after 6-weeks RT in untrained individuals. Interestingly, in these previous studies (Candow & Burke, 2007; Gentil et al., 2015) the TTV was equalized between training frequencies, that could explain the similar RT-induced outcomes between protocols. Accordingly, both the RT3 and RT2 protocols in the present study, which produced similar TTV throughout RT (Figure 1), resulted in similar muscle strength and hypertrophy gains (Figures 2 and 3). However, as we hypothesized, the RT5 produced higher TTV at W4 and W8 compared to RT3 and RT2 (Figure 1). Even so, the RT5 protocol did not result in superior muscle strength gains and hypertrophy either at W4 or at W8 compared with RT3 and RT2. These results suggest that training at higher frequencies do not produce further RT-induced benefits as compared with lower frequencies for the first 8-weeks of RT in untrained individuals, despite producing higher absolute TTV throughout RT.

At first, results reported in recent meta-analyses (Ralston et al., 2017; Schoenfeld et al., 2017) seem to be in contrast with the ones reported herein. The authors showed a graded dose-response relationship whereby increases in RT volume produce greater gains in muscle strength (Ralston et al., 2017) and hypertrophy (Schoenfeld et al., 2017). Dose-response effects were noted when stratifying sets into low ( $\leq 4$ –5 sets per week), medium (5–9 sets per week) and high ( $\geq 10$  sets per week) volumes. In the present study, the RT3 and RT2 protocols performed 6–9 weekly sets, while the RT5 executed 15 sets per week. Thus, our findings suggest that there may be a “ceiling effect” for TTV on the dose-response relationship of the weekly sets, at least for untrained individuals.

Importantly, the highest RT frequency (i.e. RT5) resulted in a shorter recovery period between sessions, which, we speculate, may impair TTV progression. In fact, we demonstrated a considerably lower TTV progression for RT5 (1.37%) than for RT3 (2.13%) and RT2 (2.24%) standardizing the increases in TTV session-by-session. Interestingly, the TTV progression rates were constant for RT3 and RT2 considering the first (W1–W4) and second (W4–W8) halves of RT (medium ES for all); whereas the RT5 showed a trend to decrease the rate of TTV progression from W4 to W8 (W1–W4: large ES; W4–W8: small ES). Thus, if the RT was continued for a longer period, the TTV performed by RT5 might have plateaued (not progressing further over time). If this is the case, we speculate that RT adaptations progression could be jeopardized over time. Altogether, training at higher frequencies can produce greater absolute TTV, mostly due to the higher number of sessions per week, but it can also impair inter-sessions recovery, resulting in similar RT-related outcomes over 8-weeks RT in untrained men.

In a practical standpoint, our study suggests that in a short RT period (e.g. eight weeks) it is more effective for novice practitioners to exercise the same muscle group using low- (two or three times a week) than high- (five times a week) weekly frequencies. Our results show that with approximately half of the resistance exercise sessions performed during the same period, low training frequencies induced similar muscle strength and mass gains than a high one. Thus, lower RT frequencies may enable more people engaging in RT practice and contribute to increase exercise adherence. Whether those results would be reproduced in a trained population remains elusive. Given that the time course of myofibrillar protein synthesis increase after an RT session changes with RT practice to a more rapid and specific one (Damas et al., 2016; Damas, Libardi, & Ugrinowitsch, 2017; Tang et al., 2008), it is reasonable to suggest that trained individuals would benefit from higher training frequencies such as five times a week. This proposal is further supported by a smaller stress impact of each RT session as training develops (Damas et al., 2016; Gordon et al., 2012), reducing the rest period required between sessions. Future studies should address these hypotheses.

In conclusion, despite a higher TTV, a RT frequency of five times a week in which the same muscle group is exercised, does not induce greater gains in muscle strength and hypertrophy after 8-weeks compared to a RT frequency of three or two times a week in untrained young men.

## Disclosure statement

The authors declare that the results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The authors declare no conflicts of interest.

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