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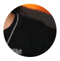

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Muscle Hypertrophy Response Is Affected by Previous Resistance Training Volume in Trained Individuals

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Abstract

Scarpelli, MC, Nóbrega, SR, Santanielo, N, Alvarez, IF, Otoboni, GB, Ugrinowitsch, C, and Libardi, CA. Muscle hypertrophy response is affected by previous resistance training volume in trained individuals. *J Strength Cond Res* XX(X): 000–000, 2020—The purpose of this study was to compare gains in muscle mass of trained individuals after a resistance training (RT) protocol with standardized (i.e., nonindividualized) volume (N-IND), with an RT protocol using individualized volume (IND). In a within-subject approach, 16 subjects had one leg randomly assigned to N-IND (22 sets·wk^{-1}, based on the number of weekly sets prescribed in studies) and IND (1.2 × sets·wk^{-1} recorded in training logs) protocols. Muscle cross-sectional area (CSA) was assessed by ultrasound imaging at baseline (Pre) and after 8 weeks (Post) of RT, and the significance level was set at $p < 0.05$. Changes in the vastus lateralis CSA (difference from Pre to Post) were significantly higher for the IND protocol ($p = 0.042$; mean difference: 1.08 cm^2; confidence interval [CI]: 0.04–2.11). The inferential analysis was confirmed by the CI of the effect size (0.75; CI: 0.03–1.47). Also, the IND protocol had a higher proportion of individuals with greater muscle hypertrophy than the typical error of the measurement (chi-square, $p = 0.0035$; estimated difference = 0.5, CI: 0.212–0.787). In conclusion, individualizing the weekly training volume of research protocols provides greater gains in muscle CSA than prescribing a group standard RT volume.

Key Words: progressive overload, individualized adaptation, muscle cross-sectional area

Introduction

It is widely known that resistance training (RT) is an effective strategy to increase skeletal muscle cross-sectional area (CSA, i.e., muscle hypertrophy) (1,4,6). It has been suggested that proper manipulation of RT variables (e.g., load, volume, rest, and frequency) can optimize muscle hypertrophic response (20,28,29,31). Training volume (number of sets or repetitions performed) is one of the variables that has received considerable attention, particularly regarding the number of sets performed per muscle group, because it seems to be associated with the hypertrophic response (15,16,36). In addition, increasing RT volume could ensure a progressive overload, likely preventing the stagnation in gains over time (i.e., overload principle) (1,14).

Most studies that compared different training protocols in well-trained subjects disregarded the overload principle because they have not taken into account the subjects' previous RT volume. Usually, subjects are assigned to a standard training volume group. In this scenario, a given subject may increase, maintain, or decrease the training volume when considering his training routine before the commencement of the experimental protocol. Theoretically, overlooking subjects RT volume history may impair the understanding of the adaptive capacity of the subjects as sudden increases or decreases in workload have the potential to modulate the adaptive response. In this regard, we suggest that prescribing individualized training volumes, based on the previous recent RT workload, may increase the precision of the estimated training effects on the muscle hypertrophic response, due to the control of a possibly confounding factor.

A previous study from our group, comparing advanced RT systems, used a novel method to determine initial volume load (VL) (sets × repetitions × load) in which each subject's previous weekly training volume (WTV) was increased by 20%. This method resulted in average gains of 7.5–7.8% in muscle CSA (4), which seems to be greater gains than the ones reported in other studies with resistance-trained individuals (3,7). However, it is currently unknown if individualized progression of RT results in greater muscle hypertrophy than a nonindividualized progression.

Therefore, the aim of this study was to compare the effects of protocols with standardized (i.e., nonindividualized) and individualized RT volume on muscle hypertrophy in trained individuals. Our hypothesis was that an individualized RT volume would result in greater muscle hypertrophy than a standardized one.

Methods

Experimental Approach to the Problem

Parallel groups are not suited to test the problem at hand because differences in muscle hypertrophy between groups may

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be due to between-subject variability and not to changes in training volume. On the other hand, a within-subject design greatly reduces the between-subject variance in the statistical model. Thus, each subject's leg was randomly allocated to 1 of 2 training protocols: nonindividualized RT volume (N-IND, $n = 16$) and individualized RT volume (IND, $n = 16$). Subject's lower limb dominance was balanced in the randomization process. The CSA of the vastus lateralis muscle was assessed before the training period (Pre) and 72 hours after the last training session (Post), at the same time of the day. Both groups performed their respective protocols twice a week for 8 weeks. For N-IND, WTV was determined based on the average number of sets per muscle group (22 ± 6.3) prescribed for resistance-trained subjects in 20 randomly selected studies (2,4,7,9,11,18–23,25,32–35,37,38,41,42). The WTV for N-IND was, thus, determined as 22 sets per week. Regarding individualized volume protocol (IND), the number of sets per week was prescribed as 1.2 times the number of weekly sets each subject was performing per muscle group—as assessed by a self-reported training log of the previous 2 weeks of training before the commencement of the experimental protocol. The increase in the number of sets (i.e., 1.2 times) was based on our previous study (4), in which slightly higher hypertrophic responses were obtained while ensuring similar relative workload progression for each subject. The assigned individualized RT volumes led to a group average of 24 weekly sets.

Subjects

Out of 21 young men invited to participate, 16 completed the experimental protocol (age: 24.8 ± 5.6 years [range: 18–35], height: 174 ± 0.04 cm, body mass: 75.3 ± 8.4 kg, RT experience: 5.1 ± 4.1 years, and CSA: 30.4 ± 5.03 cm^2; mean ± *SD*) totaling 32 legs. Three subjects dropped out due to personal reasons and 2 for injuries not related to the training protocols. To be eligible, subjects were required to have been (a) training their lower limbs twice a week for at least the past 2 years, (b) performing leg press and knee extension exercises in their RT routines, (c) not making use of anabolic steroids, and (d) free from any musculoskeletal disorder or risk factor (assessed by the PAR-Q). Subjects were informed of all benefits and risks of the study before signing an institutionally approved informed consent form. The study was conducted in accordance with the standards of the ethics committee of the Federal University of São Carlos and the revised version of the Helsinki Declaration (5) and was approved by the University Review Board. All subjects were instructed to maintain dietary habits during the intervention. In addition, individuals were required to consume no dietary supplements other than the provided by the principal investigator, after each RT session (i.e., 30 g of Iso Whey Protein, Max Titanium—Brazil).

Procedures

Muscle Cross-sectional Area. Vastus Lateralis CSA was assessed through ultrasound, according to the procedures described by Lixandrão et al. (17) by an experienced researcher. Subjects were instructed to abstain from vigorous physical activities for at least 72 hours before each CSA assessment (8). Upon arrival to the laboratory, subjects were asked to lay in a supine position for 15 minutes to allow for fluid redistribution. Images were acquired through a B-mode ultrasound, with a linear probe set at 7.5 MHz (Samsung, MySono U6, São Paulo, Brazil), using a transmission gel to ensure acoustic coupling with minimal epidermal compression. The skin was marked at the point corresponding to 50% of total femur length—measured as the distance between the greater trochanter and the lateral epicondyle (39); from this point, successive marks were made transversally toward both the medial and lateral aspects of the thigh, at intervals of 2 cm, to guide the displacement of the ultrasound probe in the sagittal plane. Sequential images of the vastus lateralis muscle were recorded every 2 cm, starting at the most medial skin mark (over the rectus femoris muscle) and moving toward the lateral direction. Next, images were opened in PowerPoint (Microsoft), manually rotated and arranged to reconstruct the full image of the vastus lateralis muscle cross-section. This image was then opened in ImageJ software, and the "polygonal" tool was used to calculate muscle CSA, excluding connective and bone tissue from the delimited area. The coefficient of variation (CV) and typical error (TE) of CSA measures were calculated from 9 individuals; vastus lateralis CSA were reconstructed and measured twice with a 72-hour interval between assessments. The CV and TE computed were 2.61% and 0.80 cm^2, respectively.

Resistance Training Protocols. Subjects trained twice a week for 8 weeks, and all of them completed the 16 planned sessions under the supervision of at least one researcher. At the beginning of each session, subjects performed a general warm-up on a cycle ergometer (Ergo-Fit; Pirmasens, Rheinland-Pfalz, Germany) pedaling at 20 km·h^{-1} for 5 minutes, followed by a specific warm-up of 2 sets of 8 repetitions with load between 40 and 60% of 8 repetition maximum (RM) obtained in training sessions. A 2-minute rest interval was timed between sets. Following, subjects performed their RT protocols, consisting of unilateral 45° leg press followed by knee extension exercises, in sets of 8–12RM. A 2-minute rest interval was allowed between sets, with a 2–3 minutes rest between exercises. Repetitions were performed to the point of muscular failure (i.e., inability to perform another concentric repetition while maintaining proper form) (27). Loads were adjusted between sets whenever the subject performed a set outside the repetitions range, i.e., if the subject performed more than 12 repetitions, the load was increased in the next set; if the subject was not able to complete at least 8 repetitions, the load was reduced. The number of sets was fixed throughout the experimental protocol. The load (kg) was recorded for each training session, and accumulated VL for each subject was calculated as sets × repetitions × load (kg) considering the entire training period.

Statistical Analyses

After visual inspection, the Shapiro-Wilk test was performed to verify the normality of the data. Paired *t*-tests were implemented to compare WTV and VL between protocols. As pre-training vastus lateralis CSA could also affect the changes in muscle hypertrophic response, a mixed model having protocol as a fixed factor, pre-training CSA as a covariate, and subjects as a random factor was implemented to compare delta changes in vastus lateralis CSA. In case of significant *F*-values, Tukey adjustment was used to test for differences between groups' delta changes. A between-group effect size (ES) for small sample sizes and the respective confidence interval (CI) were calculated according to Hedges and Olkin (13). Positive and negative CIs not crossing zero (0) were considered as significant (26). A chi-square test was performed to compare the proportion of individuals who presented increases in the vastus lateralis CSA greater than the TE in one protocol compared with the other (i.e., [IND—N-IND] > 0.80 cm^2 or [N-IND—IND] > 0.80 cm^2). In case of significant p values, standard residuals were analyzed to determine which proportions were significantly different in the contingency table. Differences in the estimated proportions were considered significantly different if standard residuals were outside the interval (−2–2). Individual values for WTV prescribed in each protocol were analyzed as percentage increases/decreases from the self-reported previous WTV. Data are presented as mean values and *SD*s, and the significance level was set at $p \leq 0.05$. All the analyses were performed on SAS 9.4 software (SAS Institute, Inc., Cary, NC).

Results

Muscle Cross-sectional Area

The ANCOVA revealed that pre-training CSA values (i.e., covariate) did not improve the precision of our statistical model ($p = 0.14$), and therefore, it was removed from it. The IND protocol had significantly higher changes in the vastus lateralis CSA than the N-IND protocol ($p = 0.042$; mean difference: 1.08 cm^2; CI: 0.04–2.11, Figure 1A). The inferential analysis was confirmed by the CI of the ES (ES = 0.75; CI: 0.03–1.47).

Comparing individual increases in muscle CSA (Figure 1B), 10 subjects (62.5% of the sample) had greater responses for IND (the difference in gains between protocols was greater than 0.80 cm^2—TE) than for the N-IND condition. For 2 subjects (12.5% of the sample), N-IND promoted better responses. For the remaining 4 subjects (25% of the sample), responses were similar between protocols (difference in gains was smaller than the TE). The IND protocol presented a significantly higher proportion (chi-square, $p = 0.0035$; estimated difference = 0.5, CI: 0.212–0.787) of individuals with greater muscle hypertrophy than the TE of the measurement ([IND—N-IND] > 0.80 cm^2).

No significant differences in VL ($p = 0.98$) and WTV ($p = 0.49$) were observed between protocols (Figure 2).

When comparing the WTV prescribed for each subject with previous recent WTV in the N-IND protocol, 8 of the 16 subjects had an increase in WTV greater than 20% (from 30 to 120%).

Discussion

This was the first study to investigate the effects of an individualized volume progression based on the training history of resistance-trained individuals. As hypothesized, our results indicate that individualizing the number of sets (IND), based on each subject previous WTV, may produce greater muscle hypertrophy when compared with RT performed with a standard weekly volume (N-IND).

A sample of RT-induced muscle hypertrophy (2,4,7,9,11,18–23,25,32–35,37,38,41,42) showed a large variability in the number of sets (22 ± 6.3) prescribed for well-trained individuals. A study by Hackett et al. (12) in which 127 competitive male bodybuilders were surveyed during the off-season period, 74% of them performed 4–5 exercises per muscle group, and 95.3% performed 3–6 sets per exercise per week. The average of weekly sets was 20 per muscle group (ranging from 12 to 30 sets), which is consistent with the average WTV prescribed for the N-IND (22 $sets \cdot wk^{-1}$). Importantly, N-IND WTV was not statistically different from the average WTV of IND nor led to different VL between protocols.

Regarding muscle hypertrophy, the analysis demonstrated that the IND protocol promoted significantly higher delta changes in muscle CSA values compared with N-IND. These findings suggest that the common practice of defining a group standard RT volume in an experimental design may be an important confounding factor, due to unpredictable effects of sudden increases or decreases in workload on muscle adaptive response. This finding may be particularly important for small samples, which usually present low statistical power (10) and precision of the estimates (i.e., betas). By contrast, personalizing the training volume of research protocols according to the previous RT experience of each subject could improve the precision of the estimates in research studies with trained individuals. Our study showed average CSA increases of 6.2 and 9.9% for the N-IND and IND conditions, respectively. These results are in consonance with previous findings from our group (~7.65% (4)) and were higher than in previous reports on trained individuals (~0% in Ahtiainen et al. (2),

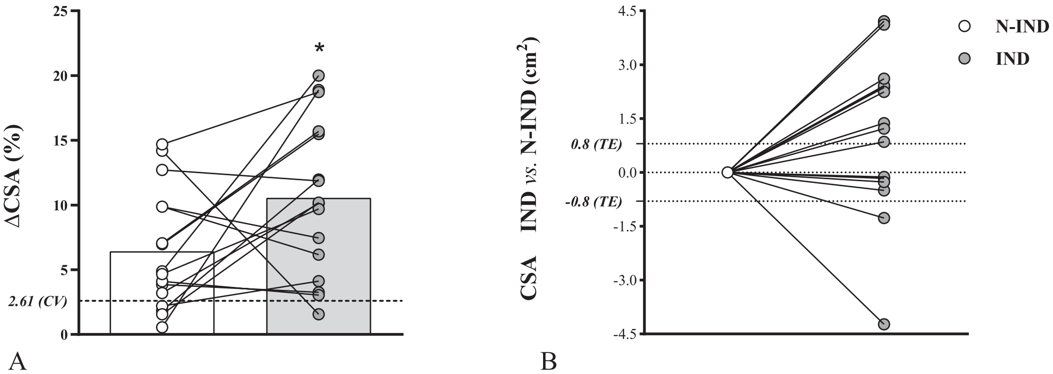

Figure 1. A) Muscle cross-sectional area (CSA) percentage increases from baseline (Pre) to after 8 weeks (Post) of resistance training with nonindividualized weekly volume (N-IND) and individualized weekly volume (IND). Dashed line indicates coefficient of variation: 2.61%. B) Gray circles indicate whether the increases in CSA obtained with the IND protocol are greater than (above 0.8 typical error [TE]), smaller than (below −0.8 TE), or similar (between 0.8 and −0.8 TE) to those obtained with the N-IND. Dashed line indicates the measurement typical error: 0.8 cm^2. *Significantly different from N-IND ($p < 0.05$).

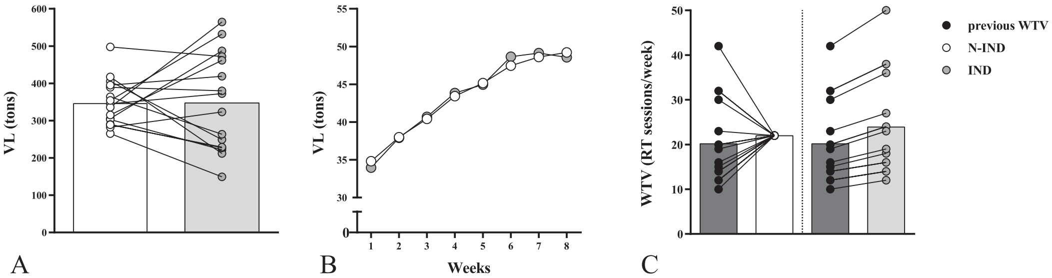

Figure 2. A) Volume load (VL) accumulated after 8 weeks (Post) of resistance training with nonindividualized weekly volume (N-IND) and individualized weekly volume (IND). B) Progression of group average volume load over 8 weeks of resistance training. C) Weekly training volume (WTV) previously performed and WTV prescribed in the nonindividualized weekly volume (N-IND) and individualized weekly volume (IND) protocols.

~4% in Brandernburg and Docherty (7), and ~4% in Ahtiainen et al. (3)). These differences may be a consequence of the protein supplementation provided (30 g of Iso Whey Protein), which seems to maximize muscle protein synthesis after resistance exercise sessions (24). Yet, the IND protocol showed even higher increases than the ones observed in the literature, which we hypothesize occurred because of the individualization of training loads.

Individual response analysis demonstrate that most subjects benefited from performing an individualized number of sets, although they may have performed a higher number of sets in the N-IND protocol. These findings were true even for a subject whose WTV was 120% greater than the volume previously performed. These results suggest that (a) a moderate progression of 20% in the number of sets is more beneficial than a vigorous one, and (b) sharp increases in weekly volume may not always result in greater increases in muscle mass due to a likely training volume ceiling effect, beyond which increases in volume are not followed by hypertrophic gains (43).

A potential limitation of the study was the prescription of individualized volume based on self-reported information, which may not have been accurate. Nevertheless, all subjects were submitted to an interview in which they received detailed explanations on the information that should be registered in the training log reported. Moreover, subjects were experienced practitioners and, therefore, acquainted to reading and interpreting training sheets. Importantly, we did not control for macronutrients daily intake, which might have impacted hypertrophic responses. However, recent evidence suggests that self-selected daily caloric and protein intakes do not differ between high and low muscle hypertrophy responders (30,40), suggesting that other intrinsic and extrinsic factors would contribute further to responsiveness than the control of daily intake of macronutrients. Yet, subjects were firmly instructed to maintain their regular nutritional habits, and a dose of 30 g of whey protein was administered after each training session to stimulate a maximum response in muscle protein synthesis (44). In addition, we believe our intrasubject design contributed to minimizing the impact of different macronutrient intakes among subjects.

Finally, this study concludes that individualizing training volume in an experimental design may indeed provide greater group gains in muscle mass, despite interindividual variability in muscle CSA gains. Moreover, a moderate increase in individual WTV (i.e., 20%) seems effective to maximize muscle hypertrophic response in trained individuals. Thus, future studies should consider previous RT volume an important confounding variable in RT studies.

Practical Applications

Research studies that compare different training protocols in well-trained subjects could benefit from the individualization of progression in subjects WTV, having as a reference the short-term self-reported individual training log. This individualized increase in WTV could safeguard a more precise determination of the adaptive capacity of the group, avoiding the interference of confounding factors in the RT-induced adaptations and, therefore, allowing for adequately testing the hypothesis proposed in the study. Importantly, a moderate increase in individual WTV (i.e., 20%) was more effective to muscle hypertrophy than a vigorous increase in the number of sets in trained individuals. This suggests that practitioners and trainers should use progressive and moderate increments in RT overload instead of sharp and abrupt ones to achieve greater hypertrophic gains.

Acknowledgments

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