Training Volume Increases Or Maintenance Based On Previous Volume: The Effects On Muscular Adaptations In Trained Males

Article *in* Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology · December 2024

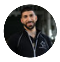
DOI: 10.1152/japplphysiol.00476.2024

12 authors, including:


Andrew Barsuhn
University of Tampa
4 PUBLICATIONS **41** CITATIONS
SEE PROFILE


Tanuj Wadhi
Auckland University of Technology
27 PUBLICATIONS **166** CITATIONS
SEE PROFILE


Baron Thompson
University of Tampa
11 PUBLICATIONS **0** CITATIONS
SEE PROFILE


Christopher Barakat
University of Tampa
16 PUBLICATIONS **255** CITATIONS
SEE PROFILE

TRAINING VOLUME INCREASES OR MAINTENANCE BASED ON PREVIOUS VOLUME: THE EFFECTS ON MUSCULAR ADAPTATIONS IN TRAINED MALES.

Running head: Individualized volume approaches and muscular adaptations

Andrew Barsuhn[1]

Tanuj Wadhi[2],

Alan Murphy[1]

Spencer Zazzo[1]

Baron Thompson[1]

Christopher Barakat[1]

Josh Bradshaw[1]

Joseph Walters[1]

Jody C. Andersen[1]

Brad Jon Schoenfeld[3]

Carlos Ugrinowitsch[1,4]

Eduardo Oliveira De Souza[1]

[1]Department of Health Sciences and Human Performance, The University of Tampa, Tampa, FL, USA,
[2]Sports Performance Research Institute New Zealand, Auckland University of Technology, Auckland, New Zealand,
[3] Department of Health Sciences, CUNY Lehman College, Bronx, New York,
[4]Laboratory of Adaptations to Strength Training, School of Physical Education and Sport, University of Sao Paulo, SP, Brazil

✉Corresponding Author: Eduardo Oliveira De Souza, Ph.D.
401 W. Kennedy Blvd (box 30F). Tampa, FL, USA. Zipcode: 33606
Office number: 1- 813 257-3210, cell-phone: 1-813-992-2069

edesouza@ut.edu

ABSTRACT

This study investigated the effects of increasing previous resistance training (RT) weekly set volume by 30% (G30) and 60% (G60) on muscle hypertrophy and strength. Fifty-five resistance-trained men were randomly allocated to the experimental groups, while 29 completed the study, as follows: control group (CON): n=10, G30: n=10, and G60: n=9. Participants underwent a lower body RT program twice a week for eight weeks. We assessed pre- and post-study thigh region-of-interest fat-free mass (ROI-FFM), anterior thigh muscle thickness (MT) at two sites: proximal (PMT) and distal (DMT) and their sum (ΣMT), one-repetition maximum (1RM), and strength-endurance via repetitions to failure (RTF) at 70% of 1RM. ROI-FFM and MT demonstrated a significant increase from pre- to post-training (main time effect, $p<0.001$), (ΔΣMT CON: 1.07cm, G30: 0.76cm, G60: 0.70cm; ΔROI-FFM CON: 1.57kg, G30: 0.47kg, G60: 1.55kg). All groups increased back squat 1RM ($p<0.0001$). However, the main group effect ($p<0.0268$) indicated that the CON group showcased a greater overall 1RM (174.7kg), than the G30(159.0kg), and G60(149.0kg). Only the G30 group increased RTF at the post-test (CON: 0.13reps, G30: 5.45reps, G60: -0.41reps), ($p<0.0263$). Our findings suggest that trained males can experience significant muscle growth and strength adaptations while maintaining their previous weekly set number above a certain weekly set volume threshold.

NEW & NOTEWORTHY: Increasing previous resistance training volume by 30% (G30), 60% (G60), or maintenance (CON) on muscular adaptations in trained individuals. Interestingly, CON group resulted in the greatest overall 1RM strength, while G30 showed the highest increase in repetitions to failure, with no differences between groups in muscle mass size. These findings suggest that more is not always better for muscle adaptations in a trained cohort, highlighting muscle growth across a wide range of weekly set numbers.

Keywords: muscle hypertrophy, muscle strength, strength endurance, weekly sets, previous volume

INTRODUCTION

Resistance training (RT) volume, herein operationally defined as the number of sets performed per week, seems to be a crucial variable for eliciting increases in muscle size and strength adaptations (1-6). Additionally, the dose-response relationship between RT volume and muscular adaptations in resistance-trained individuals has been a topic of interest in the scientific community (2, 7-11).

Several studies have explored the effects of different RT volumes on muscle hypertrophy with conflicting results in trained cohorts (2, 7-13). For example, some studies reported no statistical differences in muscle hypertrophy adaptations when comparing low, moderate, and high weekly sets numbers (e.g., 3 to approximately 37 weekly sets) (7, 8, 11). In contrast, other studies have shown that high RT volume schemes (>24 weekly sets) optimized growth in muscle thickness (2, 10). Nonetheless, most studies disregarded participants' previous RT volume and prescribed absolute RT volume.

Whether previous training volume is a moderator of RT-induced adaptations requires further scrutiny as participants’ previous RT volume may hinder the precision of the dose-response relationship between RT volume and muscular adaptations in resistance-trained individuals engaged in randomized controlled trials. Thus, accounting for previous RT volume allows for the standardization of incremental changes in RT volume across individuals, ensuring consistency in RT volume variations among the experimental groups. For example, Brigatto et al. (10) found that RT volumes of 24 and 32 weekly sets produced greater strength and hypertrophic adaptations than 16 weekly sets. Nevertheless, while the 24 and 32 groups increased their previous volume by ~50% and ~75%, respectively, the 16 group reduced their previous RT volume by ~24% during the experimental period. Therefore, when attempting to elucidate the effects of different RT volumes on muscular adaptations in trained cohorts without accounting for previous training volume, the sudden and uncontrolled changes between the previous and the actual RT volume implemented during the experimental period can bias the observed outcomes.

To our knowledge, only a few studies have accounted for the participants' previous RT volume (7, 13). Aube et al. (7) randomized resistance-trained males counterbalanced by previous training volume to low, moderate, and high volume groups of 12, 18, and 24 weekly sets, respectively, over an 8-week study period. Despite differences in the volume load, the authors observed similar hypertrophic adaptations across conditions. Additionally, Scarpelli et al. (13) increased individual lower body RT volume by 20%, resulting in an average of 24 weekly sets, in contrast to a fixed set number (22 weekly sets) in a within-subject design. They found that the individualized approach enhanced hypertrophic adaptations, with no differences in the volume load (i.e., sets x repetitions x load[kg]). Their findings suggest that individualized increases, in which no experimental unit reduced their previous volume in the experimental period, might lead to more positive hypertrophic adaptations. However, it should be noted that they employed a single increment (i.e., a 20% increase), which limited the exploration of different individualized increases and their effects on muscle hypertrophy.

Regarding strength adaptations, previous research has also produced conflicting results in trained individuals (1, 2, 7-10), further contributing to the complexity of this topic. The findings of Aube et al. (7) suggest that the middle dose (i.e., 18 weekly sets) may optimize maximum strength without hindering strength-endurance adaptations. On the other hand, Marshall et al. (9) applied a 2-week washout period before the experimental intervention and found that 16 weekly sets enhanced maximum strength compared to 2 weekly sets. However, no statistical differences were found between the 8 and 16 weekly sets. More recently, Enes et al. (11) found that a group that increased volume by six sets every two weeks, resulting in an average of 37 weekly sets over the 12-week study period, demonstrated the greatest strength gains compared to a group with an average of 32 sets and a group with a fixed volume of 22 weekly sets.

To address the lacunae in the current literature, this study investigated the effects of two individualized RT volume increases based on prior weekly set number on lower-body muscle strength, muscle thickness, and regional fat-free mass accretion in resistance-trained individuals compared to a control group that maintained their weekly sets. Considering the studies cited, which suggest that increasing previous training volume in the experimental period might enhance strength and hypertrophic adaptations, we hypothesized that a) individualized volume increases of 30% and 60% would enhance regional-of-interest fat-free mass accretion and muscle thickness adaptations compared to the control group, b) the 30% individualized increase would elicit superior maximum strength adaptation, and c) the 60% increase would elicit superior strength-endurance adaptations.

MATERIAL & METHODS

Experimental design

This study employed a parallel-group repeated-measures design, with a counterbalanced randomization. Participants were allocated to one of three RT volume conditions based on their quadriceps muscle thickness and previous self-reported weekly set number for the quadriceps as follows: control group (CON) maintained their previous volume whereas group 30 (G30) and group 60 (G60) increased their previous weekly sets by 30% and 60% respectively. We investigated the effects of these three experimental conditions on maximum strength (one repetition maximum [1RM]), strength-endurance via repetitions-to-failure (RTF) at 70% of

1RM, thigh region-of-interest fat-free mass (ROI-FFM), and muscle thickness (MT) at proximal (PMT) and distal (DMT) portions of the anterior thigh in highly-trained males (i.e., back squat 1RM:body mass > 1.5). Participants trained twice a week for 8 weeks (i.e., 16 sessions) on the squat, leg press, and leg extension exercises. All dependent variables were assessed at baseline (pre) and at least 48 hours after the last training session (post). Volume load (VL) (i.e., sets x repetitions x load [kg]) was recorded. In addition, we assessed perceived training-related exertion (RPE) and perceived recovery (PRS). PRS was collected at the beginning of every training session, and RPE was collected after the last set of every exercise. All testing and training sessions took place in the Human Performance Laboratory and were overseen by researchers and experienced trainers.

Participants

Fifty-five resistance-trained participants (age range: 18.1 to 36.7 years) volunteered to participate in the study. The inclusion criteria were as follows: males aged 18-40 years; at least three years of previous RT experience and relative barbell back squat strength of at least 1.5 times their body mass. Exclusion criteria were as follows: current/history of joint pain (e.g., tendinitis); history of drug or alcohol abuse; daily usage of NSAIDs, anticoagulants, or antiplatelet drugs; high blood pressure; heart arrhythmias; or reported sensitivity to caffeine. Participants completed a form detailing their lower body training log over a three-week period prior to the study to assess their weekly quadriceps training volume. Participants were then classified into terciles based on the total number of sets performed per week for the quadriceps and the sum of muscle thickness (ΣMT) of the anterior thigh (i.e., rectus femoris and vastus intermedius) from largest to smallest values. Next, the first three participants from each tercile were randomly assigned to one of the three experimental groups, followed by the next three, and so on. A CONSORT flow diagram of the study is presented in Figure 1. Data from 55 participants, including 29 of whom completed the study, were used for the statistical analysis (Table 1). All procedures were approved by an institutional review board, and participants were required to read and sign an informed consent before participating.

******************* Insert Table 1 here *******************

******************* Insert Figure 1 here *******************

Sample size justification

Considering the training status of our population and the small effects observed in trained cohorts, we did not calculate an a priori power analysis. However, we have conducted power analyses using as input values our data from the primary (i.e., the sum of muscle thickness) and secondary outcomes (i.e., maximum strength and repetitions to failure). We performed 1000 simulations for each outcome with an increasingly higher sample size until significant interaction effects were achieved. We used the same statistical model for our simulations (linear mixed model having group and time as fixed factors and participants as a random factor) as the one used for data analyses. Alpha and Beta values were defined as 0.15 and 0.85, respectively. Input data included between-group average values at baseline and detectable differences at post-training between the three experimental groups. A variance and covariance matrix, modeled as autoregressive lag 1, was created using values obtained from the mixed models R matrices obtained in our data analysis. Input values for the dependent variables were as follows: sum of muscle thickness – baseline 11.1 mm, detectable difference 0.12 mm; variance 1.51, and autocorrelation 0.74. Maximum strength – baseline 150.5 kg; detectable difference 20 kg, variance 794.41; and autocorrelation 0.83. Repetitions to failure – baseline 18.04 repetitions; detectable difference 6.07 repetitions; variance 29.26, and autocorrelation 0.56. Significant interaction effects were obtained with 300 participants (Alpha=0.88), 10 participants (Alpha=0.98), and 100 participants (Alpha=0.86) for the sum of muscle thickness, maximum strength, and repetitions to failure, respectively. Due to inherent logistical issues and a higher dropout rate due to the consequences of the coronavirus pandemic, only a fraction of the participants needed for our primary outcome were recruited. All analyses were run using PASS 2024, version 24.0.2.

Regional-of-interest fat-free mass and muscle thickness assessments

A Lunar Prodigy dual-energy X-ray absorptiometry (DEXA) apparatus (Hologic, Bedford, MA) was used to measure ROI-FFM. The lower body was subdivided from the iliac crest to the lateral condyle for each scan at pre-testing and post-testing (Figure 2A). On the day of the scan, participants were strictly instructed to come to the laboratory after refraining from food and water for at least 10 hours before the scan (14). Upon entering the laboratory, participants were weighed on a mechanical scale and positioned on the bed of the DEXA machine, laying supine with knees extended, and were instructed to remain still for the entire duration of the scan. Participants' positions on the machine bed were recorded and repeated to increase test-retest consistency. In addition. ROI-FFM measures were acquired at pre-testing and 48-72 hours after the last training session at approximately the same time of the day. The same researcher performed each pre- and post-training ROI measurement and was blinded to the experimental groups. The measurement error for ROI-FFM was assessed before the study using five participants with characteristics similar to those of the current participants. The coefficient of variation (CV), typical error (TE), and standard error (SEM) were: 1.28%, 0.48kg, and 0.95kg, respectively.

Anterior thigh MT was measured using B-mode ultrasound (HS40; Samsung Healthcare, Ridgefield Park, NJ) with a linear probe (LA3-16AD, Samsung Healthcare) with frequency ranges between 8.0 and 12.0 Mhz. The femur length was measured in the sagittal plane from the greater trochanter to the lateral condyle. Marks were made at 40% and 60% of the total femur length (described in (7). The combined thickness of the vastus intermedius and rectus femoris muscles was measured at proximal (PMT—40% of the femur length) and distal (DMT—60% of the femur length) sites. The sum of both sites (ΣMT) was also used for further statistical analyses. A water-soluble transmission gel (Aquasonic 100; Parker Laboratories, Inc, Fairfield, NJ) was applied to the probe, which was then placed on the skin with minimal pressure to avoid depression of the muscle. Zoom and frequency were adjusted until a clear picture of the femur and muscle fascia could be seen. The muscle thickness was measured from the highest point of the anterior curvature of the femur to the lower border of the muscle fascia of the rectus femoris using a straight vertical line (Figure 2B and 2C). Three measurements were taken at each point, and the median value was used for further analyses. All images were obtained from the anatomical right thigh. All MT assessments were performed at a similar time of the day at pre-testing and post-testing to account for diurnal effects. To minimize training-induced muscle swelling, images were obtained before the commencement of any familiarization procedures and 48–72 hours after the last training session at the end of the study. The same two researchers, who were blinded to the experimental groups, performed pre-training and post-training measurements, one researcher specifically responsible for handling the probe, and the other performing the measurements on the monitor. The measurement error for MT was assessed before the study using five participants with characteristics similar to those of the current participants. The CV, TE, and SEM for PMT and DMT were: 0.54%, 0.03cm, and 0.49cm, and 1.56%, 0.12cm, and 0.44cm, respectively.

******************* Insert Figure 2 here *******************

Maximum strength assessment

All participants completed one familiarization session for the 1RM test, followed by baseline testing for 1RM and strength-endurance interspersed by a minimum of 48 hours before the commencement of the study. At the start of every session, participants performed a general warm-up consisting of 3 minutes at ~5.0 km·h^{-1} on a treadmill (Tuff Tread; White Phoenix, LLC., Willis, TX). After the warmup, participants were given a thorough explanation of the testing procedures including the 1RM squat and repetitions-to-failure at 70% 1RM (RTF). Participants performed maximum strength testing on the barbell back squat to a depth of 100° of knee flexion, measured as the angle between the femur and the fibula using a goniometer. Briefly, the stationary arm of the goniometer was placed parallel to the long axis of the femur along a line extending from the greater trochanter to the lateral condyle, and the moveable arm was placed parallel to the long axis of the fibula in line with the head of the fibula and the lateral malleolus. Squat depth was constrained to 100° knee flexion using an adjustable seat. Participants were asked to “tap and go” to validate each repetition. Since this sample consisted of experienced lifters, it was decided by the researchers that interference with lifting technique regarding stance, barbell placement, or repetition tempo, aside from ensuring a range of motion, was not required. Participants performed two warm-up sets on the back squat using loads of 50% for eight repetitions and 70% for three repetitions of their self-estimated 1RM load in the familiarization session. Participants then had up to five attempts to achieve their 1RM, of which the first attempt was standardized to 90% of their estimated 1RM. A linear position transducer (GymAware; Kinetic Performance Technology, Canberra, Australia) was used to monitor the intensity of each attempt based on the barbell velocity. 1RM load was determined when the subject reached volitional failure (the individual's inability to exert the required force to complete the attempt with fully extended hips and knees). Additionally, RPE and barbell velocity were used as additional parameters to determine a maximum attempt. For example, after a slow ($<0.28\ m \cdot s^{-1}$) (15) or misgrooved attempt, barbell velocity and RPE were checked. Based on those parameters, the research team decided whether the given attempt was deemed a 1RM or if further testing was necessary. The heaviest weight successfully lifted was used for statistical analyses. The measurement error for 1RM was assessed during the two familiarization sessions with all the participants who were tested for 1RM. The CV, TE, and SEM for 1RM were: 2.55%, 8.32kg, and 3.91kg, respectively.

Strength-endurance assessment

To prevent fatigue during the 1RM assessments, the strength-endurance assessment was conducted only after the second 1RM testing session. Therefore, we have not assessed the measurement error for strength endurance assessment. Upon completion of the 1RM testing, participants were given a five-minute rest period, after which they were asked to perform repetitions-to-failure at 70% of their 1RM load on the Squat exercise. For a repetition to be valid, they had to “tap and go” on the adjustable seat. Volitional failure was reached when the subject could not exert the required force to complete the repetition, rested for more than two seconds between repetitions, or if the barbell velocity fell below 0.28 $m \cdot s^{-1}$ (15). Briefly, after a slow attempt, participants were given a warning, and spotters were given an indication to be prepared. The test was concluded when the participants reached volitional failure or if they took more than 2 seconds of rest after a repetition.

Perceptual assessments

Participants’ perceived recovery (PRS) was assessed upon each subject's entry to the lab and prior to the start of training, and rating of perceived exertion (RPE) was measured after the last set of every exercise and at the end of the training session (16, 17). The CR-10 is a numerical scale ranging from 0 to 10, where 10 represents the strongest effort or exertion someone can experience, whereas 0 implies no exertion at all. The PRS scale is also a single item 0 to 10 scale, where 10 indicates optimal recovery and performance, and 0 represents poor recovery and potentially reduced performance. Instructions and procedures for using the RPE and PRS scales were given to all individuals during the familiarization sessions. In addition, all assessments were performed in isolation from other participants to ensure accuracy. The perceptual assessments of the two different training blocks (i.e., first and second half) were averaged for further analysis.

Training intervention

Participants underwent an 8-week hypertrophy-oriented lower-limb RT program performed twice per week, totaling 16 sessions per subject. Upon entry to the lab, participants were given a standardized ½ serving of pre-workout supplement containing 175 mg of caffeine (Pulse; Legion Athletics Inc., Clearwater, FL) to ensure similar performance during every training session and prevent a possible confounding variable due to supplementation strategies amongst participants. The same warm-up protocol as 1RM testing described above was utilized (e.g., light jogging at ~5.0 km·h^{-1} on a treadmill, followed by two warm-up sets), with the use of an adjustable seat for back squat training, except that warm-up loads were calculated using the targeted load for that training day instead of their 1RM. All experimental groups performed the same exercises at the same repetition ranges and level of effort. The only difference between groups was the change in total number of sets performed for the quadriceps muscle per week relative to the sets performed prior to the study (i.e., no change control, 30% increase, and 60% increase groups). Sets were divided equally between the back squat, leg-press, and knee extension exercises, and all participants were strictly instructed to refrain from performing any additional lower body exercises outside of the prescribed training intervention. Additionally, to reduce the likelihood of dropouts and prevent participants from training the lower body outside of the lab, all Participants were prescribed an equalized and standardized set and repetition scheme for posterior thigh muscles in the form of Romanian deadlift and glute-ham raise exercises. However, volume load has been calculated and only presented for the exercises targeting the quadriceps exclusively.

Since muscle strength is highly influenced by exercises and loading patterns of the training protocol, our training sessions alternated between lower-repetition days (e.g., 6-8) and higher repetition days (e.g., 12-15) for quadriceps exercises during the first and second training sessions of the week, respectively. The termination criterion for the set was established when the participant subjectively reached two repetitions in reserve (RIR) (18). The exception to this was the final set of each exercise in every training session, which was performed to volitional concentric failure, meaning the participant could no longer exert the necessary force to complete the repetition while fully extending their knees and hips. If the participants were unable to complete the target repetitions, the load was decreased for the next set. Conversely, if the participants were able to complete the prescribed repetitions with ease, the set was terminated at the higher end of the repetition range for that day and the load was increased for the next set. A 2-minute and 3-minute rest interval was provided between sets and exercises, respectively. Participants were asked to report their RPE for the average of all sets for each exercise as soon as they completed the last set to gauge future session load adjustments. To help ensure proper nutrition throughout the experimental period, participants received a post-workout supplement on training days containing 22 g of protein and 2 g of carbohydrate (Whey+; Whey Isolate Protein Powder; Legion Athletics Inc., Clearwater, FL) under the supervision of the research staff.

Statistical analyses

To reduce potential bias, we implemented blinding procedures in both the data acquisition and analysis. Apart from the blinding procedures for ultrasound and ROI measurements mentioned earlier, one researcher conducted the statistical analyses in a blinded manner. Following the completion of the analyses, another researcher unveiled the correct dataset. Unfortunately, due to operational constraints, blinding was not feasible for the strength-related assessments, which may introduce some level of bias in these measures.

Normality (i.e., Shapiro-Wilk) and variance (i.e., Levene) assurance were first checked for all variables. For total volume load (i.e., sets x reps x load), a one-way ANOVA was used to determine the difference between groups. A mixed-model analysis was performed for all dependent variables (i.e., RPE, PRS, ROI-FFM, MT, RM and RTF) using an intention-to-treat approach and a per-treatment approach (19), assuming group (CON, G30, G60) and time (pre and post) as fixed factors and subject as a random factor. Whenever a statistically significant F-value was obtained, simple contrasts using a Bonferroni correction were implemented for multiple comparison purposes. The data was analyzed with and without dropouts using mixed models. Since dropouts could affect the statistical findings, we reported the intention-to-treat model in the results section. This decision was based on the fact that we had an unusual dropout rate (~45%) due to COVID. Most of the dependent variables had no differences in the results between the intention-to-treat and per-treatment approaches. However, trends were observed for a main group effect (p=0.067) and a group-by-time interaction (p=0.057) for 1RM and RTF, respectively, which the intention-to-treat model confirmed. In addition, we reported estimated differences as well as upper and lower limits of 95% confidence intervals of the between-group and within-group absolute differences (95%-CI$_{\text{diff}}$). Within-group effect sizes (ES) were calculated as follows: mean post-test minus mean pretest values divided by the pooled pre-standard deviation (SD) (20). Furthermore, an ANCOVA was run on all dependent variables having the total volume load and baseline values for all dependent variables as covariates. Although two covariates were significant (i.e., ΣMT: p=0.03 and RTF: p=0.005), they did not change post-testing comparisons between groups being the reason why ANCOVA results were not presented. The statistical significance level was set at α=0.05. Results are expressed as mean ± SD.

RESULTS

Volume load and perceptual assessments

Total volume load between groups was as follows: CON:394,505kg (95% CI: 145,735 to 643,275kg), G30: 411,667kg (95% CI: 311,581 to 511,754kg), G60: 496,328 (95% CI: 355,466 to 637,189kg). There were no significant differences in volume load between groups ($p>0.05$). The average weekly volume load throughout 16 sessions for the experimental groups is presented in Figure 3. Regarding perceptual assessments, there was a main time effect ($p<0.0001$), indicating that RPE in the second half of the study was higher than in the first phase (estimated difference: 0.38 a.u., 95% CI: 0.38 to 0.39 a.u.) [CON: 1st half: 8.38 a.u.; 2nd half: 8.55 a.u.; G30: 1st half: 8.29 a.u.; 2nd half: 8.76 a.u.; G60: 1st half: 8.06 a.u.; 2nd half: 8.59 a.u.]. However, there were no significant differences in PRS between the groups or time points ($p>0.05$) [CON: 1st half: 7.83 a.u.; 2nd half: 7.64 a.u.; G30: 1st half: 7.95 a.u.; 2nd half: 7.93 a.u.; G60: 1st half: 7.48 a.u.; 2nd half: 7.67 a.u.].

******************* Insert Figure 3 here *******************

Regional-of-interest fat-free mass and muscle thickness

For ROI-FFM, the mixed model analysis revealed a main time effect (<0.0001), (Estimated differences: 1.35kg [95%-CI: 1.33 to 1.36kg). However, no group ($p>0.05$) or group by time interaction ($p>0.05$) was observed (estimated within-group differences were: CON:1.7kg, G30:1.1kg, and G60: 1.2kg), (Table 2). Pairwise between groups; CON vs G30:

0.90kg [95%-CI: 0.63 to 1.18 kg, p=0.32]; CON vs G60: 0.97kg [95%-CI: 0.71 to 1.24 kg, p=0.23], and G30 vs G60: 0.07kg [95%-CI: -0.21 to 0.35 kg, p=0.94].

Regarding MT, there was a main time effect ($p \leq 0.001$) for PMT, DMT, and ΣMT (Estimated differences: PMT: 0.48cm [95%-CI: 0.48 to 0.49cm); DMT: 0.38cm [95%-CI: 0.37 to 0.39cm); and ΣMT: 0.87cm [95%-CI: 0.86 to 0.89cm, respectively). Additionally, no group ($p>0.05$) or group by time interaction ($p>0.05$) was observed for PMT, DMT and ΣMT (estimated within-group differences were: PMT: 0.56cm, 0.37cm, 0.48cm; DMT: 0.43cm, 0.35cm, 0.36cm, and ΣMT: 1.00cm, 0.73cm, 0.87cm for CON, G30, and G60, respectively), (Table 2). Pairwise between groups; PMT- CON vs G30: 0.07cm [95%-CI: 0.006 to 0.15cm, p=0.74]; CON vs G60: -0.02 [95%-CI: -0.04 to 0.10 cm, p=0.90], and G30 vs G60: -0.10cm [95%-CI: -0.18 to -0.03 cm, p=0.66]; DMT- CON vs G30: 0.08 cm [95%-CI: 0.008 to 0.15cm, p=0.73]; CON vs G60: -0.002 cm [95%-CI: -0.07 to 0.07, p=0.99], and G30 vs G60: -0.08cm [95%-CI: -0.15 to -0.003 cm, p=0.75], and ΣMT- CON vs G30: 0.16 cm [95%-CI: 0.02 to 0.30cm, p=0.72]; CON vs G60: -0.03 cm [95%-CI: -0.10 to 0.17, p=0.94], and G30 vs G60: -0.08cm [95%-CI: -0.34 to -0.04 to cm, p=0.68].

******************* Insert Table 2 here *******************

Individual responses for each experimental condition (CON, G30, G60) are visualized using a bubble scatter plot (Figure 4). The plot highlights the relationship between changes in ROI-FFM and ΣMT, while bubble size represents the total volume load. The density curves overlaying the scatter plot represent the distribution of changes within each group, providing additional information about the variability across conditions. Additionally, the figure illustrates a strong relationship between the delta-change in ROI-FFM and ΣMT assessments ($r=0.71$, $p<0.05$). A qualitative analysis of Figure 4 suggests that the changes in muscle mass accrual indices do not appear to be associated with the total volume load.

******************* Insert Figure 4 here *******************

Maximum strength and strength-endurance

For 1RM, there was a main time effect (<0.0001), (Estimated differences: 21.47kg [95%-CI: 21.27 to 21.66kg). Our analysis also revealed a main group effect ($p<0.0268$) in which the CON group had higher 1RM values compared to G30 and G60 (Table 3). Pairwise between groups; CON vs G30: 15.6kg [95%-CI: 12.8 to 18.5kg, $p=0.09$]; CON vs G60: 24.7kg [95%-CI: 22.0 to 27.5kg, $p=0.008$], and G30 vs G60: 9.1kg [95%-CI: 6.1 to 12.0kg, $p=0.61$].

For strength-endurance, there was a group-by-time interaction ($p<0.0263$) in which only the G30 group increased the number of repetitions to failure (estimated within-group differences: CON: 0.13 reps [95%-CI: -1.19 to 1.46 reps]; G30: 5.45reps [95%-CI: 4.04 to 6.87 reps]; and G60: -0.41reps [95%-CI: -1.81 to 0.99 reps]), (Table 3). Pairwise between groups; CON vs G30:

-3.4 reps [95%-CI: -3.9 to -2.9 reps, p=0.05]; CON vs G60: -0.95 reps [95%-CI: -1.5 to -0.4 reps, p=0.57], and G30 vs G60: 2.4 reps [95%-CI: 1.9 to 3.0 reps, p=0.17].

**************** **Insert Table 3 here** ****************

Individual responses for each experimental condition (CON, G30, G60) are visualized using a bubble scatter plot in Figure 5. The plot highlights the relationship between changes in squat 1RM load and repetitions to failure at 70% of 1RM, while the bubble size represents the total volume load The density curves overlaying the scatter plot display the distribution of changes within each group, providing additional information about the variability across conditions. Additionally, the plot demonstrates a lack of statistical agreement between maximum strength and strength endurance (p>0.05). In addition, a qualitative analysis suggests that total volume is not a factor modulating the changes in 1 RM load and repetitions-to-failure.

**************** **Insert Figure 5 here** ****************

DISCUSSION

This study compared the effects of three individualized RT volume increments (i.e., 0% - control, 30% – G30, and 60% - G60) based on weekly set number performed prior to the commencement of the study on lower-body muscular adaptations in resistance-trained individuals. We have not confirmed our hypothesis that individualized volume increases would elicit superior hypertrophic adaptations than the control group. Regarding maximum strength, while p-value did not reach significance for a traditional posthoc analysis between G30 and G60, the 95% confidence interval between these groups in the post test suggests a meaningful difference likely surpassing the measurement error (G30 vs G60: 9.1kg [95%-CI: 6.1 to 12.0kg, p=0.61). Therefore our data do not support the hypothesis that a 30% individualized increase would elicit superior maximum strength adaptation, as CON demonstrated greater aggregate maximum strength than G30 and G60. Additionally, contrary to our hypothesis, only G30 statistically improved strength endurance from pre- to post-training, with significantly higher repetitions-to-failure values than the CON and G60 groups.

Regional fat-free mass and muscle thickness significantly increased from pre to post for all groups, with pooled mean increase of ~1.20kg (4.6%) and ~0.85cm (7.0%) for ROI-FFM and ΣMT, respectively. These adaptations align with previous research that examined the impact of varying RT volumes on these metrics in resistance-trained individuals during a similar training duration (7).

The literature on RT volume has yielded conflicting findings for hypertrophic outcomes in trained cohorts (2, 7, 8, 10, 11). For instance, while Schoenfeld et al. (2) and Brigatto et al. (10) observed a dose-response relationship that favored higher RT volumes, the current study, Ostrowski et al. (8) and Aube et al. (7) did not show benefit from increased RT volumes. More recently, Enes et al. (11) found that a group that increased their sets by six every two weeks, reaching 52 weekly sets in the last two weeks of the study (with an average of 37 weekly sets), demonstrated a small advantage in muscle mass accrual compared to a group utilizing fixed volume of 22 weekly sets. It is noteworthy to mention that, despite measuring vastus lateralis and vastus intermedius muscle thickness, the absolute raw change in the ΣMT and effect sizes between Enes et al. (11) highest volume group and our control group were almost identical (e.g., 1.06 cm; 0.74 versus 1.07 cm; 0.74 respectively). Nevertheless, caution should be exercised when attempting to directly compare absolute MT changes across studies due to different exercises and measurement techniques used.

Thus far, Schoenfeld et al. (2), Brigatto et al. (10), and Enes et al. (11) have employed the highest RT volumes reported in the literature exceeding 30 weekly sets. In our individualized design, while some participants exceeded 30 weekly sets, this current study, along with other studies, has incorporated lower RT volumes in their higher volume experimental groups, averaging around 24 weekly sets (7, 8, 12). However, only Brigatto et al. (10) and Aube et al. (7) reported participants' previous RT volumes. Regardless of their approach to address this potentially confounding factor, their previous volume analyses (7, 10) indicated that individuals assigned to a low-to-moderate RT volume may have reduced their previous weekly set number during the experimental period, which could explain some of the observed outcomes. Additionally, in the current study and Aube et al. (7), participants had a notably high 1RM baseline compared to other studies (2, 10). It could be argued that as individuals become stronger, their responses to varying RT volumes may be hampered (i.e., smaller adaptation window) compared to their less strong counterparts. However, whether baseline strength influences RT-induced hypertrophic adaptations and its underlying mechanisms warrants further investigation.

Moreover, along with Scarpelli et al. (13), the current study is one of two studies that have utilized resistance-trained participants’ weekly sets before the commencement of the study to prescribe individualized RT volume during the experimental period. Scarpelli et al. (13) employed a within-subject design in which one leg increased 20% of their previous weekly set number, resulting in an average of 24 weekly sets compared to a fixed RT volume set at 22 weekly sets. Despite no differences in volume load, they found that individualized volume elicited greater hypertrophic adaptations than the fixed volume approach. Herein, we employed a parallel group design, with one group maintaining their previous weekly set number (~14 sets per week), while two other groups followed individualized progressions of 30% and 60%, resulting in averages of ~19 and ~24 weekly sets, respectively. Contrary to the findings of Scarpelli et al. (13), we did not observe adaptations in MT and ROI-FFM favoring higher RT volume changes. The parallel group design and the high attrition in our study may have decreased the precision of our MT and ROI-FFM estimates compared to Scarpelli et al. (13).

Regarding improvements in maximal strength, the groups exhibited increases in back squat 1RM performance with pooled mean increases of ~22kg (~14%). Despite only significant main effects for time and group, the CON group improved the most, with a mean absolute change of 32 kg (~19%). Moreover, between-group mean difference 95%-CIs indicated differences between CON and both G30 (7.7kg to 26.3kg) and G60 (20.3kg to 38.5kg) in the post-tests. Intriguingly, our findings suggest that maximal back squat strength can be improved with no change in lower-body quadriceps RT volume. However, the lack of a significant group-by-time interaction, coupled with similar pre- to post-test effect sizes between groups (CON=0.86; G30=0.73; and G60=0.72), suggests that the group effect may have been influenced by a slight imbalance between groups, although not statistically significant, in the pre-test.

Previous studies investigating the dose response between RT volume and changes in 1RM have produced conflicting results that could be attributed to some participants receiving either an insufficient or excessive weekly set volume compared to their acclimated RT volume (2, 7-10). Regardless of whether the volume was prescribed in relative or absolute terms, a broad analysis of existing literature suggests that employing a range of 14-18 weekly sets could potentially augment 1RM performance among trained individuals. For example, the most substantial absolute increases in 1RM have been reported in studies by Marshall et al. (9), Aube et al. (7), and the present investigation, revealing improvements of 37kg, 26kg, and 32kg, respectively, in experimental groups executing 16, 18, and ~14 weekly sets. However, adding more complexity to this topic, a recent study (11) reported that increasing RT volume by six sets every two weeks, reaching 52 weekly sets in the last two weeks, increased 1RM by 26kg. These findings suggest a wide range of RT volumes in which trained individuals could increase their maximum strength without detrimental effects in relatively short-term RT programs (8 to 12 weeks).

Regarding strength-endurance, as measured by repetitions-to-failure at 70% of 1RM, the only group that exhibited improvements was the G30 cohort, demonstrating an average increase of approximately 5.5 repetitions (~26%). The paucity of available data hinders the ability to reconcile the existing literature concerning RT volume and its impact on strength-endurance. To date, the investigations by Schoenfeld et al. (2) and Aube et al. (7) were the only studies exploring the effects of varying RT volumes on repetitions to failure; both observed no differences among weekly volumes. While our findings suggest a potential benefit from a relative increase of 30% and enhanced performance in repetitions to failure, a plausible explanation for this outcome remains elusive. Alternatively, one could speculate that a small-to-moderate increase in weekly sets (30%) may add an additional stimulus to increase maximum strength, while a large increase in weekly sets (60%) may have produced high levels of residual fatigue during and after each training session, hindering the ability to further increase maximum strength over the training period. Thus, further research is required to shed light on the intricate relationship between absolute RT volume, progression of RT volume and strength-endurance.

Similar to RTF, longitudinal data on the perceptual responses to different weekly sets in resistance-trained individuals is limited. Our analysis revealed a main time-effect for RPE ($p<0.0001$), indicating that sessions were more difficult in the second half of the study than the first half (8.6 a.u. vs. 8.2 a.u.); however, no between-group differences were observed in perceived recovery. Aube et al. (7) was the only study to explore the effects of absolute RT volumes on perceptual measures of RPE and pleasure [i.e., Feeling Scale by Hardy and Rejeski (21)]. While the researchers found no differences within or between groups on any of the perceptual responses, we observed an increase in RPE over time. Although the lack of statistical differences in volume load among the groups might partially explain our RPE findings, the capacity to accommodate different RT volumes appears to be in a per-individual basis; this aspect, coupled with the short-term nature of our study design, warrants cautious interpretation of our outcomes of perceptual responses. Additionally, the current knowledge on the perceived recovery scale does not allow establishing relationships between direct indices of muscle strength/endurance recovery (e.g., central fatigue, excitation-contraction coupling, etc.) and pre-training session values of the perceived recovery scale.

LIMITATIONS

Certainly, our study has limitations that must be addressed. First, our results are specific to lower-body training in young resistance-trained males. Further research is needed to determine if other heads of the quadriceps, muscle groups, and exercises respond similarly, as well as how this might affect other populations, such as women or older adults. Second, while participants' previous set number varied from 6 to 48 weekly, our findings might be restricted to individuals performing a moderate volume (average of 14 weekly sets) before the study. For example, on average, the G60 group in the current study yielded a weekly set number similar to Scarpelli et al. (18) in which a 20% increase resulted in an average of ~24 weekly sets. Moreover, due to the participants' previous training volumes and the current study's design, the number of sets per training session varied considerably, ranging from 3 to 24 sets across participants. Therefore, the relationship between session volume allocation and its effects on muscular adaptations in trained cohorts remains an area of interest that warrants creative research designs and further investigation. Third, our study employed a short-term intervention and thus cannot be extrapolated to training over longer periods. Additionally, the strength gains of ~22 kg (~14%) observed within this short timeframe could reflect acclimatization to the tap-and-go seat used throughout the training program. Fourth, while we standardized protein supplementation and encouraged participants to consume adequate protein and calories throughout the study, we did not control or monitor nutritional intake, which may impair ROI-FFM, muscle thickness, and performance improvements. Fifth, when attempting to standardize supplementation in a population that consumes a variety of supplements, it should be noted that experience and responses to caffeine vary significantly. This variability could potentially lead to different effects in naïve versus accustomed participants. However, the estimated values and effect sizes observed were similar to those in studies that used higher RT volumes. Sixth, while ultrasound muscle thickness strongly correlates with MRI cross-sectional area assessments Franchi et al. (22), it is important to point out that it measures only one dimension of the muscle growth, rather than two or three dimensions as CSA (i.e. thickness and width) and volume (i.e. thickness, width and length) measurements, respectively. Finally, data collection occurred during the pandemic, leading to a suspension and resumption of the project one year later. This circumstance, combined with a very specialized population, resulted in a substantial dropout rate, increasing data variability. Additionally, the power analysis indicated that our study was underpowered for our primary outcome. The observed effects are too small in the trained cohorts, posing logistical challenges to our ability to detect statistically significant interactions. Therefore, future studies should consider alternative experimental designs and statistical models when studying trained populations with limited sample sizes.

Conclusions

Our research suggests that maintaining a moderate (~12 weekly sets) RT volume has no adverse effect on medial quadriceps hypertrophy, showing muscle growth comparable to increased volume schemes provided a high level of effort is sustained (i.e., 0-2 RIR) in resistance trained males. Yet, maintaining a moderate volume appears to produce a greater overall 1RM back squat performance compared to increasing weekly set volume by 30% or 60%. Additionally, maintaining or increasing the weekly set number by 60% showed no effect on strength-endurance. Conversely, a 30% increase appears to increase the number of repetitions performed to failure at 70% of 1RM in the back squat exercise.

DATA AVAILABILITY

Data will be made available upon request.

ACKNOWLEDGMENTS

The authors express their gratitude to the volunteers for their active participation throughout the experiment's duration, as well as to all the student research assistants who contributed to data collection. Additionally, we extend our thanks to Legion Athletics for generously providing both the pre-workout and post-workout protein supplementation used in the study.

DISCLOSURES

BJS serves on the scientific advisory board of Tonal Corporation, a manufacturer of fitness equipment. CB is the owner of Competitive Breed LLC and SchoolOfGainz.com. All the other authors do not have professional relationships with companies or manufacturers to disclose.

AUTHORS CONTRIBUTIONS

E.O.S.; C.U.; B.J.S.; T.W.; and C.B. conceived and designed research; A.B.; T.W.; A.M.; S.Z.; B.T. and J.B. performed experiments; T.W. and C.U. analyzed data; E.O.S, C.U., and A.B interpreted results of experiments; T.W. and E.O.S prepared figures; E.O.S. and A.B. drafted the manuscript; T.W.; B.T; C.B.; J.C.A.; J.W.; B.J.S.; C.U. and E.O.S edited and revised manuscript; A.B.; T.W.; A.M.; S.Z.; B.T.; J.B.; J.C.A.;J.W.; B.J.S.; C.U. and E.O.S. approved final version of manuscript.

REFERENCES

1. **Ralston GW, Kilgore L, Wyatt FB, and Baker JS**. The Effect of Weekly Set Volume on Strength Gain: A Meta-Analysis. *Sports Med* 47: 2585-2601, 2017. DOI: 10.1007/s40279-017-0762-7

2. **Schoenfeld BJ, Contreras B, Krieger J, Grgic J, Delcastillo K, Belliard R, and Alto A**. Resistance Training Volume Enhances Muscle Hypertrophy but Not Strength in Trained Men. *Med Sci Sports Exerc* 51: 94-103, 2019. DOI: 10.1249/MSS.0000000000001764

3. **Baker JS, Davies B, Cooper SM, Wong DP, Buchan DS, and Kilgore L**. Strength and body composition changes in recreationally strength-trained individuals: comparison of one versus three sets resistance-training programmes. *Biomed Res Int* 2013: 615901, 2013. DOI: 10.1155/2013/615901

4. **Radaelli R, Botton CE, Wilhelm EN, Bottaro M, Lacerda F, Gaya A, Moraes K, Peruzzolo A, Brown LE, and Pinto RS**. Low- and high-volume strength training induces similar neuromuscular improvements in muscle quality in elderly women. *Exp Gerontol* 48: 710-716, 2013. DOI: 10.1016/j.exger.2013.04.003

5. **Radaelli R, Fleck SJ, Leite T, Leite RD, Pinto RS, Fernandes L, and Simao R**. Dose-response of 1, 3, and 5 sets of resistance exercise on strength, local muscular endurance, and hypertrophy. *J Strength Cond Res* 29: 1349-1358, 2015. DOI: 10.1519/JSC.0000000000000758

6. **Hammarstrom D, Ofsteng S, Koll L, Hanestadhaugen M, Hollan I, Apro W, Whist JE, Blomstrand E, Ronnestad BR, and Ellefsen S**. Benefits of higher resistance-training volume are related to ribosome biogenesis. *J Physiol* 598: 543-565, 2020. DOI: 10.1113/JP278455

7. **Aube D, Wadhi T, Rauch J, Anand A, Barakat C, Pearson J, Bradshaw J, Zazzo S, Ugrinowitsch C, and De Souza EO**. Progressive Resistance Training Volume: Effects on Muscle Thickness, Mass, and Strength Adaptations in Resistance-Trained Individuals. *J Strength Cond Res* 2022. DOI: 10.1519/JSC.0000000000003524

8. **Ostrowski KW, GJ, Weatherby, R; Murphy, PW; Lyttle, AD.** The Effect of Weight Training Volume on Hormonal Output and Muscular Size and Function. *J Strength Cond Res* 11: 148-154, 1997.

9. **Marshall PW, McEwen M, and Robbins DW**. Strength and neuromuscular adaptation following one, four, and eight sets of high intensity resistance exercise in trained males. *Eur J Appl Physiol* 111: 3007-3016, 2011. DOI: 10.1007/s00421-011-1944-x

10. **Brigatto FA, Lima LEM, Germano MD, Aoki MS, Braz TV, and Lopes CR**. High Resistance-Training Volume Enhances Muscle Thickness in Resistance-Trained Men. *J Strength Cond Res* 36: 22-30, 2022. DOI: 10.1519/JSC.0000000000003413

11. **Enes A, De Souza EO, and Souza-Junior TP**. Effects of Different Weekly Set Progressions on Muscular Adaptations in Trained Males: Is there a Dose-Response Effect? *Med Sci Sports Exerc* 2023. DOI: 10.1249/MSS.0000000000003317

12. **Heaselgrave SR, Blacker J, Smeuninx B, McKendry J, and Breen L**. Dose-Response Relationship of Weekly Resistance-Training Volume and Frequency on Muscular Adaptations in Trained Men. *Int J Sports Physiol Perform* 14: 360-368, 2019. DOI: 10.1123/ijspp.2018-0427

13. **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* 2022.DOI: 10.1519/JSC.0000000000003558

14. **Tinsley GM, Morales E, Forsse JS, and Grandjean PW**. Impact of Acute Dietary Manipulations on DXA and BIA Body Composition Estimates. *Med Sci Sports Exerc* 49: 823-832, 2017.

15. **Martinez-Cava A, Moran-Navarro R, Sanchez-Medina L, Gonzalez-Badillo JJ, and Pallares JG**. Velocity- and power-load relationships in the half, parallel and full back squat. *J Sports Sci* 37: 1088-1096, 2019. DOI: 10.1249/MSS.0000000000001148

16. **Tolusso DV, Dobbs WC, MacDonald HV, Winchester LJ, Laurent CM, Fedewa MV, and Esco MR**. The Validity of Perceived Recovery Status as a Marker of Daily Recovery Following a High-Volume Back-Squat Protocol. *Int J Sports Physiol Perform* 17: 886-892, 2022. DOI: 10.1123/ijspp.2021-0360

17. **Borg G**. Psychophysical scaling with applications in physical work and the perception of exertion. *Scand J Work Environ Health* 16 Suppl 1: 55-58, 1990. DOI: 10.5271/sjweh.1815

18. **Helms ER, Cronin J, Storey A, and Zourdos MC**. Application of the Repetitions in Reserve-Based Rating of Perceived Exertion Scale for Resistance Training. *Strength Cond J* 38: 42-49, 2016. DOI: 10.1519/SSC.0000000000000218

19. **McCoy CE**. Understanding the Intention-to-treat Principle in Randomized Controlled Trials. *West J Emerg Med* 18: 1075-1078, 2017. DOI: 10.5811/westjem.2017.8.35985

20. **Lakens D**. Calculating and reporting effect sizes to facilitate cumulative science: a practical primer for t-tests and ANOVAs. *Front Psychol* 4: 863, 2013. DOI: 10.3389/fpsyg.2013.00863

21. **Hardy CJ, & Rejeski, W. J.** Not what, but how one feels: The measurement of affect during exercise. *Journal of Sport & Exercise Psychology* 11: 304-317, 1989. DOI: https://doi.org/10.1123/jsep.11.3.304

22. **Franchi MV, Longo S, Mallinson J, Quinlan JI, Taylor T, Greenhaff PL, and Narici MV**. Muscle thickness correlates to muscle cross-sectional area in the assessment of strength training-induced hypertrophy. *Scand J Med Sci Sports* 28: 846-853, 2018. DOI: 10.1111/sms.12961

Figure legends

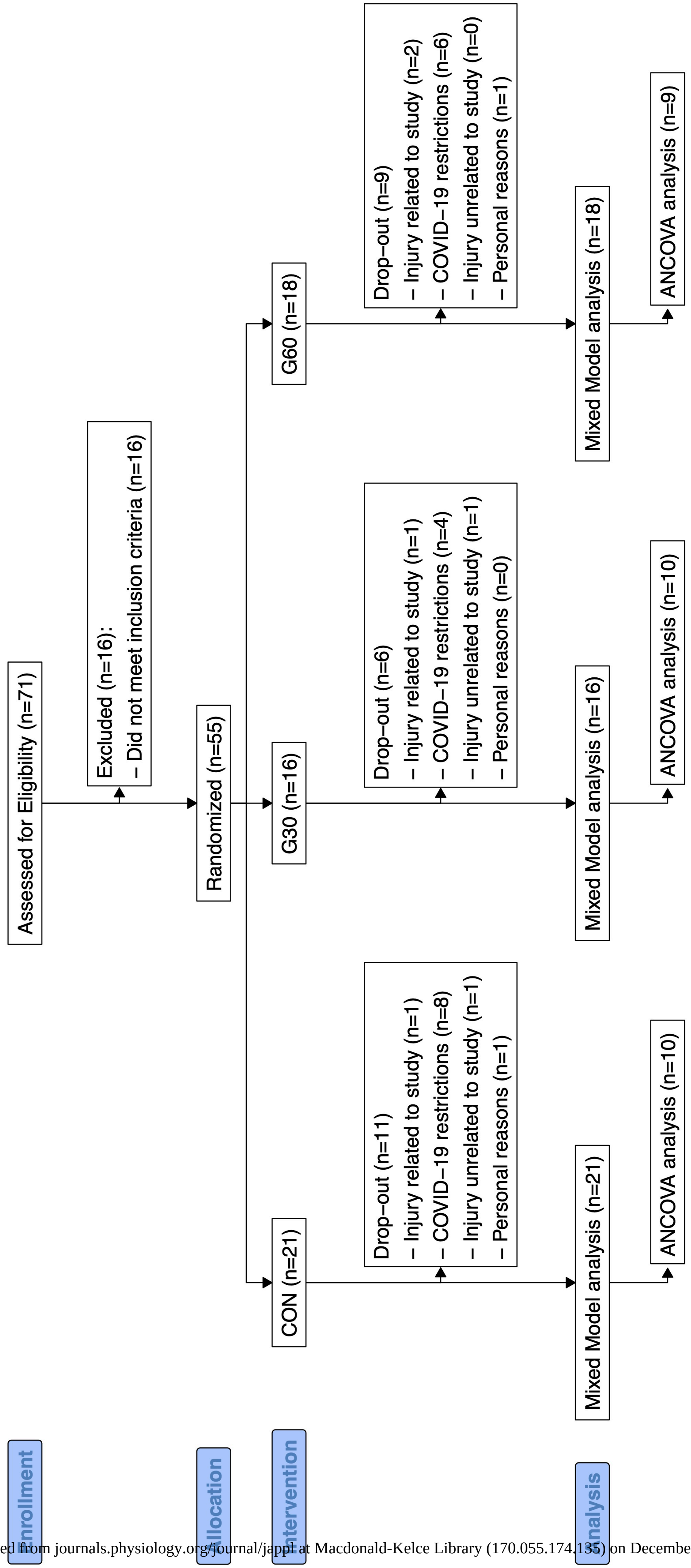
Figure 1. CONSORT flow diagram

Figure 2. Overview of the region-of-interest fat-free mass (ROI-FFM) and anterior thigh muscle thickness: RF- Rectus femoris, VI- Vastus intermedius. A- ROI-FFM, B- proximal muscle thickness, and (C) distal muscle thickness assessments.

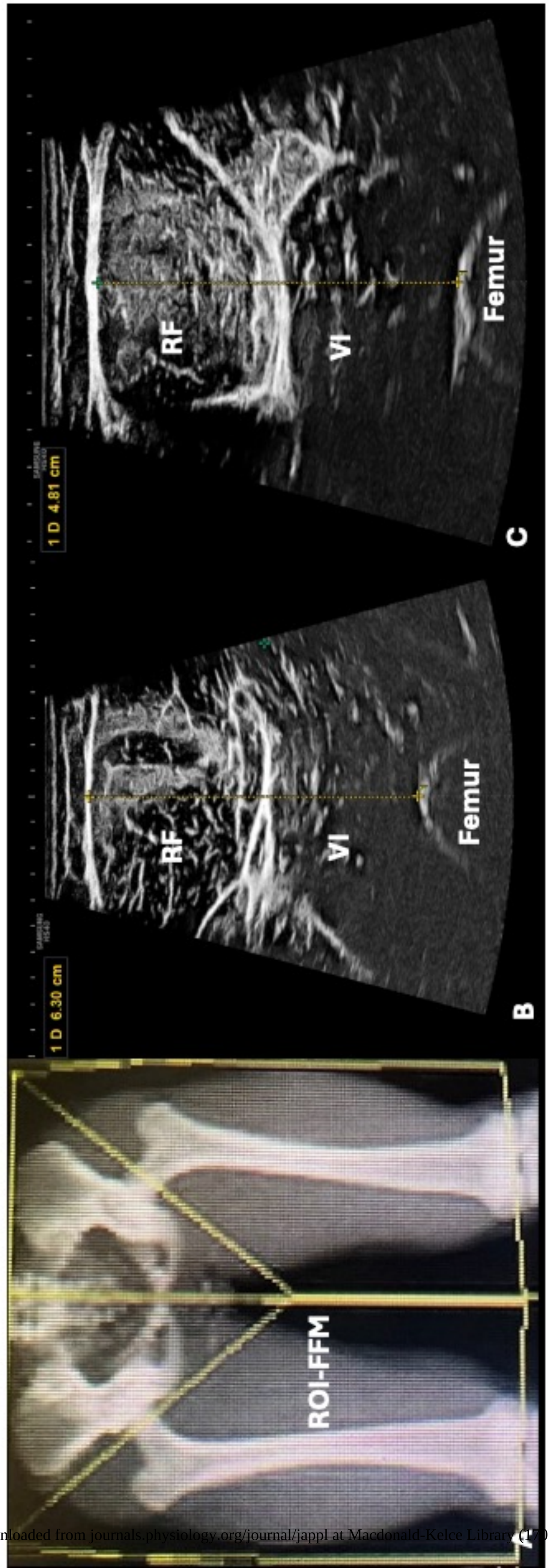
Figure 3. The average weekly volume load for the intervention exercises throughout 16 sessions across experimental groups. Control group (CON – blue line), 30% increase in the number of sets (G30 – orange line), and 60% increase in the number of sets (G60 – green line).

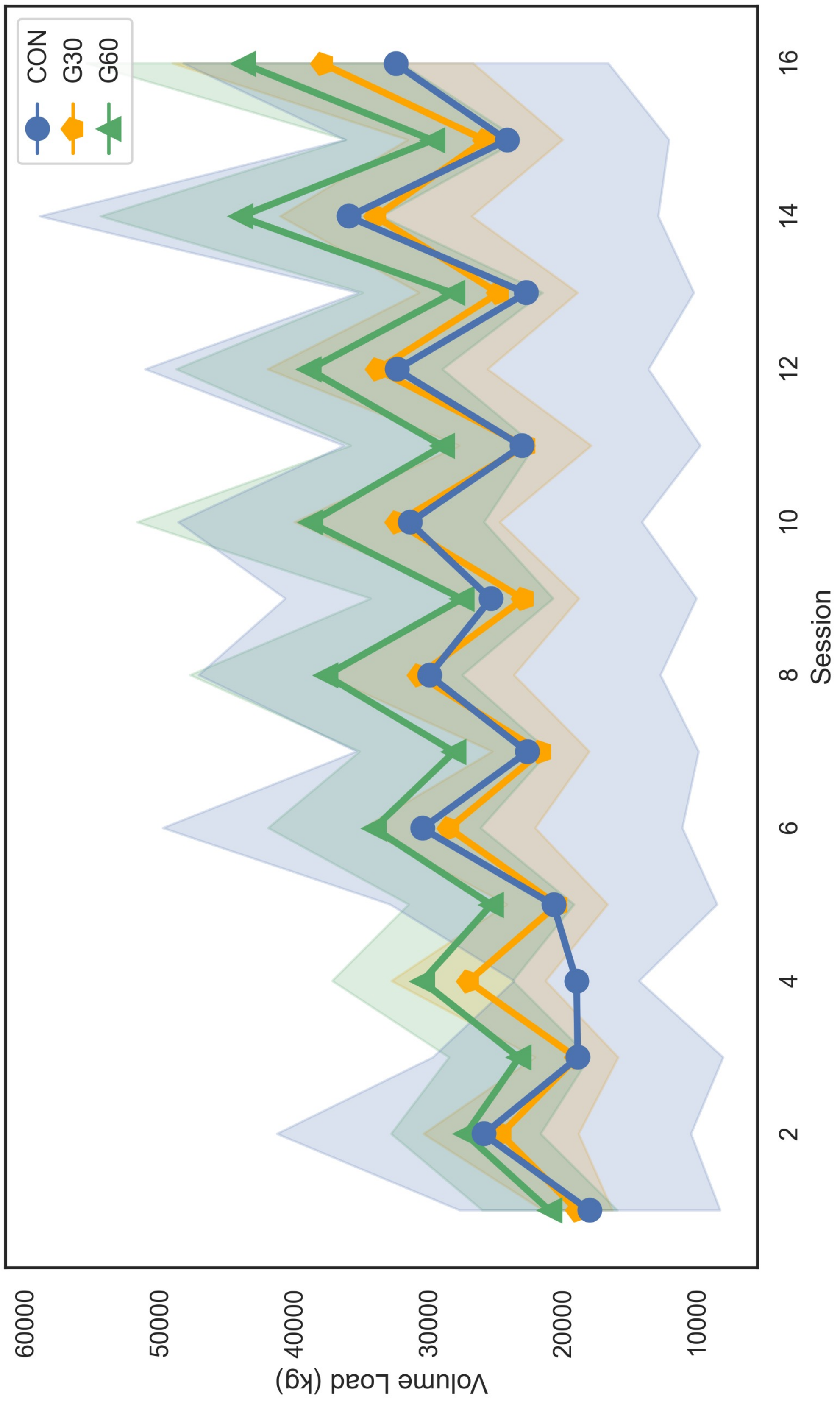
Figure 4. Delta-change in fat-free mass and muscle thickness per participant. Scatterplot of individual changes in muscle thickness plotted against the change in region-of-interest fat-free mass. The size of the marker indicates the subject's volume load. Density plots for the responses are plotted on respective axis spines.

Figure 5. Delta change in repetition to failure and 1RM per participant. Scatterplot of individual changes in one-repetition-maximum plotted against the change in repetitions-to-failure. The size of the marker indicates the subject's volume load. Density plots for the responses are plotted on respective axis spines.

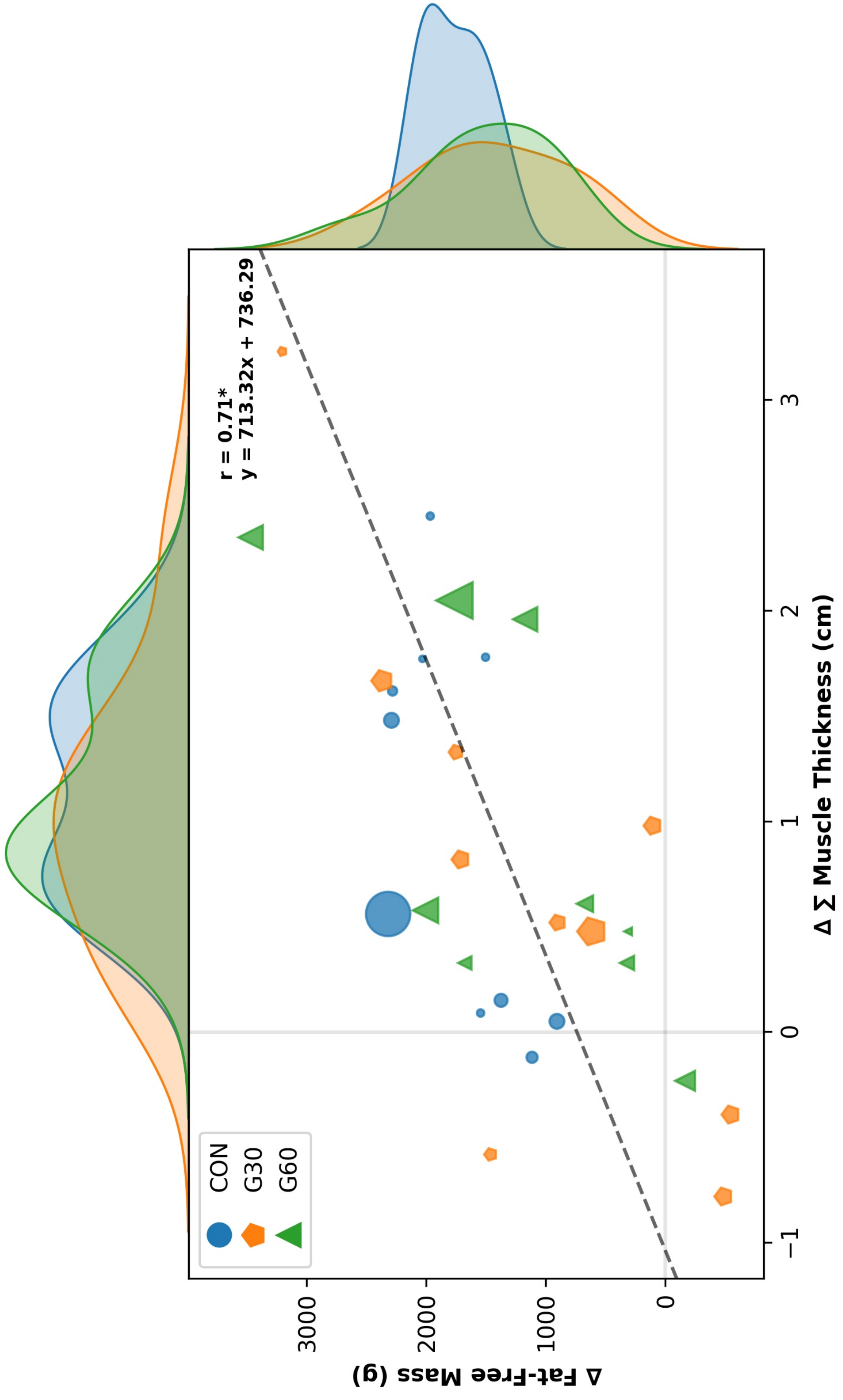


nrollment
Assessed for Eligibility (n=71)
Excluded (n=16):
– Did not meet inclusion criteria (n=16)
llocation
Randomized (n=55)
ntervention
CON (n=21)
G30 (n=16)
G60 (n=18)
Drop–out (n=11)
– Injury related to study (n=1)
– COVID–19 restrictions (n=8)
– Injury unrelated to study (n=1)
– Personal reasons (n=1)
Drop–out (n=6)
– Injury related to study (n=1)
– COVID–19 restrictions (n=4)
– Injury unrelated to study (n=1)
– Personal reasons (n=0)
Drop–out (n=9)
– Injury related to study (n=2)
– COVID–19 restrictions (n=6)
– Injury unrelated to study (n=0)
– Personal reasons (n=1)
nalysis
Mixed Model analysis (n=21)
Mixed Model analysis (n=16)
Mixed Model analysis (n=18)
ANCOVA analysis (n=10)
ANCOVA analysis (n=10)
ANCOVA analysis (n=9)


A
ROI-FFM
B
1 D 6.30 cm
RF
VI
Femur
C
1 D 4.81 cm
RF
VI
Femur



CON
G30
G60
Volume Load (kg)
60000
50000
40000
30000
20000
10000
Session
2
4
6
8
10
12
14
16


CON
G30
G60
r = 0.71*
y = 713.32x + 736.29
Δ Σ Muscle Thickness (cm)
−1
0
1
2
3
Δ Fat-Free Mass (g)
0
1000
2000
3000

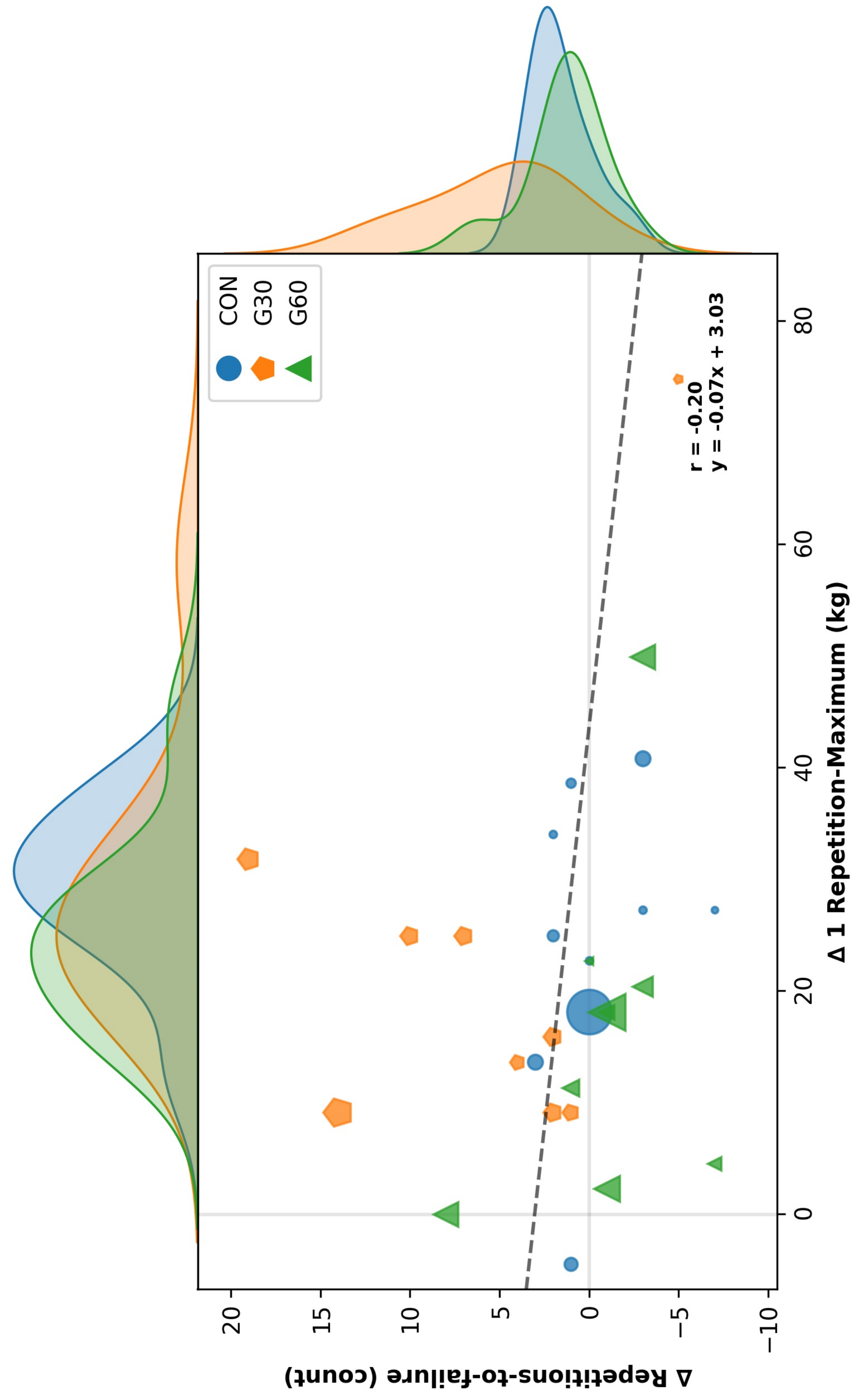

CON
G30
G60
r = -0.20
y = -0.07x + 3.03
Δ 1 Repetition-Maximum (kg)
0
20
40
60
80
Δ Repetitions-to-failure (count)
20
15
10
5
0
−5
−10

Table 1. Characteristics of all subjects who completed baseline testing.

Variable	CON	G30	G60
N	21	16	18
Body mass (kg)	79.03±10.84	77.31±8.65	77.44±10.06
Age (yrs.)	21.01±1.66	21.91±3.83	22.84±4.61
BF%	13.07±5.37	13.79±3.47	14.14±5.02
PSN (sets·week^{-1})	12.05±9.22	14.47±4.87	16.11±8.27
SPS (sets·week^{-1})	12.1±8.98	18.80±6.22	25.22±12.43
SET_{DIFF} (sets·week^{-1})	0.05±0.38	4.33±1.45	9.11±4.28
Squat 1RM:BM (a.u)	2.05±0.30	1.92±0.28	1.84±0.22

BF%- body fat percentage; PSN- Previous set number performed per week for the lower body; SPS- weekly set number performed during the study; SET_{DIFF}- number of sets added to PSN for intervention protocol; 1RM:BM- squat one-repetition maximum to body mass ratio.

Table 2. Region-of-interest fat-free mass and muscle thickness assessments (mean ± SD)

Variable	Group	Pre(n)	Pre	Post(n)	Post*	95% CI_{diff}	ES
ROI-FFM (kg)	CON	21	26.40±2.43	10	27.97±2.78	1.44 to 1.99	0.62
	G30	15	25.82±2.92	10	26.29±2.76	0.78 to 1.33	0.17
	G60	18	25.65±2.68	9	27.20±2.72	0.97 to 1.55	0.58
PMT (cm)	CON	21	6.22±0.78	10	6.85±0.77	0.42 to 0.71	0.81
	G30	16	6.23±0.61	10	6.62±0.70	0.24 to 0.53	0.60
	G60	18	6.28±0.76	9	6.76±0.87	0.34 to 0.65	0.59
DMT (cm)	CON	21	4.85±0.73	10	5.30±0.98	0.27 to 0.58	0.54
	G30	16	4.81±0.67	10	5.18±0.45	0.19 to 0.50	0.62
	G60	18	4.88±0.78	9	5.10±0.83	0.20 to 0.53	0.27
ΣMT (cm)	CON	21	11.08±1.49	10	12.15±1.59	0.73 to 1.28	0.70
	G30	16	11.05±1.25	10	11.81±1.09	0.46 to 1.01	0.64
	G60	18	11.17±1.49	9	11.87±1.67	0.58 to 1.16	0.45

ROI-FFM – Region-of-interest fat-free mass; PMT – Proximal muscle thickness; DMT- Distal muscle thickness; ΣMT – sum of proximal and distal muscle thickness assessments.

[*] Main time effect, post-test values greater than pre-test ones ($p \leq 0.001$)

Table 3. Maximum strength and strength-endurance test assessments (mean ± SD)

Variable	Group	Pre(n)	Pre	Post(n)	Post*	95%-CI	ES
1RM (kg)	CON	21	161.90±33.16	10	193.70±44.52	21.10 to 30.00	0.86
	G30	16	147.70±23.76	10	165.55±25.81	17.98 to 27.39	0.73
	G60	18	141.87±22.10	9	156.98±18.49	11.47 to 20.85	0.72
RTF (reps)	CON	21	17.38±5.04	10	18.20±4.89	-1.19 to 1.46	0.16
	G30	16	18.12±6.11	10	22.88±5.96	4.04 to 6.87[*,!]	0.79
	G60	18	18.61±5.50	9	18.66±4.69	-1.81 to 0.99	0.01

1RM- One-repetition maximum; RTF- Repetitions to failure. [*] Significantly different from pre-training values ($p<0.05$); [!] Significantly different from the CON and G60 groups at the post-training assessment ($p<0.05$).

TRAINING VOLUME INCREASES OR MAINTENANCE BASED ON PREVIOUS VOLUME: THE EFFECTS ON MUSCULAR ADAPTATIONS IN TRAINED MALES

Methods

53 trained individuals were screened and tested, while only 29 completed the study.

Assessments before and post-intervention:

● 1RM testing
● Repetitions to Failure (RTF)

● Region-of interest fat-free mass

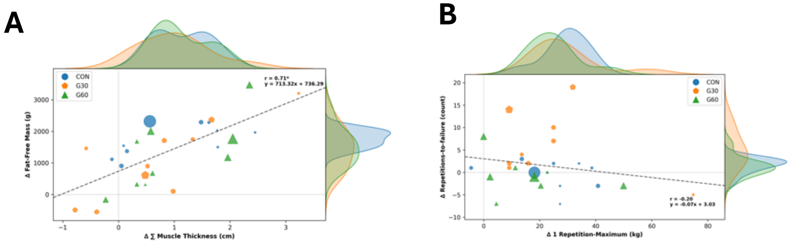
● Muscle thickness

Experimental groups:

- ● CON- Volume maintenance
- ● G30- 30% increase in the previous weekly set
- ● G60- 60% increase in the previous weekly set
- ➡ Duration: 8-week training period
- ➡ Exercises: squat, leg press and knee extension
- ➡ Twice-a-week

Results

- ➡ ROI-FFM and MT demonstrated a significant main time effect;
- ➡ While all experimental groups increased 1RM, CON demonstrated a greater overall 1RM;
- ➡ Only the G30 group increased RTF at the post-test.



Individual responses for each experimental condition (CON, G30, G60) are visualized using a bubble scatter plot. The plot highlights the relationship between changes in ROI-FFM and ΣMT (**A**) and 1RM and RTF **(B)** while bubble size represents the total volume load. The density curves overlaying the scatter plot represent the distribution of changes within each group, providing additional information about the variability across conditions.

Conclusions

Our findings suggest that trained males can experience significant muscle growth and strength adaptations while maintaining their previous weekly set number above a certain weekly set volume threshold.