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Title Page

Effect of Resistance Training Frequency on Neuromuscular Performance and Muscle Morphology after Eight Weeks in Trained Men

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Brief running head: Resistance Training Frequency

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Abstract

The purpose of this study was to investigate the chronic effects of training muscle groups 1 day per week vs. 2 days per week on neuromuscular performance and morphological adaptations in trained men with the number of sets per muscle group equated between conditions. Participants were randomly assigned in 2 experimental groups: 1 session·wk^{-1} per muscle group (G1, n = 10), where every muscle group was trained once a week with 16 sets or 2 sessions·wk^{-1} per muscle group (G2, n = 10), where every muscle group was trained twice a week with 8 sets per session. All other variables were held constant over the 8-week study period. No significant difference between conditions for maximal strength in the back squat or bench press, muscle thickness in the elbow extensors, elbow flexors, or quadriceps femoris, and muscle endurance in the back squat and bench press performed at 60% 1RM was detected. Effect size favored G2 for some outcome measurements, suggesting the potential of a slight benefit to the higher training frequency. In conclusion, both G1 and G2 significantly enhance neuromuscular adaptations, with a similar change noted between experimental conditions.

Keywords: Split body routine; resistance training frequency; muscle hypertrophy; maximal strength.

INTRODUCTION

Resistance training (RT) is a well-established modality to generate an improvement in strength, power, muscular endurance and muscle hypertrophy (29). These neuromuscular adaptations are maximized by manipulating RT variables, such as volume, intensity, frequency of training, rest interval, choice and order of exercises, velocity of execution, muscular actions, and range of motion (29). On a general level, RT frequency refers to the number of sessions performed during a specific period, usually described on a weekly basis. Frequency can be further characterized by the number of sessions per week (sessions$\cdot$wk^{-1}) in which the same muscle group is trained (36).

As a general rule, those involved in RT programs with hypertrophy as a primary goal train each muscle group relatively infrequently but perform a high volume of work per muscle group in a session (36). Indeed, a recent meta-analysis conducted by Schoenfeld et al. (35) showed that muscular development is greater when performing at least 10 weekly sets per muscle group in comparison to 9 or less sets (35). Accordingly, split routines (where multiple exercises are performed for a specific muscle group in a training bout) may enhance hypertrophy by allowing for a greater weekly RT volume (number of sets per muscle group) to be performed (17).

A survey of 127 competitive male bodybuilders found that a majority of participants performed ~4 sets per exercise of ~4 different exercises per muscle group, thus totaling ~16 sets targeting a specific muscle group within a single training session per week (13). Furthermore, the training frequency ranged between 5 to 6 sessions a week among bodybuilders' surveyed. The study found that 69% of bodybuilders train each muscle group only once per week, while the remaining 31% reported to train each muscle group twice weekly (13).

The American College of Sports Medicine (ACSM) recommends that advanced lifters employ split routines training 1 to 3 muscle groups per workout to maximize muscular adaptations (29). In addition, the ACSM recommends 4 to 6 split-body training sessions·wk^{-1} whereby muscle groups are trained once or twice weekly (29). Literature reviews and systematic reviews with meta-analyses are somewhat equivocal in the topic (28,30,34,44). Rhea et al. (30) concluded that trained individuals demonstrated a maximum strength gain when they performed 2 sessions·wk^{-1} for each muscle group. With respect to muscle hypertrophy, a recent meta-analysis by Schoenfeld et al. (34) concluded that 2 sessions·wk^{-1} result in a superior hypertrophy development compared to 1 session·wk^{-1}.

However, there have been a paucity of randomized trials conducted in resistance trained subjects comparing the effects of different RT frequencies on muscle hypertrophy. Of the 7 studies meeting inclusion criteria in the meta-analysis of Schoenfeld et al. (34), 5 were specific to untrained subjects including young (11) and middle-aged men (5); and middle-aged (3,5) and elderly women (6,22); only 2 studies were carried out using resistance trained subjects (24,36). Moreover, the study with the highest statistical weight in the meta-analysis was composed of a sample of 53 untrained elderly women (6). Although the meta-analysis conducted by Schoenfeld et al. (34) provides relevant knowledge about the effects of different RT frequencies on measurement of muscle hypertrophy, it is difficult to draw conclusions to a dose-response relationship due to heterogeneity of subjects and training frequencies across the studies.

The vast majority of studies assessing the effects of training frequency on the change in muscle size have been limited to indirect measures of total lean mass (e.g., whole body dual-energy X-ray absorptiometry, bioelectrical impedance analysis, skinfold technique and circumference measurements) (3,5,6,22,24,25,31). To the authors' knowledge, only 1 published study investigated the effects of different RT frequencies on morphological adaptations in trained subjects using validated diagnostic imaging methods (e.g., ultrasound) to assess the change in muscle size (36).

Moreover, to the authors' knowledge, no published study has compared the volume equated effects of 1 vs. 2 sessions per muscle group per week on muscular adaptations in trained men, which are the 2 most often employed frequencies by bodybuilders (13). Therefore, the purpose of this study was to investigate the chronic effects of training muscle groups 1 day per week vs. 2 days per week (where the number of sets per muscle group was equated: 16 weekly sets per muscle group) on neuromuscular performance and morphological adaptations in trained men. The authors employed high RT volumes typically associated with bodybuilding-style training and the use of validated diagnostic imaging methods to directly assess the change in MT. Based on meta-analytic data, the authors hypothesized that training muscle groups 2 sessions with 8 sets per muscle per week would induce a significantly greater gain in muscle size and strength compared to 1 day a week with 16 sets.

METHODS

Experimental Approach to the Problem

The present study followed a randomized, longitudinal design (38). Participants were pair-matched according to baseline strength and then randomly assigned to 1 of 2 experimental groups: 1 session·wk^{-1} per muscle group (G1, n = 10), where every muscle group was trained once a week with 16 sets or 2 sessions·wk^{-1} per muscle group (G2, n = 10), where every muscle group was trained twice a week with 8 sets per session.

All other RT variables (e.g., exercise performed, exercise order, range of repetitions, rest interval between sets and exercises, etc.) were held constant. The experimental period lasted 11 weeks: 1st week – familiarization period; 2nd week – pre-intervention period (baseline); 3rd-10th week – training intervention period; 11th week – post-intervention period. The training intervention period lasted 8 weeks and the total load lifted (TLL) and the internal training load (ITL) was calculated for every RT session in order to compare the accumulated external training load (assessed by TLL) and the ITL between experimental groups across the intervention period.

Testing was carried out pre- and post-intervention periods for maximal voluntary muscle strength (1RM test for bench press and parallel back squat exercises), muscular endurance (maximum repetitions at 60% of 1RM test for bench press and parallel back squat exercises), and muscle thickness (MT) of the triceps brachii, elbow flexors (biceps brachii and brachialis), vastus lateralis and anterior quadriceps (rectus femoris and vastus intermedius). In the 1st week, volunteers attended 2 familiarization sessions in the laboratory and they reported to have refrained from performing any exercise other than activities of daily living for at least 48 hours prior to first familiarization session. In the first session, volunteers were familiarized to 1RM and 60%1RM tests. The following day (24 h after), volunteers were familiarized to standard procedures adopted in all RT exercises; such as body position, cadence, range of motion, rest, etc. Additionally, subjects were trained and instructed to record their dietary intake.

Subjects

Twenty healthy young males (27.1 ± 5.5 years; 1.74 ± 0.05 m; total body mass = 77.9 ± 6.7 kg; RT experience = 4.1 ± 1.8 years; RT frequency = 4.5 ± 0.7 session·wk^{-1}) volunteered to participate in this study. The sample size was justified by a priori power analysis based on a pilot study where the vastus lateralis MT was assessed as the outcome measure with a target effect size difference of 0.75, an alpha level of 0.05, and a power ($1-\beta$) of 0.80 (9). Subjects were well trained; all had been performing RT a minimum of 3 day-week for at least 1 year in the University RT facility. The range of RT experience was 2-8 years. All subjects regularly performed (minimum frequency of once a week) all exercises utilized in the training intervention and in the strength tests for at least 1 year before entering the study. Moreover, subjects were free from any existing musculoskeletal disorders; history of injury with residual symptoms (pain, "giving-away" sensations) in the trunk, upper and lower limbs within the last year and stated they had not taken anabolic steroids or any other illegal agents known to increase muscle size currently and for the previous year. Thus, participation in the study required that the subjects answered negatively to all questions on the Physical Activity Readiness Questionnaire (PAR-Q) and had a minimum 1RM parallel back squat of 1.25x total body mass and a 1RM bench press of at least equal to total body mass (18). This study was approved by the university research ethics committee (protocol 1.792.429); all subjects read and signed an informed consent document.

*** Table 1 about here ***

Resistance Training Program

The RT protocol consisted of 9 exercises targeting each of the major muscle groups. Subjects were instructed to refrain from performing any additional resistance-type training for the duration of the study. Over the course of each training week, all subjects performed the same exercises and repetition volume throughout the duration of the study, that is, consisting of a linear mesocycle with a duration of 8 weeks (29).

The specific protocols for G1 and G2 are outlined in Table 2. The exercises were chosen based on their common inclusion in bodybuilding and strength-type RT programs (2). The weekly training protocol for both groups consisted of 2 split routines targeting specific muscle groups: split routine A (A_{rout}) – bench press, dumbbell flat fly, cable triceps press-down, parallel back squat and leg extension; and split routine B (B_{rout}) – lat pulldown machine, cable straight-arm lat pulldown, dumbbell standing biceps curl and machine seated leg curl.

The G1 weekly training consisted of 2 training sessions (A_{rout} + B_{rout}) whereas G2 weekly training consisted of 4 training sessions (A_{rout} + B_{rout} + A_{rout} + B_{rout}). Thus, both experimental groups performed 16 weekly sets for the major muscle groups, comprising 8 sets of multi-joint exercises and 8 sets of single-joint exercises, except for hamstrings muscles that were stimulated with 16 weekly sets of single-joint exercise (machine seated leg curl). Each set involved 8-12 maximum repetitions (RM) with 60 seconds of rest afforded between sets and 120 seconds between exercises. All sets were carried out to the point of momentary concentric muscular failure, operationally defined as the inability to perform another concentric repetition while maintaining proper form. Cadence of repetitions was carried out in a controlled fashion, with concentric and eccentric actions of approximately 1.5 s, for a total repetition duration of approximately 3 s. The external load was adjusted for each exercise as needed on successive sets to ensure that subjects achieve failure in the target repetition range. All RT sessions were preceded by a specific warm-up consisting of two sets of 10 repetitions with 50% of the external overload used in the first set of all exercises of the session. All subjects reported a rating of perception exertion (RPE) based on the RPE/RIR scale (14) of 9.5-10 for all sets and exercises across RT sessions.

All routines were directly supervised by research assistants to ensure proper performance of the respective routines. Before the training intervention period, all subjects underwent 10RM testing (according to guidelines established by the National Strength and Conditioning Association, NSCA (2)) to determine individual initial training loads for each exercise. Attempts were made to progressively increase the external loads lifted each week while maintaining the target repetition range. No injuries were reported and the adherence to the program was 100% for both groups.

*** Table 2 about here ***

Estimate of Food Intake

To avoid potential dietary confounding of results, subjects were advised to maintain their customary nutritional regimen and to avoid taking any supplements during the study period. Dietary nutrient intake was assessed by 24-hour food recalls on 2 nonconsecutive weekdays and 1 day of the weekend. The subjects were instructed to record in detail: time of consumption, types and quantity of food preparations consumed during 24 hours. The quantity of food was recorded in cooking units (spoons, cups and glass) and transformed in to grams. The estimation of energy intake (macronutrients) was analyzed by NutWin software (UNIFESP, Sao Paulo, Brazil). The estimated food intake was assessed during weeks 1 and 8 of the training intervention period.

*** Table 3 about here ***

Measurements

Muscle Strength. Upper- and lower-body maximum strength was assessed by 1RM testing in the bench press ($1RM_{BENCH}$) and parallel back squat ($1RM_{SQUAT}$) exercises. Subjects reported to the laboratory having refrained from any exercise other than activities of daily living for at least 48 hours before baseline testing and at least 48 hours before testing at the conclusion of the study. Maximum strength testing was consistent with recognized guidelines as established by the NSCA (2). Prior to testing, subjects performed a general warm-up consisting of 5 minutes cycling (Schwinne, AC Sport) at 60-70 rpm and 50w. Next, a specific warm-up set of the given exercise of 5 repetitions was performed at ~50% 1RM followed by 1 to 2 sets of 2–3 repetitions at a load corresponding to ~60–80% 1RM. Subjects then performed sets of 1 repetition of increasing weight for 1RM determination. The external load was adjusted by ~5-10% in subsequent attempts until the subject was unable to complete 1 maximal muscle action. The 1RM was considered the highest external load lifted. A 3- to 5-minute rest was afforded between each successive attempt. All 1RM determinations were made within 5 attempts.

Successful $1RM_{BENCH}$ was achieved if the subject displayed a 5-point body contact position (head, upper back, and buttocks firmly on the bench with both feet flat on the floor), lowered the bar to touch his chest, and executed full elbow extension. The grip width was standardized at 200% of biacromial width (27). In the $1RM_{SQUAT}$, subjects were required to squat down so that the top of the thigh was parallel to the ground (~90 degrees of knee joint flexion) for the attempt to be considered successful as determined by a research assistant who was positioned laterally to the subject. The barbell was positioned on the shoulders (high bar position) and the subjects' feet were always positioned at hip width (8).

A $1RM_{BENCH}$ testing was conducted before $1RM_{SQUAT}$ with a 20-minute rest period separating tests. Strength testing was carried out using free weights. Recording of feet and hands placement were made during familiarization strength testing and then used for pre- and post-intervention performance tests as well as at all training sessions.

All testing sessions were supervised by the research team to achieve a consensus for success on each attempt. The test-retest intraclass correlation coefficient (ICC), coefficient of variation (CV) and the standard error of the measurement (SEM) from our lab for $1RM_{BENCH}$ are 0.989, 0.8% and 2.05 kg, respectively. The ICC, CV and SEM for $1RM_{SQUAT}$ are 0.990, 0,7% and 1.95 kg, respectively.

Muscle Endurance (ME). For assessments of ME, participants performed as many repetitions as possible to muscular failure with proper form at 60% of 1RM load (4) on both the bench press ($60\%1RM_{BENCH}$) and parallel back squat ($60\%1RM_{SQUAT}$). The ME testing' cadence was standardized at 40bpm (Metronome Beats, Stonekick). ME was measured 30-minute after 1RM testing for each exercise, with 60% of the 1RM load obtained on each specific testing day. A $60\%1RM_{BENCH}$ testing was conducted before $60\%1RM_{SQUAT}$ with a 30-minute rest period separating tests. The test-retest ICC, CV and SEM from our lab for $60\%1RM_{BENCH}$ are 0.943, 2.3% and 0.83 repetitions, respectively. The ICC, CV and SEM for $60\%1RM_{SQUAT}$ are 0.910, 3.3% and 1,13 repetitions, respectively.

Muscle Thickness (MT). Ultrasound imaging was used to obtain measurements of MT. A trained technician performed all testing using an A-mode ultrasound imaging unit (Bodymetrix Pro System; Intelametrix Inc., Livermore, CA, USA). Following a generous application of a water-soluble transmission gel (Mercur S.A. – Body Care, Santa Cruz do Sul, RS, Brazil) to the measured site, a 2.5-MHz linear probe was placed perpendicular to the tissue interface without depressing the skin. Equipment settings were optimized for image quality according to the manufacturer's user manual and held constant among testing sessions. When the quality of the image was deemed to be satisfactory, the image was saved to the hard drive and MT dimensions were obtained by measuring the distance from the subcutaneous adipose tissue–muscle interface to the muscle-bone interface per methods used by Abe et al. (1). Measurements were taken on the right side of the body at 4 sites: triceps brachii (MT_{TB}), elbow flexors (MT_{EF}), vastus lateralis (MT_{VL}) and anterior quadriceps (MT_{AQ}). Upper arm measurements were conducted while participants were standing. Following, participants laid supine on an examination table for measurements of the thigh muscles.

For the anterior and posterior upper arm, measurements were taken 60% distal between the lateral epicondyle of the humerus and the acromion process of the scapula; for the thigh muscles, measurements were taken 50% of the distance between the lateral condyle of the femur and greater trochanter. For each measurement, the examined limb was secured to minimize unwanted movement. To maintain consistency between pre- and post-intervention testing, each site was marked with henna ink (reinforced every week). In an effort to help ensure that swelling in the muscles from training did not obscure results, images were obtained 48-72 hours before commencement of the study and after the final training session. This is consistent with research showing that an acute increase in muscle thickness returns to baseline within 48 hours following a RT session (26).

To further ensure accuracy of measurements, at least 3 images were obtained for each site. If measurements were within 1mm of one another the figures were averaged to obtain a final value. If measurements were more than 1mm of one another, a fourth image was obtained and the closest 3 measurements were then averaged. The test-retest ICC from our lab for MT_{TB}, $MT_{EF,}$ MT_{VL} and MT_{AQ} are 0.998, 0.996, 0.999 and 0.995, respectively. The CV for these measures are 0.6, 0.4, 0.6 e 0.7%, respectively. The SEM for these measures are 0.42, 0.29, 0.41 and 0.40 mm, respectively.

Total Load Lifted (TLL). TLL (sets x repetitions x external load [kgf]) (37) was calculated from training logs filled out by research assistants for every RT session. The weekly TLL (TLL_{WEEK}) was calculated as the values corresponding to the sum of the loads calculated for the RT sessions (G1 = 2 sessions·wk^{-1}; G2 = 4 sessions·wk^{-1}) in each week. The accumulated TLL (ATLL) was the sum of all RT weeks. Only repetitions performed through a full range of motion were included for analysis. The data were expressed in kilogram-force units (kgf).

Internal Training Load (ITL). Subjects reported their session-RPE (sRPE), according to the OMNI-Resistance Exercise Scale (OMNI-RES), validated to measure RPE in RT (32). Subjects were shown the scale 10 minutes after each session (7) and asked: "How intense was your session?" and were request to make certain that their RPE referred to the intensity of the whole session rather than to the most recent exercise intensity. The ITL for each session was calculated multiplying the total time under tension spent in the session in minutes by the sRPE (10). The weekly ITL (ITL_{WEEK}) were calculated as the values corresponding to the sum of the ITLs calculated for the RT sessions (G1 = 2 sessions·wk^{-1}; G2 = 4 sessions·wk^{-1}) in each week. Total ITL (ITL_{TOTAL}) was the sum of all RT weeks. The data were expressed in arbitrary units (a.u.).

Statistical analyses

The normality and homogeneity of the variances were verified using the Shapiro-Wilk and Levene tests, respectively. The mean, standard deviation (SD) and 90% confidence intervals (CI) were used after the data normality was assumed. To compare mean values of the descriptive variables, ATLL and ITL_{TOTAL} between-groups (G1 vs G2), a paired t-test was used. A 2x2 repeated measures ANOVA (interaction groups [G1 and G2] ×

time [pre- vs post-intervention]) was used to compare the food intake and dependent-variables ($1RM_{BENCH}$, $1RM_{SQUAT}$, $60\%1RM_{BENCH}$, $60\%1RM_{SQUAT}$, MT_{TB}, MT_{EF}, MT_{VL}, MT_{AQ}). A 2x8 repeated measures ANOVA (interaction groups [G1 and G2] × time [week 1 to 8]) was used to compare the variables TLL_{WEEK} and ITL_{WEEK}. Post hoc comparisons were performed with the Bonferroni test (with correction). Assumptions of sphericity were evaluated using Mauchly's test. Where sphericity was violated ($p < 0.05$), the Greenhouse–Geisser correction factor was applied. In addition, effect sizes were evaluated using a partial eta squared (η^2_p), with < 0.06, 0.06-0.14 and, >0.14 indicating a small, medium, and large effect, respectively (38). All analyses were conducted in SPSS-22.0 software (IBM Corp., Armonk, NY, USA). The adopted significance was 5%. Furthermore, the magnitudes of the difference were examined using the standardized difference based on Cohen's *d* units by means of effect sizes (*d*) (15). The *d* results were qualitatively interpreted using the following thresholds: <0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; 1.2-2.0, large; 2.0-4.0, very large and; >4.0, nearly perfect. The quantitative chances for higher or lower differences were qualitatively assessed as follows: <1%, almost certainly not; 1−5%, very unlikely; 5−25%, unlikely; 25−75%, Possibly; 75−95%, likely; 95−99%, very likely; >99%, almost certain. If the chances for having higher or lower values than the smallest worthwhile difference were >5%, the true difference was considered unclear. Data analysis was performed using a modified statistical Excel spreadsheet (15).

RESULTS

No significant difference was noted between groups in any baseline measurements (all $p > 0.05$ [Table 1]). There was no significant difference in any dietary intake variable either within- or between-groups over the course of the study (all $p > 0.05$ [Table 3]).

Maximal Strength

A significant main effect of time ($F_{1,18}$ = 83.232, p < 0.001, η^2_p = 0.822), but not group x time interaction ($F_{1,18}$ = 0.003, p = 0.954, η^2_p = 0.0002), was observed for $1RM_{BENCH}$. Both groups showed a significant increase from baseline to post-intervention by 7.8 kg (7.5%; p < 0.001; d = 0.57) and 7.8 kg (7.8%; p < 0.001; d = 0.57) for G1 and G2, respectively (Table 4). There was a significant main effect of time ($F_{1,18}$ = 83.839, p < 0.001, η^2_p = 0.823), but not group x time interaction ($F_{1,18}$ = 0.019, p = 0.891, η^2_p = 0.001) for $1RM_{SQUAT}$. Both groups showed a significant increase from baseline to post-intervention by 20.1 kg (13.5%; p < 0.001; d = 1.00) and 19.5kg (13.9%; p < 0.001; d = 0.91) for G1 and G2, respectively (Table 4).

Muscular Endurance

A significant main effect of time ($F_{1,18}$ = 14.564, p = 0.001, η^2_p = 0.447), but not group x time interaction ($F_{1,18}$ = 0.963, p = 0.339, η^2_p = 0.051), was observed for $60\%1RM_{BENCH}$. A significant increase was noted for the G2 (+2.2 rep: 14.3%; p = 0.003; d = 1.36) but not the G1 (+1.3 rep: 8.4%; p = 0.060; d = 0.51) from baseline to post-study (Table 4).

There was a significant main effect of time ($F_{1,18}$ = 31.342, p < 0.001, η^2_p = 0.635), but not group x time interaction ($F_{1,18}$ = 1.342, p = 0.262, η^2_p = 0.069) for $60\%1RM_{SQUAT}$. Both groups showed a significant increase from baseline to post-intervention by 2.3 rep (13.1%; p = 0.006; d = 1.10) and 3.5 rep (18.8%; p = < 0.001; d = 1.14) for G1 and G2, respectively (Table 4).

*** Table 4 about here ***

Muscle Thickness

A significant main effect of time ($F_{1,18}$ = 168.162, p < 0.001, η^2_p = 0.903), but not group x time interaction ($F_{1,18}$ = 0.112, p = 0.741, η^2_p = 0.006) was observed for MT_{TB}. A significant increase was noted for both G1 (+2.5mm: 5.5%; p < 0.001; d = 0.53) and G2 (+2.5 mm: 5.7%; p < 0.001; d = 0.53) from baseline to post-intervention (Table 5).

There was a significant main effect of time ($F_{1,18}$ = 147.486, p < 0.001, η^2_p = 0.891), but not group x time interaction ($F_{1,18}$ = 0.007, p = 0.935, η^2_p = 0.0004) for MT_{EF}. A significant increase was noted for both G1 (+3.0 mm: 6.1%; p < 0.001; d = 0.47), and G2 (+2.9 mm: 5.7%; p < 0.001; d = 0.38) from baseline to post-intervention (Table 5).

A significant main effect of time ($F_{1,18}$ = 228.930, p < 0.001, η^2_p = 0.927), but not group x time interaction ($F_{1,18}$ = 0.110, p = 0.744, η^2_p = 0.006), was observed for MT_{VL}. A significant increase was noted for both G1 (+4.7 mm: 9.2%; p < 0.001; d = 1.00) and G2 (+4.9 mm: 9.6%; p < 0.001; d = 0.94) from baseline to post-intervention (Table 5).

There was a significant main effect of time ($F_{1,18}$ = 383.183, p < 0.001, η^2_p = 0.955), but not group x time interaction ($F_{1,18}$ = 1.666, p = 0.213, η^2_p = 0.085) for MT_{AQ}. A significant increase was noted for both G1 (+4.2 mm: 9.2%; p < 0.001; d = 1.02) and G2 (+4.8 mm: 10.9%; p < 0.001; d = 1.36) from baseline to post-intervention (Table 5).

*** Table 5 about here ***

Figure 1 about here

Total Load Lifted

Figure 2 shows the TLL_{WEEK} measured during the intervention period. A significant main effect of time ($F_{2.991,53.834} = 51.182$, $p < 0.001$, $\eta^2_p = 0.740$), and group x time interaction ($F_{2.991,53.834} = 8.485$, $p < 0.001$, $\eta^2_p = 0.320$), was observed for TLL_{WEEK}. No significant difference among weeks was observed for G1 group (all $p > 0.05$). In G2 group, a significant increase was observed for TLL_{WEEK-6}, TLL_{WEEK-7} and TLL_{WEEK-8} as compared to TLL_{WEEK-1} (all $p < 0.05$) (Figure 2). A significant difference between groups was noted such that G2 produced superior TLL_{WEEK} compared to G1 in weeks 2-8 (all $p < 0.05$) (Figure 2). A significant difference between groups was noted such that G2 produced superior ATLL compared to G1 (16.3%; $p = 0.010$; $d = 1.24$) (Figure 3).

*** Figure 2 about here ***

Internal Training Load

A significant main effect of time ($F_{2.670,48.062} = 7.923$, $p < 0.001$, $\eta^2_p = 0.306$), but not group x time interaction ($F_{2.670,48.062} = 2.693$, $p = 0.063$, $\eta^2_p = 0.130$), was observed for ITL_{WEEK}. No significant between-weeks difference was observed for G1 group (all $p > 0.05$). In G2 group, a significant increase was observed for ITL_{WEEK-4}, ITL_{WEEK-7} and ITL_{WEEK-8} as compared to ITL_{WEEK-1}, ITL_{WEEK-2} and ITL_{WEEK-3} (all $p < 0.05$) (Figure 2). No significant between-group difference was noted in any ITL_{WEEK} (all $p > 0.05$) (Figure 2). A significant between groups difference was noted such that G2 produced superior ITL_{TOTAL} compared to G1 (25.4%; $p = 0.003$; $d = 1.57$) (Figure 3).

*** Figure 3 about here ***

DISCUSSION

This is the first study to assess the chronic effects of training muscle groups 1 day per week vs. 2 days per week on neuromuscular performance and morphological adaptations in trained men. The main finding of this study was that training a muscle group only once a week is as efficient as training twice a week to promote an increase in maximal strength, lower-body muscular endurance and muscle size. Alternatively, the increase in upper-body muscular endurance seems to be more pronounced when this region of the body is stimulated twice a week.

Specifically, G1 and G2 produced almost an identical gain in maximal strength. On a percentage basis, the increase in $1RM_{BENCH}$ (7.5% vs. 7.8%, respectively) and $1RM_{SQUAT}$ (13.5 vs. 13.9, respectively) was very similar. The effect sizes were also almost identical, being small for $1RM_{BENCH}$ (0.57 for both groups) and moderate for $1RM_{SQUAT}$ (1.00 vs. 0.91, respectively). When comparing these findings to other studies that investigated the effects of different RT frequencies on the maximal strength gains in trained subjects, Schoenfeld et al. (36) and McLester et al. (24) assessed 1 versus 3 weekly sessions per muscle group and both RT frequencies provided a significant increase in maximal strength, with no significant difference between conditions. However, McLester et al. (24) reported that the strength gain in the lower frequency condition were less than 2/3 of the higher frequency condition after 12 weeks of RT. Schoenfeld et al. (36) observed superior percentage gains for a higher frequency versus a lower frequency condition on 1RM testing for bench press (10.6% vs 6.8%, respectively) and back squat (11.3% vs 10.6%, respectively) exercises after 8 weeks of RT. Additionally, Hunter (16) reported a significant difference between groups such that 4 sessions$\cdot$wk^{-1} per muscle group produced a superior improvement in 1RM testing for bench press compared to 3 sessions·wk^{-1}. Moreover, a meta-analysis by Rhea et al. (30) found that trained individuals maximize the strength gain through twice weekly RT sessions per muscle group in comparison to working muscle groups only once per week.

The results observed in the present study run contrary to those mentioned above, possibly due to the greater RT volume applied in both experimental groups. Sixteen weekly sets were performed per muscle group. This weekly RT volume represents 13, 7 and 7 more sets per muscle group than the weekly RT volume used by McLester et al. (24), Hunter (16) and Schoenfeld et al. (36), respectively, and 8 more sets than the weekly RT volume found by Rhea et al. (30) as being optimal to maximize strength development. The present study used high RT volumes due to evidence of a dose-response relationship between RT volume and muscle hypertrophy, with greater volumes (10 or more weekly sets per muscle group) resulting in additional improvement in muscle mass (35), and also because this RT volume was typically associated with bodybuilding-style training (13). Thus, according to the current findings, it seems that weekly RT volume is more important than RT frequency for promoting strength gain in trained men. In other words, when weekly RT volume employed is high enough, it seems there is a diminished neural advantage of the higher training frequency observed in other studies.

Conversely, the current findings indicate that RT frequency influences the magnitude of muscular endurance enhancement. Although, no significant difference between groups was observed for measures of upper- and lower-body muscular endurance, only the G2 intervention resulted in a significant increase in $60\%1RM_{BENCH}$. Additionally, on a percentage basis, an advantage was seen for G2 compared to G1 with respect to the increase in $60\%1RM_{BENCH}$ (14.3% vs. 8.4%, respectively) and $60\%1RM_{SQUAT}$ (18.8% vs. 13.1%, respectively). The effect sizes for $60\%1RM_{BENCH}$

favored G2 compared to G1 (1.36 [large] vs. 0.51 [small], respectively), suggesting a meaningful difference in results. The effects sizes for 60%1RM$_{SQUAT}$ were very similar between groups (1.10 [moderate] vs. 1.14 [moderate], respectively), indicating that meaningful advantages of the higher frequency condition appear to be specific to upper body muscular endurance.

The present study expands on previous findings by providing direct evidence of a greater site-specific increase in muscular endurance with a higher weekly RT frequency in trained men. This can be explained by the greater TLL developed by G2 compared to G1, which implies that distributing the weekly RT volume in 2 sessions per muscle group results in a higher external weekly TLL per muscle group. The mechanistic underpinnings for this finding are not clear. It can be speculated that performing high volumes in a given session as was the case in G1 may ultimately lead to greater fatigue over time and thus diminishing the capacity to increase TLL. Alternatively, it is possible that spreading out the TLL over more frequent sessions enhances buffering capacity to a greater extent than performing a higher per-session volume less frequently, thereby increasing fatigue resistance. Further research is needed to determine causal effects of this phenomenon.

Regarding the measurement of MT, the improvement in upper-body MT was very similar between G1 and G2 groups. On a percentage basis, the increase in MT$_{TB}$ (5.5% vs. 5.7%, respectively) and MT$_{EF}$ (6.1 vs. 5.7, respectively) was nearly identical. The effect sizes were also very comparable for MT$_{TB}$ (0.57 for both groups) and MT$_{EF}$ (1.00 vs. 0.91, respectively). The present findings are in opposition to those of Schoenfeld et al. (39), who observed a significantly greater increase in elbow flexors MT for a higher frequency (3 sessions·wk^{-1}) versus a lower frequency protocol (1 session·wk^{-1}). Moreover, although triceps brachii MT was not statistically different between groups as in the present study, the effect size reported by Schoenfeld et al. (36) for a higher frequency protocol was 96% greater than that of a lower frequency protocol (0.90 vs 0.46, respectively). Nevertheless, the effect size for difference between G1 and G2 for MT_{TB} (d = 0.14) in the current study was very similar to the effect size difference between a higher and a lower frequency protocols (d = 0.19) reported in a recent meta-analysis conducted to evaluate de effects of RT frequency on the measurement of muscle hypertrophy (34). Contrarily, the between-group difference in MT_{EF} was d = 0.03 with a greater increase for G1 in comparison to G2.

A modest advantage was seen for G2 compared to G1 on a percentage basis in respect to the increase in MT_{AQ} (10.9% vs. 9.2%, respectively). For MT_{VL}, the percentage of increase was very similar (9.6% vs. 9.2%, respectively). The effect sizes for MT_{AQ} favored G2 compared to G1 (1.36 [large] vs. 1.00 [moderate], respectively), suggesting a meaningful difference in results. The effects sizes for MT_{VL} were comparable between groups (1.00 [moderate] vs. 0.94 [moderate], respectively). Schoenfeld et al. (36) also reported a greater effect size for quadriceps thickness on a higher frequency protocol compared to a lower frequency protocol (0.70 vs. 0.18, respectively). The between-groups difference in MT_{VL} (d = 0.15) was similar to the effect size reported by meta-analysis about RT frequency (34). Conversely, the between-groups difference in MT_{AQ} (d = 0.58) was greater than preconized by meta-analysis (34). Considering the greater percentage of increase and the effect sizes for some of the measured outcomes ($60\%1RM_{BENCH}$ and MT_{AQ}), it can be speculated that trained individuals may benefit from including periods of training muscle groups at least 2 day-week when the goal is to maximize muscular endurance and muscle hypertrophy.

The G2 group produced 54590 kgf more ATLL, and 1693 a.u. more ITL_{TOTAL} than the G1 group, equating to a 16.3% greater accumulated external training load with a large associated effect size (*d* = 1.24) and 25.4% greater accumulated ITL with a large associated effect size (*d* = 1.57). While ITL is indicative of the intensity of effort (10,37), it is reasonable to speculate that the RT scheme that generated greatest TLL also induced a higher ITL value. Indeed, there is a significant positive relationship between TLL and sRPE (10,23).

Thus, the present study expands on previous findings by providing direct evidence of the greater TLL increase with a higher weekly RT frequency (2 vs 1 weekly session per muscle group) in trained men. This is important, as the increment in muscle strength and mass is strongly dependent on TLL of RT. In fact, a clear dose-response relationship has been reported between TLL and both muscle strength (20) and hypertrophy (21,35). Moreover, a higher load induces a greater mechanical tension, which is purported to be a primary driving force with respect to hypertrophy development (33). Therefore, it is plausible to hypothesize that this greater TLL achieved through high frequency protocol if executed for a longer time frame (more than 8 weeks) may possibly culminate in a significantly greater increase in strength and hypertrophy compared to a single session·wk^{-1} per muscle group. This hypothesis requires further investigation.

Although this study suggests that G2 protocol may enhance certain muscular adaptations in trained individuals, the results do not necessarily imply that a G1 protocol is without merit, as working a muscle with a greater training volume in the same session helps to increase intramuscular metabolic stress (12), which in turn may enhance the hypertrophic response to the exercise bout (33). Indeed, no significant between group difference was observed for any primary outcomes. Additionally, qualitative assessment revealed that standardized differences between groups were classified as “unclear” and “most likely trivial” (Figure 1), and the majority of outcome measures showed minimal effect size differences.

The present study had several limitations that must be considered when attempting to draw evidence-based inferences. First, the study period lasted only 8 weeks. Although this duration was sufficient to achieve a significant increase in muscular strength and hypertrophy (assessed by MT) in both groups, it is conceivable that results between groups would have diverged over a longer time frame. Second, the novelty factor of changing programs may have unduly influenced results. In the pre-intervention interview, 17 of the 20 subjects reported training lower-body muscles once a week on a regular basis. Additionally, all subjects reported training upper-body muscles with 10 weekly sets or less on a regular basis. Although the topic has not been well studied, there is evidence indicating that muscular adaptations are enhanced when program variables are altered outside of traditional norms (19). It also is possible that periodizing training frequencies might provide a means to maintain novelty of the stimulus and thus promote a continued gain over time. This hypothesis demands additional investigation. Third, the small sample size affected statistical power. As is the case in the majority of longitudinal RT studies, a high degree of inter-individual variability was noted among subjects, which limited the ability to detect a significant difference in several outcome measures. Despite this limitation, analysis of effect sizes provides a good basis for drawing inferential conclusions from the results. Finally, the findings of the present study are specific to young resistance-trained men, and therefore cannot necessarily be generalized to other populations including adolescents, women, and the elderly. It is possible that the higher RT volumes may not be as well tolerated in these individuals and perhaps could hasten the onset of overtraining when combined with a high intensity of effort. Future research is required to determine the frequency-related responses to RT across different populations.

PRACTICAL APPLICATIONS

This study shows that training muscle groups once and twice per week are both viable strategies to increase muscle strength, endurance, and hypertrophy. The greater effect size favoring G2 for some outcome measures suggests a potential benefit to a twice-weekly training schedule. It is possible that these benefits may be related to distributing the same weekly RT volume over a greater number of training sessions, which in turn may attenuate accumulated intra-session muscle fatigue. Given that training the same muscle group on different days is thought to be less energetically taxing compared to condensing the weekly volume in a single session, dividing the muscle group RT volume in 2 sessions$\cdot$wk^{-1} provides a practical means to perform a higher TLL per muscle group while maintaining intensity of effort and providing adequate recovery between sessions. Alternatively, G1 may be more economical for those with limited time for RT, as it requires only 2 training days per week versus 4 weekly sessions for G2 while producing a similar improvement in most outcome measures.

Since muscular adaptations are strongly dependent on TLL, it is plausible that optimal strength and hypertrophic benefits could be obtained by periodizing training loads with frequency over the course of a long-term training cycle. Such a strategy would maintain the novelty of the training stimulus and thus conceivably allow a continuous improvement in neuromuscular performance and muscle morphology. This hypothesis warrants further investigation.

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FIGURES LEGENDS

Figure 1. Efficiency of the group that have trained one session per muscle group per week ($G1 \cdot wk^{-1}$) in comparison with the group that have trained two sessions per muscle group per week ($G2 \cdot wk^{-1}$) to improve maximum strength in bench press ($1RM_{BENCH}$) and parallel back squat ($1RM_{SQUAT}$) exercises; muscular endurance in bench press ($60\%1RM_{BENCH}$) and parallel back squat ($60\%1RM_{SQUAT}$) exercises; muscle thickness of the triceps brachii (MT_{TB}), elbow flexors (MT_{EF}), vastus lateralis (MT_{VL}) and anterior quadriceps (MT_{AQ}) muscles; total load lifted (ATLL) and internal training load (ITL_{TOTAL}) (bars indicate uncertainty in the true mean changes with 90% confidence intervals). Trivial areas were the smallest worthwhile change (SWC) (see methods).

Figure 2. Mean and standard deviation values for (A) weekly total load lifted; and (B) weekly internal training load for G1 and G2. # Significant difference between groups in the corresponding week ($p < 0.05$). * Significantly greater than week 1 of the respective group ($p < 0.05$). ** Significantly greater than week 2 of the respective group ($p < 0.05$). *** Significantly greater than week 3 of the respective group ($p < 0.05$).

Figure 3. Mean and standard deviation values for (A) total load lifted (sun of the 8 weeks); and (B) internal training load (sun of the 8 weeks) for G1 and G2. * Significantly greater than G1 ($p < 0.05$).

TABLES

Table 1. Baseline descriptive data of G1 and G2 (mean ± SD).

Groups	**Age** (years)	**Height** (m)	**Total Body Mass** (Kg)	**RT Experience** (years)	**RT Frequency** (sessions·wk^{-1})
G1 (n=10)	28.6±5.6	1.76±0.04	80.7±5.8	5.2±1.6	4.3±0.7
G2 (n=10)	25.5±5.1	1.80±0.10	75.2±6.8	4.9±2.1	4.7±0.7

G1 = one session·wk^{-1} per muscle group; **G2** = two sessions·wk^{-1} per muscle group; **m** = meters; **kg** = kilograms; **RT** = resistance training; **sessions·wk^{-1}** = sessions per week.

Table 2. Training protocols for G1 and G2.

	Monday	Tuesday	Wednesday	Thursday	Friday
G1 (n=10)	**A_{rout}** Bench press 8x8-12RM Dumbbell flat fly 8x8-12RM Cable triceps 8x8-12RM Parallel back squat 8x8-12RM Leg extension 8x8-12RM	XXXX	XXXX	**B_{rout}** Lat pulldown 8x8-12RM Straight-arm pulldown 8x8-12RM Biceps curl 8x8-12RM Seated leg curl 16x8-12RM	XXXX
G2 (n=10)	**A_{rout}** Bench press 4x8-12RM Dumbbell flat fly 4x8-12RM Cable triceps 4x8-12RM Parallel back squat 4x8-12RM Leg extension 4x8-12RM	**B_{rout}** Lat pulldown 4x8-12RM Straight-arm pulldown 4x8-12RM Biceps curl 4x8-12RM Seated leg curl 8x8-12RM	XXXX	**A_{rout}** Bench press 4x8-12RM Dumbbell flat fly 4x8-12RM Cable triceps 4x8-12RM Parallel back squat 4x8-12RM Leg extension 4x8-12RM	**B_{rout}** Lat pulldown 4x8-12RM Straight-arm pulldown 4x8-12RM Biceps curl 4x8-12RM Seated leg curl 8x8-12RM

G1 = one session$\cdot$ wk^{-1} per muscle group; **G2** = two sessions$\cdot$ wk^{-1} per muscle group; **A_{rout}** = split routine A; **B_{rout}** = split routine B; **RM** = repetition maximum.

Table 3. Estimated dietary nutrient intake for G1 and G2 (mean ±SD).

Variables	G1 (n=10)	Week 1	Week 8	G2 (n=10)	Week 1	Week 8
Total (Kcal)		2592.8 ± 223.8	2535.2 ± 256.4		2423.5 ± 128	2414.0 ± 137.1
Protein						
g/kg^{-1}		2.1 ± 0.2	2.0 ± 0.2		2.1 ± 0.4	2.1 ± 0.3
%		26.0 ± 1.3	25.6 ± 1.9		25.5 ± 2.9	26.3 ± 2.5
Carbohydrate						
g/kg^{-1}		3.7 ± 0.6	3.7 ± 0.6		3.6 ± 0.6	3.7 ± 0.7
%		46.2 ± 3.1	47.7 ± 2.8		44.5 ± 3.1	45.4 ± 2.8
Lipids						
g/kg^{-1}		1.1 ± 0.2	1.0 ± 0.2		1.1 ± 0.1	1.0 ± 0.1
%		27.8 ± 2.4	26.7 ± 3.0		30.0 ± 2.5	28.3 ± 2.2

G1 = one session·wk^{-1} per muscle group; **G2** = two sessions·wk^{-1} per muscle group; **Total (Kcal)** = total kilocalories intake (3 recorded days' average); **g/kg^{-1}** = grams per kilogram of body mass; **%** = percentage of total energy intake.

Table 4. Pre- vs. Post-intervention Muscle Strength and Muscle Endurance measures for G1 and G2 (mean ±SD).

	Variables	Pre	Post	Δ%	*p*	*d* (±90% CL) *classification*	Qualitative Assessment	Chances (%)
G1 (n=10)	$1RM_{BENCH}$ (kg)	95.7 ± 14.5	103.5 ± 12.9*	7.5	<0.001	0.57 (±0.25) *small*	Possibly	68/32/0
	$1RM_{SQUAT}$ (kg)	128.5 ± 18.6	148.6 ± 21.7*	13.5	<0.001	1.00 (±0.44) *moderate*	Very Likely	97/3/0
	$60\%1RM_{BENCH}$ (rep)	14.2 ± 2.7	15.5 ± 2.3	8.4	0.060	0.51 (±0.53) *small*	Possibly	51/48/0
	$60\%1RM_{SQUAT}$ (rep)	15.3 ± 2.4	17.6 ± 1.9*	13.1	0.006	1.10 (±0.47) *moderate*	Likely	95/5/0
G2 (n=10)	$1RM_{BENCH}$ (kg)	92.6 ± 14.3	100.4 ± 13.3*	7.8	<0.001	0.57 (±0.25) *small*	Possibly	68/32/0
	$1RM_{SQUAT}$ (kg)	121.1 ± 17.2	140.6 ± 25.4*	13.9	<0.001	0.91 (±0.40) *moderate*	Very Likely	95/5/0
	$60\%1RM_{BENCH}$ (rep)	13.2 ± 1.9	15.4 ± 1.3*	14.3	0.003	1.36 (±0.69) *large*	Very Likely	98/2/0
	$60\%1RM_{SQUAT}$ (rep)	15.1 ± 2.8	18.6 ± 3.3*	18.8	<0.001	1.14 (±0.62) *moderate*	Very Likely	99/1/0

G1 = one session·wk^{-1} per muscle group; **G2** = two sessions·wk^{-1} per muscle group; **$1RM_{BENCH}$** = one maximal repetition test in bench press exercise; **$1RM_{SQUAT}$** = one maximal repetition test in parallel back squat exercise; **$60\%1RM_{BENCH}$** = 60% of 1RM test in bench press exercise; **$60\%1RM_{SQUAT}$** = 60% of 1RM test in parallel back squat exercise; **kg** = kilograms; **rep** = repetitions ***d*** = Effect Size; **CL** = Confidence Limits; **Chances** = rate of having better/similar/poorer chances. *Significantly greater than the corresponding pre-intervention value ($p < 0.05$).

Table 5. Pre- vs. Post-intervention Muscle Morphology measures for G1 and G2 (mean ±SD).

	Variables	Pre	Post	Δ%	*p*	*d* (±90% CL) *classification*	Qualitative Assessment	Chances (%)
G1 (n=10)	MT_{TB} (mm)	43.1 ± 4.6	45.6 ± 4.5*	5.5	<0.001	0.53 (±0.23) *small*	Possibly	59/41/0
	MT_{EF} (mm)	46.2 ± 6.5	49.2 ± 6.1*	6.1	<0.001	0.47 (±0.21) *small*	Possibly	40/60/0
	MT_{VL} (mm)	46.1 ± 4.8	50.8 ± 4.5*	9.2	<0.001	1.00 (±0.44) *moderate*	Very Likely	97/3/0
	MT_{AQ} (mm)	41.3 ± 3.9	45.5 ± 4.4*	9.2	<0.001	1.02 (±0.45) *moderate*	Very Likely	97/3/0
G2 (n=10)	MT_{TB} (mm)	41.5 ± 4.9	44.0 ± 4.8*	5.7	<0.001	0.53 (±0.23) *small*	Possibly	59/41/0
	MT_{EF} (mm)	47.7 ± 7.8	50.6 ± 7.5*	5.7	<0.001	0.38 (±0.17) *small*	Possibly	12/88/0
	MT_{VL} (mm)	46.3 ± 5.5	51.2 ± 4.9*	9.6	<0.001	0.94 (±0.42) *moderate*	Very Likely	96/4/0
	MT_{AQ} (mm)	39.2 ± 3.5	44.0 ± 3.7*	10.9	<0.001	1.36 (±0.60) *large*	Most Likely	100/0/0

G1 = one session$\cdot$wk^{-1} per muscle group; **G2** = two sessions$\cdot$wk^{-1} per muscle group; $\mathbf{MT_{TB}}$ = muscle thickness of the triceps brachii muscle; $\mathbf{MT_{EF}}$ = muscle thickness of the elbow flexors muscles; $\mathbf{MT_{VL}}$ = muscle thickness of the vastus lateralis muscle; $\mathbf{MT_{AQ}}$ = muscle thickness of the anterior quadriceps muscle; **mm** = millimeters; ***d*** = Effect Size; **CL** = Confidence Limits; **Chances** = rate of having better/similar/poorer chances. *Significantly greater than the corresponding pre-intervention value ($p < 0.05$).

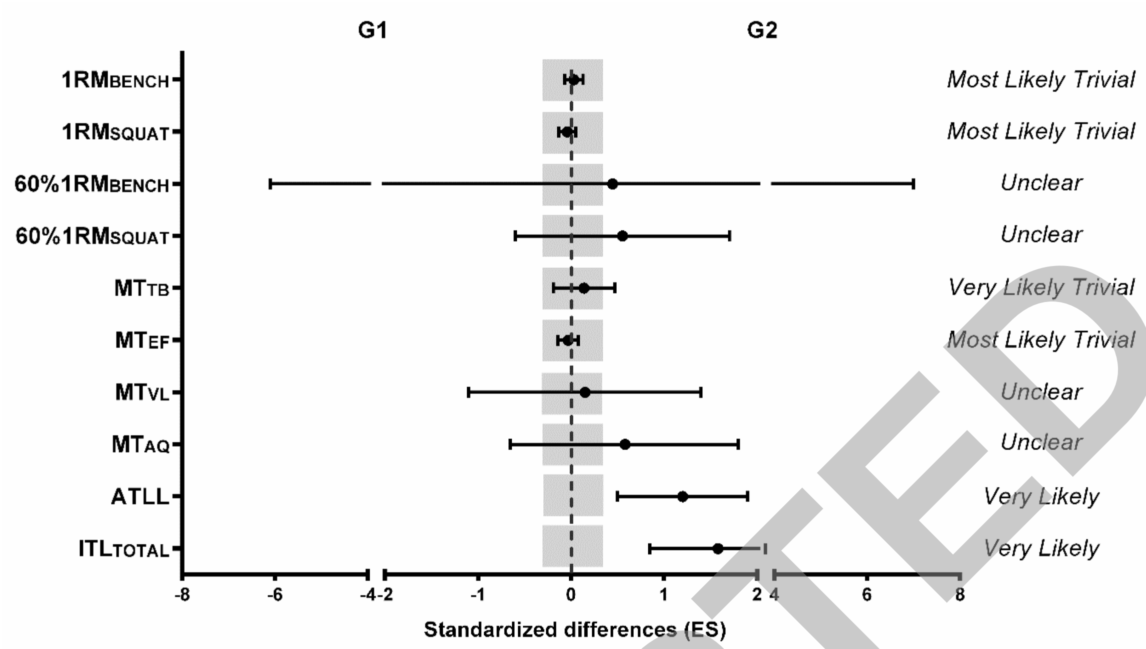

Figure 1. Efficiency of the group that have trained one session per muscle group per week ($G1 \cdot wk^{-1}$) in comparison with the group that have trained two sessions per muscle group per week ($G2 \cdot wk^{-1}$) to improve maximum strength in bench press ($1RM_{BENCH}$) and parallel back squat ($1RM_{SQUAT}$) exercises; muscular endurance in bench press ($60\%1RM_{BENCH}$) and parallel back squat ($60\%1RM_{SQUAT}$) exercises; muscle thickness of the triceps brachii (MT_{TB}), elbow flexors (MT_{EF}), vastus lateralis (MT_{VL}) and anterior quadriceps (MT_{AQ}) muscles; total load lifted (ATLL) and internal training load (ITL_{TOTAL}) (bars indicate uncertainty in the true mean changes with 90% confidence intervals). Trivial areas were the smallest worthwhile change (SWC) (see methods).

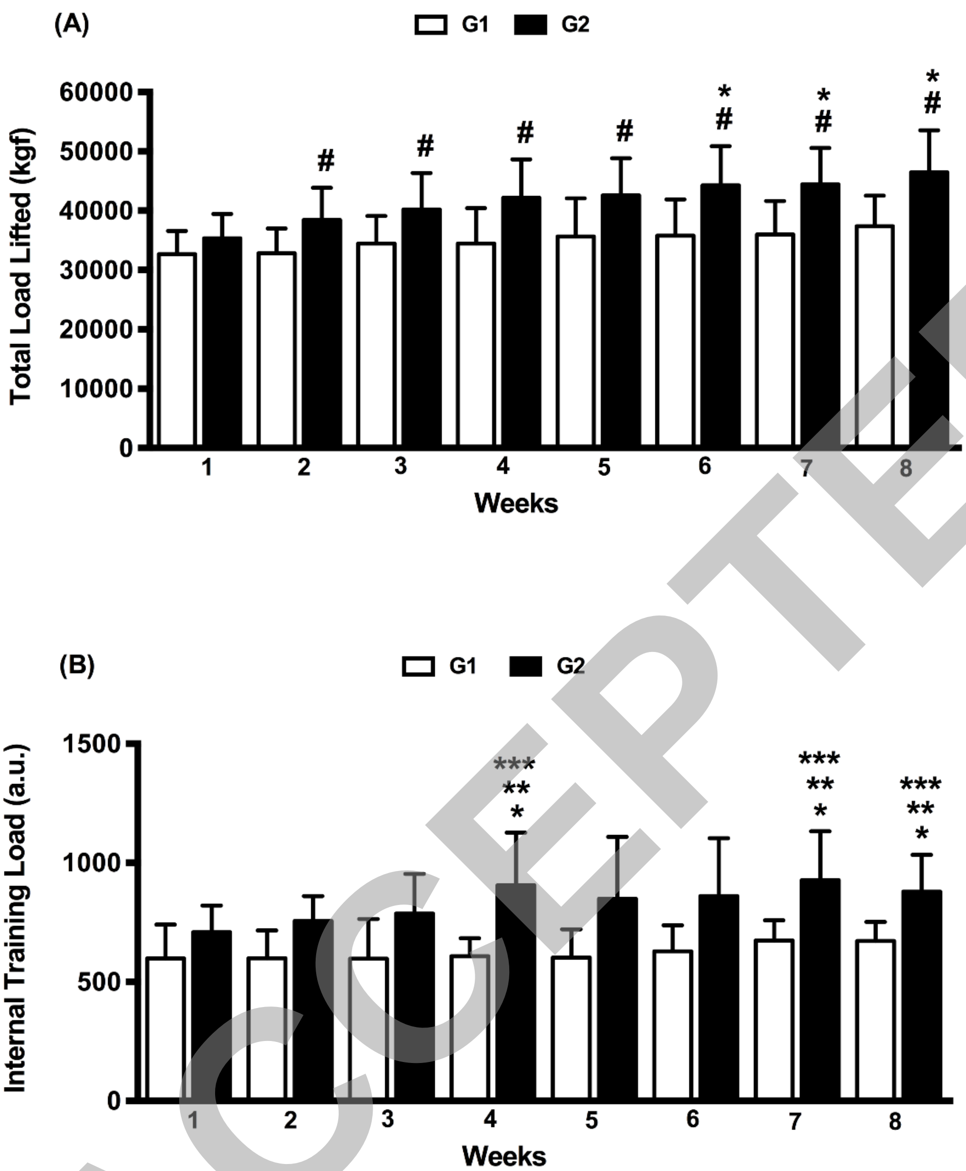

Figure 2. Mean and standard deviation values for (A) weekly total load lifted; and (B) weekly internal training load for G1 and G2. # Significant difference between groups in the corresponding week ($p < 0.05$). * Significantly greater than week 1 of the respective group ($p < 0.05$). ** Significantly greater than week 2 of the respective group ($p < 0.05$). *** Significantly greater than week 3 of the respective group ($p < 0.05$).

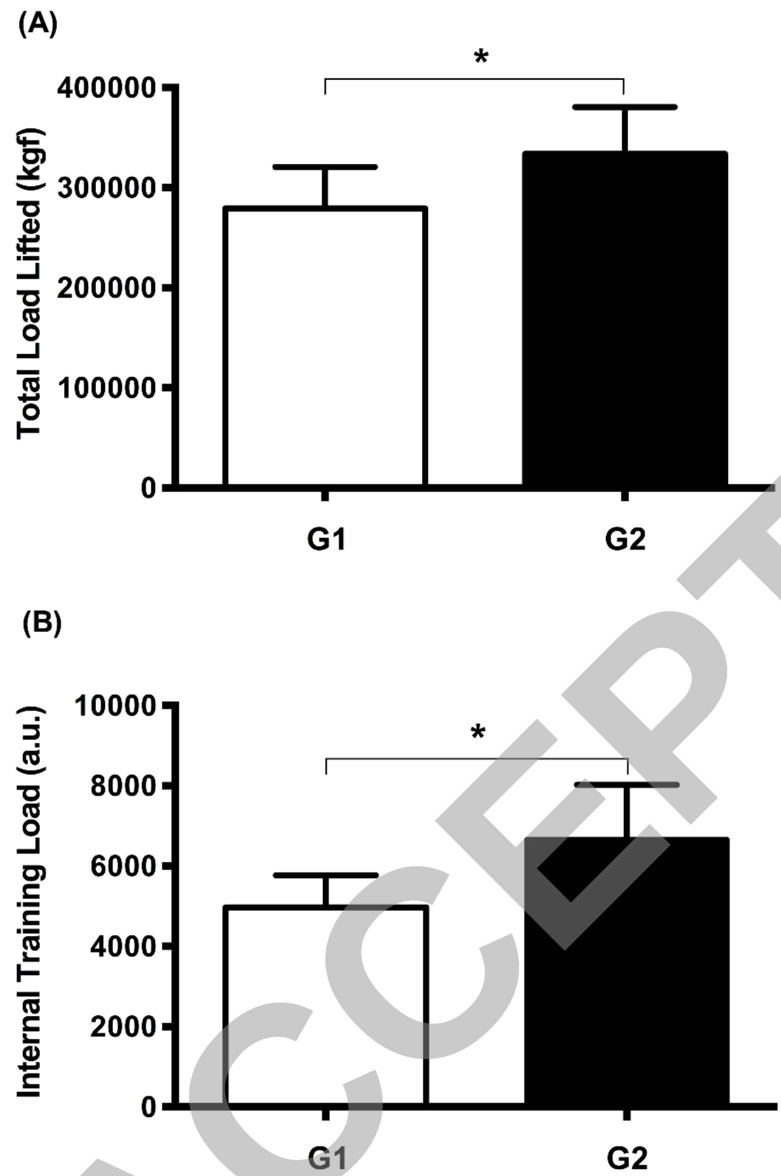

Figure 3. Mean and standard deviation values for (A) total load lifted (sun of the 8 weeks); and (B) internal training load (sun of the 8 weeks) for G1 and G2. * Significantly greater than G1 ($p < 0.05$).