DOSE-RESPONSE OF 1, 3, AND 5 SETS OF RESISTANCE EXERCISE ON STRENGTH, LOCAL MUSCULAR ENDURANCE, AND HYPERTROPHY

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ABSTRACT

Radaelli, R, Fleck, SJ, Leite, T, Leite, RD, Pinto, RS, Fernandes, L, and Simão, R. Dose-response of 1, 3, and 5 sets of resistance exercise on strength, local muscular endurance, and hypertrophy. *J Strength Cond Res* 29(5): 1349–1358, 2015—The study's purpose was to compare the response of performing 1, 3, and 5 sets on measures of performance and muscle hypertrophy. Forty-eight men, with no weight training experience, were randomly assigned to one of the 3 training groups, 1 SET, 3 SETS, 5 SETS, or control group. All training groups performed 3 resistance training sessions per week for 6 months. The 5 repetition maximum (RM) for all training groups increased in the bench press (BP), front lat pull down (LPD), shoulder press (SP), and leg press (LP) ($p \leq 0.05$), with the 5RM increases in the BP and LPD being significantly greater for 5 SETS compared with the other training groups ($p \leq 0.05$). Bench press 20RM in the 3-SET and 5-SET groups significantly increased with the increase being significantly greater than the 1-SET group and the 5-SET group increase being significantly greater than the 3-SET group ($p \leq 0.05$). LP 20RM increased in all training groups ($p \leq 0.05$), with the 5-SETS group showing a significantly greater increase than the 1-SET group ($p \leq 0.05$). The 3-SET and 5-SET groups significantly increased elbow flexor muscle thickness (MT) with the 5-SET increase being significantly greater than the other 2 training groups ($p \leq 0.05$). The 5-SET group significantly increased elbow extensor MT with the increase being significantly greater than the other training groups ($p \leq 0.05$). All training groups decreased percent body fat, increased fat-free mass, and vertical jump ability ($p \leq 0.05$), with no differences between groups. The results demonstrate a dose-response for the number of sets per exercise and a superiority of multiple sets compared with a single set per exercise for strength gains, muscle endurance, and upper arm muscle hypertrophy.

KEY WORDS muscle strength, muscle hypertrophy, training volume

INTRODUCTION

It is well established that strength training is effective for increasing muscular strength and fat-free body mass (22,34,35). However, the training volume needed to maximally increase strength and fat-free body mass is less clear. Training volume is often calculated as the number of sets completed of each exercise performed times the number of repetitions completed in each set of all exercises performed times the resistance used (10). There are a substantial number of investigations comparing the effect of training volume, expressed as the number of sets performed, on maximal strength increases.

Many studies concerning training volume compared the effects of performing 1 or 3 sets of each exercise per training session on strength increases and muscle hypertrophy in untrained subjects during the early stage (6–12 weeks) of strength training (5,20,33). Some studies reported superiority of 3 sets (13,20,25,26,29), whereas other studies found no difference between 1-set and 3-set (4,10,23,24) for increases in strength and hypertrophy. It has been hypothesized comparisons between 1 set and 3 sets may not represent sufficiently different training volumes to show differences in strength and hypertrophy gains, if they exist, and do not reflect the higher training volumes typically prescribed for resistance-trained individuals (16). One recent study comparing 1, 4, and 8 sets showed 8 sets to be superior to 1 set in bringing about maximal strength gains, but no other differences in strength increases were shown between the number of sets performed (16). This result supports the contention that comparisons of 1 set vs. 3 sets may not be

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different enough in training volume to show differences in training outcomes, if they exist.

The interest in the effect training volume on strength and hypertrophy has resulted in several meta-analyses and reviews on this topic. Some reviews and meta-analyses favor multiple sets in causing increases in strength and hypertrophy compared with 1 set (14,15,22,39), whereas other reviews have criticized the veracity of the meta-analyses concluding there is no difference in strength and hypertrophy increases between single and multiple sets (33,38). A meta-analysis examining the effect of the number of sets performed has on hypertrophy concluded multiple sets result in significantly greater hypertrophy than single-set programs (15). However, there was only a trend for 2–3 sets and 4–6 sets to show significantly greater increases than single-set programs with both of these being significant if permutation of p values were considered. There was no significant difference in hypertrophy increases between 2–3 sets and 4–6 sets (15). The conclusions of these meta-analyses are affected by the relatively few studies comparing the effect of multiple sets, greater than 3 sets, on strength and muscle hypertrophy gains during long duration training periods (16).

Because of the lack of studies comparing the effects of multiple sets, greater than 3 sets, on strength and muscle hypertrophy due to long training periods, the aim of this study was to compare the effects of 1, 3, and 5 sets on the changes in the muscle strength and endurance, muscle hypertrophy, vertical jump performance, and body composition due to 6 months of training. The hypotheses of the study were multiple sets would result in greater changes in training outcomes than single sets, and there would be a dose-response for training outcomes.

Methods

Experimental Approach to the Problem

To investigate the effects of 3 different strength training volumes due to 6 months of training muscle thickness (MT), vertical jump ability, body composition, 5 repetition maximum (RM) of the bench press (BP), leg press (LP), front lat pull down (LPD) and shoulder press (SP), and 20RM of the BP and LP were assessed pre- and post-training. At pre- and post-testing, each dependent variable was tested and retested on 2 different days by the same investigator using the same procedures (Figure 1). This testing protocol allowed the determination of test-retest reliability. The same investigator performed testing pre- and post-training for each of the tests performed. No physical activity, other than testing, was allowed during the pre- and post-testing periods.

After pretesting, participants were randomly assigned to either a 1-set (1-SET), 3-set (3-SETS), or 5-set (5-SETS) training groups or control group (CG). The training groups then performed 6 months of resistance training 3 days per week. Two to five days after the last training session, posttesting was performed using the same timeline and procedures as during pretesting.

Subjects

Subjects were 48 men from the Brazilian Navy School of Lieutenants (mean ± SD; age = 24.4 ± 0.9 years; body mass = 79.3 ± 9.1 kg; height = 174.5 ± 5.5 cm) with no weight training experience. Subjects were experienced in traditional military training involving body weight exercises, such as push-ups, pull-ups, and abdominal exercises. All subjects were free of any functional limitations that prevented performing the resistance training program or any of the tests related to the study, did not present any medical condition that could affect their ability to perform the training program or any of the testing related to the study, and did not use any nutritional or ergogenic supplementation. Meals were eaten in the same dining facility by all participants. Before data collection, all participants were informed of the purpose, procedures, benefits, and risks due to study participation, answered the PAR-Q questionnaire (31), and gave written informed consent to participate in the study. All procedures performed in this study were approved by an Institutional Ethics Committee and followed the ethical guidelines of the Declaration of Helsinki (last modified in 2000).

Training Program

The subjects trained for 6 months, completing 3 sessions per week with at least 48–72 hours of rest between sessions (totaling 73 training sessions). Subjects were randomly assigned to one of the 3 training groups: 1 SET ($n = 12$; 24.1 ± 0.8 years; 79.7 ± 9.4 kg; 177.9 ± 5.2 cm), 3 SETS ($n = 13$; 24.1 ± 1.2 years; 76.2 ± 8.1 kg; 174.9 ± 3.4 cm), or 5 SETS ($n = 13$; 24.7 ± 1.0 years; 82.2 ± 10.7 kg; 172.9 ± 7.3 cm), or the CG ($n = 10$; 24.8 ± 0.6 years; 79.3 ± 8.2 kg; 173.2 ± 3.4 cm). The CG did not perform the weight training program, but did perform a traditional military calisthenics program of body weight exercises 3 times per week for approximately 1 hour per session. Before each training session, the training groups performed a specific warm-up, consisting of 10 repetitions with approximately 50% of the resistance used in the first exercise of the training session. The training program consisted of the following weight training machine exercises (Life Fitness, USA) in the order listed: BP, LP, LPD, leg extension, SP, leg curl, biceps curl, abdominal crunch lying on the floor, and triceps extension. All training groups performed sets with a RM resistance of 8–12RM to concentric failure, with a rest interval of 90–120 seconds between sets and exercises (6). The training resistance was increased by 5–10% for the next session when subjects were able to perform more than 12 repetitions in all sets of an exercise. All subjects participated in at least 95% of the training sessions (missed no more than 4 sessions). All training sessions were monitored by an experienced investigator and the subjects were not allowed to perform aerobic or flexibility exercises during the 6-month training period.

Five Repetition Maximum Testing

The 5RM for the BP, LP, LPD, and SP were determined in the order listed, on 2 separate occasions before and after training as described in the Experimental Approach to the Problem section. All 5RM testing was performed using the same equipment used during training. Five repetition maximum testing was used to determine strength increases because the subjects trained using 8–12RM resistances and had no weight training experience. Thus, the subjects did not train using close to 1RM resistances and because subjects were untrained and they had no experience using close to 1RM resistances. Both of these factors could affect exercise technique when using very heavy resistances, which would affect the accuracy of 1RM testing; thus, 5RM testing was chosen to determine strength. Before the pretraining 5RM tests, all subjects performed a familiarization session of 2–4 sets of 10 repetitions per set of each exercise with a light resistance on day 2 of testing as shown in Figure 1. To minimize the error during 5RM tests, the following strategies were adopted (32): (a) standardized instructions concerning the testing procedures and exercise technique were given to participants; (b) the exercise technique of subjects was monitored and corrected as needed, during all testing sessions; and (c) verbal encouragement was provided during the testing procedure. The 5RM of each exercise was determined in fewer than 3 attempts with a rest interval of 5 minutes between 5RM attempts and 10 minutes between the different exercises tested. No pause was allowed between the eccentric and concentric phases of a repetition or between repetitions. For a repetition to be considered successful, the complete range of motion as normally defined for each exercise had to be completed. The heaviest 5RM resistance achieved in each exercise during pre- and post-training was used in the statistical analysis. Pretraining 5RM test-retest intraclass correlation coefficients (ICCs) between the 2 days of testing for BP, LP, LPD, and SP exercises were 0.98, 0.96, 0.98, and 0.98, respectively. Posttraining 5RM test-retest ICCs on the 2 days of testing for BP, LP, LPD, and SP exercises were 0.98 for all exercises.

Twenty Repetition Maximum Testing

The 20RM was assessed for the BP and LP exercises on the same weight training machines used for 5RM testing and training. Testing followed the timeline outlined in Figure 1. The same procedures and standardized testing protocol that were used during the 5RM testing was adapted for 20RM tests. The heaviest load achieved on either of the 2 testing sessions for 20RM was considered the 20RM and used in the statistical analysis. Test-retest reliability ICCs at pre- and post-testing for both the BP and LP were 0.98.

Muscle Thickness Measurements

Muscle thickness of the elbow flexors (biceps brachii + brachialis) and elbow extensors (triceps brachii long head + triceps brachii medial head) of the left arm were obtained using real-time B-mode ultrasonography (EUB-405; Hitachi, Japan), with an 80-mm 7.5-MHz linear array probe. The scans were taken at 60% of the distance between the acromion process of the scapula and the lateral epicondyle of the humerus (18). All MT measures were obtained with the subject in a seated position with the arms extended and relaxed. The probe was positioned perpendicular to the tissue and was coated with a water-soluble transmission gel to provide acoustic contact without depressing the dermal surface. In all images, MT was determined as the distance between the interface of the muscle tissue and subcutaneous fat to the bone (1) (Figure 2). To avoid the acute effect of muscle tissue swelling due to weight training at posttesting, the measurements were obtained 2–5 days after the last training session. Test-retest reliability ICCs for the elbow flexors and extensors were 0.98 and 0.96, respectively, at both pre- and post-training.

Maximum Height Countermovement Jump

The maximum height no step countermovement jump (CMJ) was determined using standardized procedures previously described (9). Pre- and post-training maximum height CMJ was tested on 2 days as shown in the Figure 1.

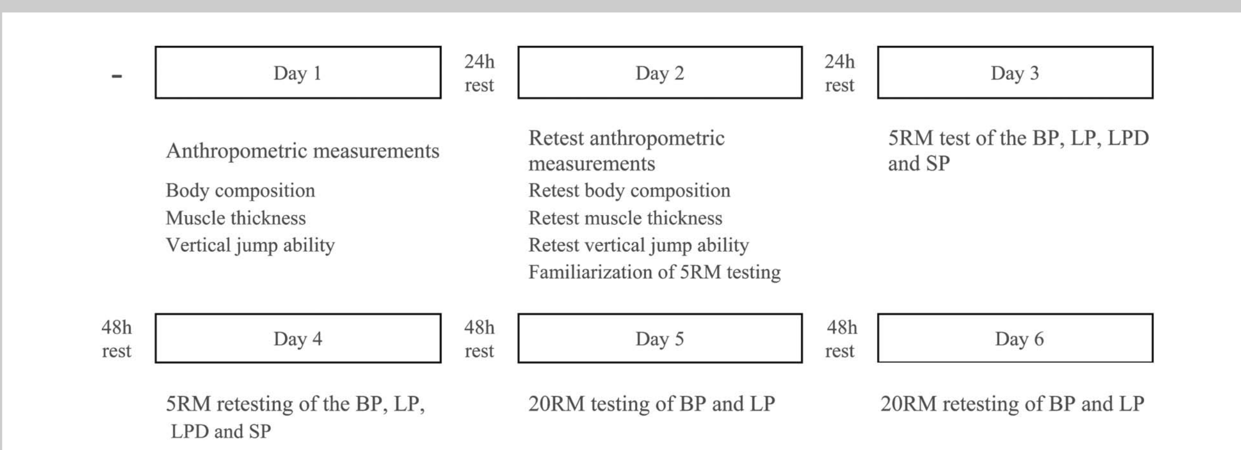

Figure 1. Experimental design of pretesting. RM = repetition maximum; BP = bench press; LPD = lat pull down; SP = shoulder press; LP = leg press.

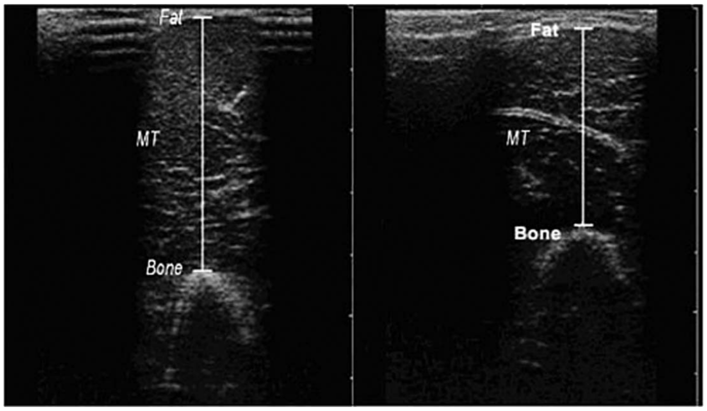

Figure 2. Ultrasonographic images representing muscle thickness of the elbow flexors (left) and of the elbow extensors (right). MT = muscle thickness.

Each subject was allowed 1 practice trial, followed by 3 more trials with 2–3 minutes of rest between trails. To measure reach height, the subjects stood with their side to a wall and reached up as high as possible with the dominant hand closest to the wall. The subjects were instructed to rapidly do a CMJ for maximum height. To perform a CMJ, subjects began in an erect standing position, moved into a semisquat position, and then immediately jumped to allow the use of a stretch-shortening cycle during the jump. An arm swing was allowed to maximize vertical jump height. Before jumping, subjects chalked their dominant hand finger tips and then jumped as high as possible touching a chalk board on the wall with their dominant hand at the highest point of the jump. The maximum height CMJ was determined by subtracting standing reach height from maximal jump height. The highest CMJ height achieved was used in the statistical analysis. The pre- and post-training test-retest ICC for CMJ was 0.98.

Body Composition

Body composition was assessed 2 times at pre- and post-training as outlined in Figure 1. Three skinfold measurements (chest, abdomen, and thigh) obtained with a Lange Skinfold Caliper (Santa Cruz, CA, USA) were used to estimate body density using the equation of Jackson and Pollock with methods previously described (11). Percent body fat was estimated using the Siri equation. Fat-free mass (FFM) was calculated as total body mass − percent fat × total body mass. The ICCs for test-retest for percent fat at pre- and post-training were 0.96 and 0.98, respectively.

Statistical Analyses

All values are reported as mean ± *SD* and 95% confidence interval. The normality of the distribution and homocedasticity for outcome measures were tested using the Shapiro-Wilk and Barlett criterion, respectively. Main training effects within and between groups were assessed by a 2-way analysis of variance (ANOVA) (time [pre vs. post] × group [1 SET vs. 3 SETS vs. 5 SETS vs. CG]). When a significant F level was identified from the ANOVA procedures, a Tukey post hoc test was performed to locate pairwise mean differences. Test-retest reliability was determined by calculating ICCs with a 1-tailed *t*-test used to determine whether a significant difference existed between the 2 tests for a variable at pre- or post-testing. Effect sizes (ESs) were calculated as described previously (25) and the scale proposed by Rhea (25) was used to determine ES magnitude. Training volume was calculated as resistance used times repetitions per set times number of sets. An alpha level of $p \leq 0.05$ was used to determine statistical significance.

Table 1. Training volume by training group before and after 6 months of training (values are mean ± *SD*).*

	Volume load (repetitions × sets × resistance; kg)			
Group	Pre	95% CI	Post	95% CI
1 SET	23,664.41 ± 4.6	18.854–29.347	27,553.85 ± 3.1†	23.104–30.753
3 SETS	75,049.11 ± 5.1‡	69.135–82.015	87,087.54 ± 7.8†‡	80.531–91.341
5 SETS	140,119.80 ± 8.5‡§	132.859–149.891	161,990.70 ± 10.9†‡§	151.895–166.789

*CI = confidence interval.
†$p \leq 0.05$ statistically significant difference from the corresponding pretraining value.
‡$p \leq 0.001$ statistically significant difference compared with the 1-SET group.
§$p \leq 0.001$ statistically significant difference compared with the 3-SET group.

Table 2. Absolute values of 5RM before and after 6 months of training and effect size (values are mean ± *SD*).*

Group	Pre (kg)	95% CI	Post (kg)	95% CI	Effect size
BP (kg)					
Control	68.3 ± 11.4	59.5–77.1	64.4 ± 8.8	57.6–71.2	−0.34
1 SET	64.5 ± 9.5	58.3–70.8	73.2 ± 9.9†‡	66.9–79.5	0.91
3 SETS	73.4 ± 9.4	67.7–81.0	86.1 ± 8.4†‡§	79.1–91.2	1.35
5 SETS	89.6 ± 9.6	83.3–95.8	99.6 ± 5.5†‡§∥	96.2–103.0	0.97
LPD (kg)					
Control	60.5 ± 6.8	55.3–65.8	62.2 ± 6.6	57.1–67.3	0.24
1 SET	57.9 ± 10.7	51.0–64.7	68.7 ± 9.5†‡	62.6–74.8	1.01
3 SETS	62.5 ± 6.21	58.5–66.4	70.0 ± 4.76†‡§	66.9–73.0	1.21
5 SETS	74.2 ± 9.5	68.4–80.0	86.5 ± 6.5†‡§∥	82.5–90.5	1.29
SP (kg)					
Control	26.1 ± 7.4	20.4–31.8	29.4 ± 7.6	23.5–35.3	0.45
1 SET	31.6 ± 7.1	27.1–36.2	38.7 ± 9.3†‡	32.8–44.6	0.99
3 SETS	34.2 ± 7.5	29.6–38.8	42.3 ± 6.3†‡§	38.4–46.1	1.06
5 SETS	41.5 ± 8.2	36.5–46.5	56.1 ± 11.9†‡§	48.9–63.3	1.77
Leg press (kg)					
Control	157.8 ± 21.0	141.6–174.0	155.0 ± 25.0	130.8–169.2	−0.37
1 SET	170.0 ± 34.1	148.3–191.7	196.7 ± 15.5†‡	186.8–206.6	0.78
3 SETS	172.5 ± 30.1	153.3–191.7	199.2 ± 14.4†‡	190.0–208.3	0.88
5 SETS	178.5 ± 24.4	163.7–193.2	201.5 ± 25.4†‡	186.2–216.9	0.94

*RM = repetition maximum; CI = confidence interval; BP = bench press; LPD = lat pull down; SP = shoulder press.
†$p \leq 0.05$ statistically significant difference from the corresponding pretraining value.
‡$p \leq 0.05$ statistically significant difference compared with the control group.
§$p \leq 0.05$ statistically significant difference compared with the 1-SET group.
∥$p \leq 0.05$ statistically significant difference compared with the 3-SET group.

Statistical version 7.0 (Statsoft, Inc., Tulsa, OK, USA) statistical software was used for all the statistical analyses.

Results

Volume Load

Training volume (Table 1) significantly increased for all training groups pre- (first session) to post-training (last session) ($p \leq 0.05$). At pretraining, the training volume for the 3-SET and 5-SET groups was significantly greater compared with the 1-SET group ($p \leq 0.001$), and training volume for the 5-SET group was significantly greater than the 3-SET group ($p \leq 0.001$). At posttraining, both the 3-SET and 5-SET groups showed a training volume significantly greater than the 1-SET group ($p \leq 0.001$) and the training

Table 3. Absolute values of 20RM before and after 6 months of training and effect size (values are mean ± *SD*).*

Group	Pre	95% CI	Post	95% CI	Effect size
BP (kg)					
Control	36.1 ± 4.8	32.37–39.84	37.7 ± 3.6	34.98–40.56	0.34
1 SET	34.1 ± 3.5	37.28–37.71	35.8 ± 5.1	33.32–41.11	0.47
3 SETS	41.9 ± 7.2	36.23–47.10	49.2 ± 6.4†‡§	43.62–53.04	1.01
5 SETS	46.5 ± 4.7	42.37–49.84	57.6 ± 4.3†‡§∥	53.33–59.99	2.36
LP (kg)					
Control	93.3 ± 11.1	84.73–101.92	97.7 ± 14.8	86.39–109.16	0.40
1 SET	91.6 ± 10.2	82.98–101.46	102.5 ± 9.65†‡	93.82–110.62	1.05
3 SETS	105.3 ± 19.8	92.81–127.18	112.3 ± 18.7†‡	100.82–132.51	0.35
5 SETS	96.9 ± 10.3	88.07–105.26	131.5 ± 16.2†‡§	114.73–131.92	3.36

*RM = repetition maximum; CI = confidence interval; BP = bench press; LP = leg press.
†$p \leq 0.05$ statistically significant difference from the corresponding pretraining value.
‡$p \leq$ 0.0 5statistically significant difference when compared with the control group.
§$p \leq 0.05$ statistically significant difference when compared with the 1-SET group.
∥$p \leq 0.05$ statistically significant difference when compared with the 3-SET group.

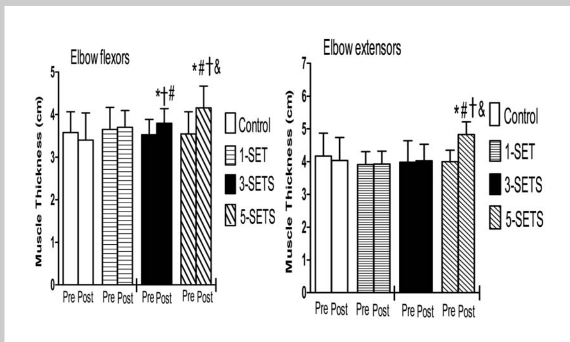

Figure 3. Absolute MT of elbow flexors and extensors in left arm before and after 6 months of training (data are mean and *SD*). $*p \leq 0.05$ statistically significant difference from the corresponding pretraining value; $\#p \leq 0.05$ statistically significant difference when compared with the CG; $\dagger p \leq 0.05$ statistically significant difference when compared with the 1-SET group; $\&p \leq 0.05$ statistically significant difference when compared with the 3-SET group. CG = control group; MT = muscle thickness.

volume of the 3-SET group was significantly lower than the 5-SET group ($p \leq 0.001$).

Five Repetition Maximum

Pre- and post-training values of the 5RMs are reported in Table 2. At pretraining, there were no significant differences among groups in any one of the 4 exercises tested ($p \geq 0.05$). All training groups significantly increased the 5RM for all exercises from pre- to post-training and compared with the CG ($p \leq 0.05$). Posttraining for the BP and LPD exercises, the 3-SET and 5-SET groups showed strength gains greater than the 1-SET group ($p \leq 0.05$), and the 5-SET group showed an increase significantly greater than 3-SET group ($p \leq 0.05$). At posttraining for SP exercise, the 3-SET and 5-SET groups showed an increase significantly greater than the 1-SET group ($p \leq 0.05$). Posttraining for the LP exercise, the strength gains were similar among the training groups.

The ES values of the 5RM are reported in Table 2. The ES for the change in BP 5RM was small for 1-SET (0.91) and 5-SET (0.97) groups and was moderate for the 3-SET group (1.35). For LPD and SP exercises, the ES for the change in 5RM was small for the 1-SET (1.01 and 0.99) and 3-SET (1.21 and 1.06) groups and moderate for the 5-SET group (1.29 and 1.77). In the LP exercise, the ES for the change was small for 1-SET (0.78), 3-SET (0.88), and 5-SET (0.94) groups.

Twenty Repetition Maximum

Before training, there was no difference among groups for 20RM in the BP and LP exercises ($p \geq 0.05$). Absolute values pretraining, posttraining and ES values of the 20RM are reported in Table 3. After training, the 1-SET group did not show a significant change in BP 20RM, whereas the 3-SET and 5-SET groups significantly increased 20RM in the BP compared with pretraining and showed significantly greater increases compared with the 1-SET group and CG ($p \leq 0.05$). Pre- to post-training, the 5-SET group exhibited gains significantly greater than the 3-SET group ($p \leq 0.05$). The ES for changes in 20RM in the BP were trivial for the 1-SET (0.47) group and moderate for the 3-SET group (1.70) and large for the 5-SET group (4.35) groups.

The LP 20RM significantly increased pre- to post-training in all training groups and compared with the CG ($p \leq 0.05$). The 5-SET group showed a significantly greater increase than the 1-SET group ($p \leq 0.05$). The ES for the change in the LP 20RM was small for 1-SET group (1.05), moderate for the 3-SET group (1.71), and large for the 5-SET group (3.36).

Muscle Thickness

No significant differences were observed among groups in MT of the elbow flexors and extensors at pretraining ($p \geq 0.05$). Absolute MT of elbow flexors and extensors pre- and post-training are shown in the Figure 3. Muscle thickness of the elbow flexors and extensors of the 1-SET group did not change significantly pre- to post-training. The MT of the elbow flexors in the 3-SET and 5-SET groups significantly increased from pre- to post-training and showed a significant difference compared with the 1-SET group and CG ($p \leq 0.05$). The 5-SET group showed a significantly greater increase than the 3-SET group ($p \leq 0.05$). The ES for the change in the elbow flexor MT was trivial for the 1-SET group (0.10) and small for the 3-SET (0.73) and 5-SET

Table 4. CMJ height (in centimeters) before and after 6 months of training and effect size (values are mean ± *SD*).*

Group	Pre	95% CI	Post	95% CI	Effect size
Control	40.1 ± 8.5	32.94–47.30	39.5 ± 8.6†	32.30–46.69	−0.77
1 SET	48.4 ± 7.9	40.49–55.75	50.81 ± 7.2†‡	43.91–57.58	0.30
3 SETS	47.7 ± 7.4	39.70–54.04	50.38 ± 7.1†‡	42.73–56.51	0.35
5 SETS	45.5 ± 7.7	41.17–52.32	48.61 ± 6.6†‡	44.68–54.31	0.40

*CMJ = countermovement jump; CI = confidence interval.
$\dagger p \leq 0.05$ statistically significant difference from the corresponding pretraining value.
$\ddagger p \leq 0.05$ statistically significant difference when compared with the control group.

Table 5. Percentage body fat and FFM by group before and after 6 months of training (values are mean ± *SD*).*

Group	Pre	95% CI	Post	95% CI	Effect size
Percentage body fat					
Control	17.3 ± 2.2	15.9–18.7	17.3 ± 2.2	15.8–18.73	0.02
1 SET	16.6 ± 3.1	15.4–17.8	12.6 ± 3.3†‡	10.6–14.6	1.29
3 SETS	16.7 ± 3.3	14.7–18.7	10.7 ± 2.8†‡	9–12.5	1.77
5 SETS	17.1 ± 2.8	15.4–18.8	11.8 ± 2.6†‡	10.2–13.4	1.86
Fat-free mass (kg)					
Control	61.95 ± 7.80	55.95–67.95	64.86 ± 8.06†	58.66–71.06	0.37
1 SET	67.24 ± 8.26	60.89–73.60	67.70 ± 6.51†	62.69–72.71	0.06
3 SETS	63.01 ± 4.39	59.63–66.38	65.99 ± 5.17†	62.02–69.97	0.68
5 SETS	71.39 ± 5.92	66.83–75.95	74.71 ± 4.98†	70.88–78.55	0.56

*FFM = fat-free mass; CI = confidence interval.
†$p \leq 0.05$ statistically significant difference from the corresponding pretraining value.
‡$p \leq 0.05$ statistically significant difference compared with the control group.

(1.10) groups. The elbow extensor MT significantly increased only for the 5-SET group from pre- to post-training and showed a significantly greater increase compared with the other training groups and CG ($p \leq 0.05$). The ES for the change was trivial for the 1-SET (0.05) and 3-SET (0.05) groups and large for the 5-SET group (2.33).

Maximum Height Countermovement Jump

Before testing, there was no significant difference among the groups in maximum height CMJ ($p \geq 0.05$). All training groups significantly increased CMJ maximum height pre- to post-training and compared with the CG ($p \leq 0.05$) with no significant difference among training groups (Table 4). The ES for the change in maximum height CMJ was trivial for 1-SET (0.30), 3-SET (0.35), and 5-SET groups (0.40).

Body Composition

Pre- and post-training values of percentage body fat and FFM are shown in Table 5. At pretraining, no significant differences in percentage body fat and FFM were observed among groups ($p \geq 0.05$). All training groups exhibited a significant decrease in percentage body fat pre- to post-training and compared with the CG ($p \leq 0.05$). No significant differences were observed among training groups at posttraining ($p \geq 0.05$). The ES for the change in percentage body fat were large for all training groups (1 SET, 1.27; 3 SETS, 1.77; 5 SETS, 1.86), but followed a dose-response pattern. The FFM of all groups showed a significant increase from pre- to post-training ($p \leq 0.05$), with no significant difference among groups ($p \geq 0.05$). The ES for the change in FFM was trivial for the CG (0.37) and 1-SET group (0.06) and was small for the 3-SET (0.68) and 5-SET (0.56) groups.

Discussion

Because of 6 months of weight training, all training groups increased the 5RM, a measure of strength, in all 4 exercises tested and 20RM, a measure of local muscular endurance, in at least one of the 2 of exercises tested. For both 5RM and 20RM increases due to training, a dose-response to training volume was generally shown. The 5-SET group demonstrated significantly greater increases than the 1-SET group for both exercises tested for 20RM and a significantly greater increase than the 3-SET group in one of the 2 exercises tested for 20RM. The 5-SET group also showed a significantly greater increase than the 1-SET group in 5RM for 3 of the 4 exercises tested and a significantly greater increase than the 3-SET group in 2 of the 4 exercises tested. Thus, the major hypotheses that multiple sets would result in greater changes in strength and local muscular endurance than single-set training and that there would be a dose-response for these same measures were supported.

The ES for all training outcomes investigated supported a dose-response effect due to training volume. These findings support meta-analyses and reviews concluding training volume, in the form of multiple sets per exercise or muscle group, shows a dose-response pattern with greater increases shown with greater volume (14,15,22,27,39). The results of this study also support a meta-analysis concluding multiple sets per exercise or muscle group result in significantly greater strength, hypertrophy, and local muscular endurance than single-set programs (15). In particular, higher volume training (5 sets) results in greater increases than low-volume training (1 set) for strength, local muscular endurance, and hypertrophy.

Our results showed that 5 sets per exercise resulted in greater 5RM strength gains compared with 1 and 3 sets in 2 of 3 upper-body exercises. While in the only lower-body exercise tested (LP), although the ES favored the 3-SET and 5-SET groups, no significant difference among groups in 5RM strength was shown. The results of this study indicate that increased training volume is more effective in the upper body than lower body in producing strength increases.

The results of this study that multiple sets are more effective for producing strength increases in the upper body, but not the lower body, disagree with some previous studies. Over 6 weeks of training with three or 1 set of upper- and lower-body exercises, 3 sets were superior (21% vs. 14%) to 1 set in increasing 1RM strength in 3 lower-body exercises, but similar (16% vs. 14%) in 1RM increases in 4 upper-body exercises (20). During 11 weeks of training with 3 or 1 set of lower- and upper-body exercises, 3 sets were superior (41% vs. 21%) for 1RM increases in 3 lower-body exercises, but similar (25 vs. 25%) for 1RM increases in 5 upper-body exercises (28). Untrained males were the subjects in this study and the 2 previous studies. Thus, training status does not account for the discrepancy among studies concerning number of sets and strength increases. In both previous studies, all lower-body exercises were performed before performing the upper-body exercises. In this study, an upper to lower body alternating exercise order was used.

The effect of exercise order in the form of lower-body exercises preceding upper-body exercises has received some research attention (29). When 3 lower-body exercises preceded exercises for the elbow flexors, during 11 weeks of training, biceps curl 1RM, power at 30 and 60% of biceps curl 1RM, and elbow flexor muscle volume increased significantly more compared with not performing lower-body exercises before elbow flexor exercises. The significantly greater increases when lower-body exercises preceded elbow flexor exercises were attributed to the acute greater plasma growth hormone and testosterone concentrations due to performing the large muscle mass lower-body exercises. These greater hormone concentrations resulted in a more favorable anabolic environment over the 11 weeks of training, which resulted in greater increases in strength, power, and hypertrophy of the elbow flexors. Thus, in the previous 2 studies (20,28) performing the leg exercises before the upper-body exercises may have created, a more favorable anabolic environment that in part negated the effect of greater exercise volume (3 sets vs. 1 set per exercise) for the upper-body exercises. While in this study, large muscle group exercises were performed before smaller muscle group exercises, but in an upper and lower body alternating exercise order. Thus, the hormonal effect of large muscle group lower-body exercises before upper-body exercises may have been less evident. This resulted in training volume of the upper-body exercises having a more pronounced effect on upper-body strength measures. The possible interaction of exercise order with training volume warrants further investigation.

The training intensity, in this study, was standardized between 8 and 12RM, which emphasizes both strength and local muscular endurance (7,10). Local muscular endurance as measured by 20RM in the BP and LP showed a clear dose-response to training volume. Significant differences in 20RM increases between training groups and ES showed a dose-response to be especially evident in the BP with the 3-SET group showing a significantly greater increase than the 1-SET group and the 5-SET group showing a significantly greater increase than both the 1-SET and 3-SET groups. In the LP, a 20RM dose-response is also evident, but to a lesser extent, with the only significant difference being a significantly greater increase by the 5 SETS compared with the 1-SET group. However, ESs showed a dose-response effect for LP 20RM increases. It is also important to note that the BP 20RM of the 1-SET group did not show a significant increase due to training.

The local muscular endurance dose-response shown in this study supports the hypothesis that high-volume protocols improve local muscular endurance to a greater extent than a low-volume single-set program (17). The present results concerning a volume dose-response for local muscular endurance are supported by Marx et al. (17), reporting that in untrained women, 2–4 sets per exercise, performed until the targeted number of repetitions, produced superior increases than 1 set per exercise performed to momentary muscular failure in LP and BP local muscular endurance after 24 weeks of training. However, some studies do not support a training volume dose-response for local muscular endurance. Hass et al. (10), after 13 weeks of training, found that in recreational weight trainers, with an average of 6.2-year strength training experience, 1 set and 3 sets to concentric failure similarly increased leg extension and chest press local muscular endurance determined by the number of repetitions to failure at 75% of 1RM. Although some discrepancy is apparent, collectively, these studies support a dose-response for training volume and local muscular endurance for both the upper- and lower-body exercises.

Previous studies found that 1 set and 3 sets are effective in promoting significant muscle hypertrophy in upper-body muscles (4,8,28). In contrast, after 6 months of training, our results showed that the 1-SET group did not demonstrate significant hypertrophy in the elbow flexor and extensor muscle groups. While the 3-SET and 5-SET groups exhibited hypertrophy of the elbow flexors and only the 5-SET group showed significant muscle hypertrophy of the elbow extensors. It has been hypothesized that due to the minimal amount of total work performed during daily-life activities by muscles of the upper body, compared with the lower body, a minimal amount of resistance training would cause hypertrophy of the upper-body musculature (7,11). Our data do not support this hypothesis rather our data indicate during long training periods (6 months) at least 3 sets may to be necessary to promote significant muscle hypertrophy of the upper body and that in some muscle groups, such as the elbow extensors, greater than 3 sets may be needed to induce significant hypertrophy. One limitation of this study was that MT was determined at only 1 site for each muscle group; however, muscle hypertrophy may be nonuniform along a muscle's length due to different tensions generated along the length of the muscle fibers (2,19). Thus, future studies exploring the volume dose-response on muscle hypertrophy at different sites along the length of a muscle are necessary, especially to observe if different regions of the same muscle respond differently to different training volumes.

Countermovement jump ability increased in all training groups with no significant difference shown between groups. This contradicts the results of previous studies reporting superior increases in the vertical jump using multiple sets compared with single-set training programs (13,30). Methodological differences may have caused the discrepancy among studies. Kraemer et al. (13), used trained subjects in their study, whereas in the Sanborn et al. (30) study, only the subjects in the multiple-set group were encouraged to perform the resistance exercises as explosively as possible. Thus, these previous studies indicate in trained subjects multiple sets and performing multiple sets in an explosive manner increase CMJ to a greater extent than single-set programs. In this study, the subjects were untrained and performed each repetition at a self-selected velocity. Improvement in CMJ ability has a correlation with strength gains in the leg and hip musculature (30). In this study, the 1-, 3- and 5-SET groups significantly increased LP 5RM with no significant difference shown among groups. So no significant difference in CMJ among training groups in this study may be in part explained due to no significant difference in leg strength increases between training groups.

The percentage of body fat was reduced significantly and FFM significantly increased in all training groups, with no significant difference between groups. This finding is supported by Marshall et al. (16), reporting that in resistance-trained males, 6 weeks of strength training of squat exercise with 1, 4, and 8 sets promoted similar improvement in body composition assessed by skinfolds. Previous studies investigating the effects of strength training volume on body composition report decreases and no change in percent fat (10,12,13,37) due to weight training. In that changes in body composition are affected by factors other than resistance training volume, such as diet, lack of a significant difference among training groups is not surprising. Percentage of body fat is also influenced by metabolic factors such as insulin sensitivity through fat-specific cytokine-mediated pathways and direct influence of intramyocellular fat storage on insulin receptor function within muscle tissue (3,36). Subjects in this study were instructed not to change their diet and all subjects ate all meals at the same dining facility. The increases in FFM shown by all training groups indicate sufficient intake of nutrients. Weaknesses of the present and previous studies are diet was not controlled and body fat percentage was assessed using skinfolds, which may not be sensitive enough to measure body fat changes caused by resistance training.

In conclusion, in this study, ES and significant differences between groups generally support a dose-response for strength, local muscular endurance, and muscle hypertrophy increases. However, significant differences between groups performing 1, 3, and 5 sets of each exercise in a training program do not always demonstrate a training volume dose-response. Countermovement jump ability in this study did not show a training volume dose-response.

Practical Applications

After 6 months of training, multiples sets of each exercise were superior to a single set of each exercise in promoting strength, muscle endurance, and muscle hypertrophy increases in upper-body musculature. Therefore, during a long training period, 5 sets per exercise is superior to 3 sets per exercise and 3 sets per exercise is superior to 1 set per exercise to cause increases in upper-body strength, local muscular endurance, and hypertrophy. These results suggest that the upper body shows a dose-response to training volume. Increases in lower-body muscle endurance also showed multiple sets to be superior to a single set. Although no significant difference was shown between training volumes for strength development in the lower body, however, ESs of 5RM increases of the LP indicated a dose-response to training volume for strength increases. Our findings have direct implications for long-term program design of subjects with no previous weight training experience.

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