Effects of Training Volume on Strength and Hypertrophy in Young Men

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Abstract

Sooneste, H, Tanimoto, M, Kakigi, R, Saga, N, and Katamoto, S. Effects of training volume on strength and hypertrophy in young men. *J Strength Cond Res* 27(1): 8–13, 2013–Knowledge of the effects of training volume on upper limb muscular strength and hypertrophy is rather limited. In this study, both arms of the same subject were trained in a cross-over-like design with different training volumes (1 or 3 sets) to eliminate the effects of genetic variation and other individual differences. The purpose of this study was to investigate the effects of training volume on muscular strength and hypertrophy in sedentary, untrained young Japanese men. Eight subjects (age, 25.0 ± 2.1 years; body mass, 64.2 ± 7.9 kg; height, 171.7 ± 5.1 cm) were recruited. The subjects trained their elbow flexor muscles twice per week for 12 consecutive weeks using a seated dumbbell preacher curl. The arms were randomly assigned to training with 1 or 3 sets. The training weight was set at 80% of 1 repetition maximum for all sets. The 3-set protocol increased cross-sectional area significantly more than did 1 set (1 set, 8.0 ± 3.7%; 3 sets, 13.3 ± 3.6%, $p < 0.05$). Furthermore, gains in strength with the 3-set protocol tended to be greater than those with 1 set (1 set, 20.4 ± 21.6%; 3 sets, 31.7 ± 22.0%, $p = 0.076$). Based on the results, the authors recommend 3 sets for sedentary untrained individuals. However, this population should incorporate light training days of 1 set into their training program to prevent overtraining and ensure adherence. The findings are relevant for the sedentary, untrained young male population and must be interpreted within the context of this study.

Key Words muscle hypertrophy, muscle strength, resistance training

Introduction

Resistance training (RT) helps to improve muscular fitness and health. Regardless of age and sex, many people are engaged in regular RT (3) because it has been demonstrated to be the most effective method available for maintaining and increasing lean body mass and muscular strength (12). However, designing a RT program is a complex process that requires a thorough knowledge of acute training variables and key principles, which were first introduced by DeLorme (5) and DeLorme and Watkins (6). Kraemer (19) redefined the acute training variables, including (a) muscle action, (b) loading and volume, (c) exercise selection and order, (d) rest periods, (e) repetition velocity, and (f) frequency. These acute training program variables are the most important components of any RT program. The combinations of these variables affect the degree of RT stimulation, which, in turn, determines how neuromuscular and musculoskeletal systems respond to training. All of these acute training variables have been intensively studied, and evidence-based conclusions have been reached during the past decade, with the exception of training volume (2).

Many well-conducted analytical reviews (9,10,23,33,41) and independent studies (16–18,21,32,37) have investigated the effects of training volume (single vs. multiple sets) on strength gains. A meta-analysis by Rhea et al. (33) reported that 4 sets of RT per muscle group elicits the greatest gains in strength, and a meta-regression by Krieger (23) found that 2 to 3 sets per exercise results in 46% greater strength gains compared with 1 set. This large body of evidence clearly demonstrates the superiority of multiple sets over a single-set protocol. However, results concerning training volume in sedentary untrained individuals contradict the above recommendations. A bulk of the scientific literature has found that sedentary untrained individuals benefit equally from single- and multiple-set training during the initial phase (<3 months) of RT (2,9,10,41). These inconsistencies may be because of large differences in study design (e.g., periodized vs. non-periodized training, free weights vs. machines, different muscles used, training to failure or not, and washout period) and different training variables (e.g., rest periods between sets, intensity, and frequency), which make direct

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comparisons between the results of different studies difficult. Additionally, individual differences such as genetic variation, daily condition of the body, nutritional intake, sleep, and training method must also be considered. Previous studies have mainly used different groups of subjects and/or wash-out periods between bouts of low- and high-volume training. However, this type of methodological approach does not provide sufficient control over individual differences within the same timeframe and may therefore influence the outcome of the study. Considering this, further studies using well-controlled designs that consider individual differences could provide insights into this hypothesis.

The purpose of this study was to investigate the effects of training volume on muscular strength and hypertrophy in sedentary untrained elbow flexors of young men. This study was unique in that both upper limbs were trained with different training volumes (1 vs. 3 sets) in a crossover-like design. This design allowed each subject to act as their own control and thus individual differences such as genetic variation, daily condition of the body, nutritional intake, sleep, and training method were eliminated.

We hypothesized that sedentary untrained subjects will benefit equally from 1 and 3 set training with respect to muscle strength and growth. However, muscle hypertrophy is more volume dependent (23,26); therefore, the rate of muscle hypertrophy may be significantly different for the 3-set group.

Methods

Experimental Approach to the Problem

A crossover-like design was chosen. Right and left arms of 8 sedentary untrained subjects were randomly assigned to training with 1 or 3 sets. This study design allowed each subject to act as their own control. We used a seated dumbbell preacher curl to ensure strict form during training and to avoid inertia and the bouncing effect. Execution speed was also controlled using a digital metronome. At least 6 weeks are required for muscle hypertrophy to become apparent, and it can be difficult to detect (29). Thus, the training period was set at 12 weeks. Blood lactate was measured to ensure that all subjects were training with a high enough intensity.

Subjects

Eight young Japanese men (age, 25.0 ± 2.1 years; body mass, 64.2 ± 7.9 kg; height, 171.7 ± 5.1 cm) volunteered for the study (Table 1). All subjects were healthy, sedentary untrained volunteers without RT experience. Subjects were included if they were free from upper limb injury and not involved in regular strength training 12 months before commencement of the study. Subjects were not allowed to participate in any form of exercise except light recreational jogging during the experiment. There were no dietary restrictions for subjects during the study period except that taking any kind of performance enhancing nutritional supplements was strongly prohibited. Water was allowed ad libitum. Six subjects were right handed, and 2 subjects were left handed. Approval by the Institutional Review Board of Juntendo University was obtained before the investigation. All subjects were informed of any risks associated with participating in the study and signed an informed consent form, according to the Declaration of Helsinki, before participating in any of the testing or training.

Table 1. Physical characteristics of the subjects (mean ± SD).

Subjects (*n*)	Age (y)	Height (cm)	Body mass (kg)
8	25.0 ± 2.1	171.7 ± 5.1	64.2 ± 7.9

Procedures

Testing. The training period started in December and ended in February (12 consecutive weeks). The before training measurements were made during the last week of November, and the after training measurements were performed at the end of February and at the beginning of March. All testing and the majority of training sessions were performed in the afternoon with some exceptions because of the subjects' class schedules.

Each subject was weighed on a digital scale (Yamato EDI-303, Tokyo, Japan) before and after the 12-week training period, and height was measured.

Muscle strength was assessed using the 1 repetition maximum (1RM) for a seated dumbbell preacher curl on 4 occasions: before training (pretest) and at 4, 8, and 12 weeks (posttest). The 1RM assessment procedure was conducted as described by Earle (7). Briefly, light stretching and 1 set of 10 reps with a weight of approximately 50% of the 1RM were used as a warm-up before starting the assessment. The same well-trained research assistant always controlled for proper technique and maximum effort during the tests. It took 3–4 attempts to determine the pretraining 1RM and 2–3 attempts on the other 3 occasions. Subjects were reminded before each trial to perform at maximal exertion, but no verbal encouragements were given during the lift. Weight was adjusted and determined to the closest 1.0 kg by the same research assistant on all occasions. The nontest arm remained in a relaxed posture on the preacher curl bench throughout the testing procedure. The speed of movement was not controlled during the 1RM tests, and no training was done on the day of 1RM testing. Three minutes of rest were allowed between attempts on all 4 occasions, and 1RM was measured on both arms on the same day. Five minutes of rest were taken between measuring the 2 arms. Test–retest reliability was determined during a pilot study on 9 sedentary, untrained young male subjects. Our calculations revealed an intraclass correlation coefficient (ICC) of 0.974 for the left arm and

0.993 for the right arm, indicating that the testing procedures were highly reliable.

Before and after the 12-week training period, magnetic resonance imaging (MRI) (Esaote C-Scan, Genova, Italy) measurements were performed to assess changes in the cross-sectional area (CSA) of the biceps brachii and brachialis muscles. To avoid temporary exercise effects, such as swelling or water shifts, the MRI was performed before the 1RM assessment for the pretest and 72 hours after the last 1RM assessment for the posttest. It was very important that the positioning of each subject was reliably reproduced during the MRI to avoid errors. Thus, the subject was asked to abduct his arm to shoulder height and flex, making skin folds visible at the elbow. After marking the uppermost skinfold on the subject's skin with black ink, the subject adducted his arm, and the length of the arm from the acromion of the scapula to the skinfold was measured using a metal nonstretchable tape measure. Then, 20% of the overall length was calculated, and wet cotton was taped on the subject's skin to make the location viewable on MRI. The marker was placed at the 20% line because of the technical limitations of the MRI scanner. We collected 15 slices (thickness, 3.0; gap, 0.4) for each arm (pre/post). A picture of the arm in the transverse position was taken with a digital camera through the preview window to ensure that the humerus was at the same angle before and after scanning.

The CSAs of the biceps brachii and brachialis were measured using the scanner's built-in image tracing software by tracing the muscle borders. The mean value of the 3 slices surrounding the cotton were used for statistical analyses.

Blood lactate concentration was measured on separate days for the 1-set and 3-set arm exercises during week 10. Subjects were not allowed to engage in any kind of vigorous activity on that day. Blood samples were collected before (pretest) and immediately after every set and at 2, 3, and 5 minutes after training. Resting blood level samples were collected after 15 minutes of complete rest. Approximately 5 μl of blood was taken from the subject's earlobe via a needle and immediately analyzed for blood lactate concentration using a lactate analyzer (Lactate Pro; Japan Arkray, Inc., Kyoto, Japan). The Lactate Pro analyzer had high repeatability with a coefficient of variation of 3% and is very accurate and reliable (30).

Table 2. Average number of repetitions per set (mean ± SD).

Subjects (n)	1-set arm	3-set arm		
		1 set	2 sets	3 sets
8	9.6 ± 0.3	9.8 ± 0.2	9.0 ± 0.8	7.3 ± 1.5*†

*Significant differences from 1 set ($p < 0.05$); †significant differences from 2 sets ($p < 0.05$).

Training. Training was performed 2 times per week for 12 weeks. A light warm-up, consisting of stretching and 1 set of 10 reps with about 50% of the training weight, was always performed before training. Subjects were required to alternate their arms; that is, on 1 day, they started training with the 1-set arm, and the next time, the 3-set arm was trained first. A 5-minute rest was taken between the 2 protocols.

The training weight was set at 80% of the 1RM. The subjects trained with the same weight for 4 weeks until the next 1RM test (i.e., no weight load adjustments were made between 1RM tests.) The subjects trained to muscular failure each time or until 10 reps were completed. The supervising researcher did not provide any verbal encouragement and did not spot.

The speed of movement was controlled by a digital metronome: 2 seconds for raising and 2 seconds for lowering the weight. Thus, 1 repetition lasted 4 seconds. Faster training velocities are more effective than slower movements for gaining strength (14,27). The lifting and lowering phase were set at 2 seconds to minimize the risk of injury and the inertial effects at faster rates.

Statistical Analyses

All data are expressed as mean ± SD. Pre/posteffect sizes (ES), representing a standardized mean difference, were calculated with the following formula: [(post-test mean − pre-test mean)/pre-test SD] (4). Power calculations (statistical power) were performed using G*power computer software. Statistical power of >80% was obtained for (1 and 3 sets) muscle strength and CSA measurements in both groups. The average number of reps per set for the 3-set arm was

Table 3. Gains in the 1 repetition maximum (1RM) (mean ± SD).

	Pretest	1RM (kg) Wk 4	Wk 8	Posttest (wk 12)
1-set arm	9.1 ± 1.6	9.6 ± 1.8	10.5 ± 2.3*	10.9 ± 2.5*†
3-set arm	9.1 ± 1.8	9.8 ± 2.0	11.5 ± 2.4*†	11.9 ± 2.9*†

*Significant differences from prevalue ($p < 0.05$); †significant difference from 4-week value ($p < 0.05$); $n = 8$.

compared with that for the 1-set arm using a one-way repeated-measures analysis of variance (ANOVA). Blood lactate values were analyzed by two-way (volume × time) repeated-measures ANOVA. Post-hoc testing was performed with the Bonferroni test, when appropriate. The paired *t*-test was used to analyze pre- and posttraining values and percentage gains in muscle CSA and strength. Intraclass correlation coefficients were used to determine 1RM test–retest reliability. The ICC method was used based on a repeat measurement of maximal strength. Statistical significance was accepted at $p < 0.05$. Statistical analyses were conducted with Prism 5.0 statistical software (GraphPad Software, Inc., La Jolla, CA, USA).

Results

All 8 subjects completed all training sessions. No significant differences were observed for muscle strength and CSA prevalues between the 1-set and 3-set arm groups. The number of repetitions per set (mean ± SD) is presented in Table 2. No significant difference was observed in the number of repetitions between the first and second sets of the 3-set arm group. However, the number of repetitions in the third set was significantly lower than that in the first and second sets ($p < 0.05$).

According to Cohen's categories to classify ES (small, <0.41; moderate, 0.41–0.70; large, >0.70), the degree to which our training program produced favorable changes in muscle strength was large (1 set, 1.13; 3 sets, 1.56, $p < 0.05$). Only the 3-set group had a large ES for muscle hypertrophy (1 set, 0.32; 3 sets, 0.86, $p < 0.05$) (4). These data demonstrate a larger treatment effect for muscle strength than that of hypertrophy.

Gains in 1RM (mean ± SD) during the 12 weeks of RT are shown in Table 3. After 12 weeks of training, the 1RM for both arms (1 and 3 sets) increased significantly. The posttest value for the 1-set arm group was 10.9 ± 2.5 kg, which was a 20.4 ± 21.6% gain in muscle strength. The posttest value for the 3-set arm was 11.9 ± 2.9 kg, and the percent gain was 31.7 ± 22.0%. A comparison of the 1RM percent gains revealed a tendency to favor the 3-set protocol ($p = 0.076$).

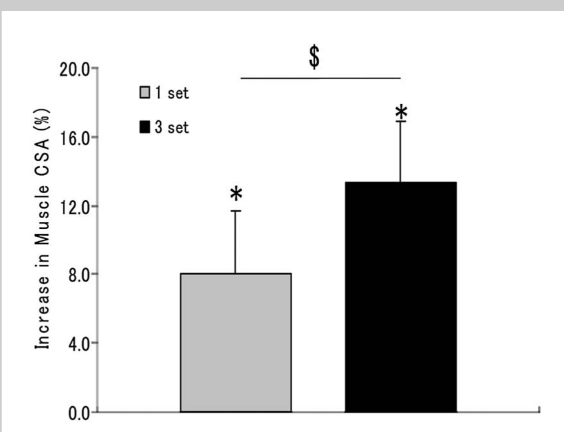

Figure 1. Comparison of percent gains in cross-sectional area (CSA) of elbow flexor muscles for the 1-set and 3-set arm groups (mean ± SD); $n = 7$. *Significant difference between pre- and posttraining values ($p < 0.05$). $Significant difference between groups ($p < 0.05$).

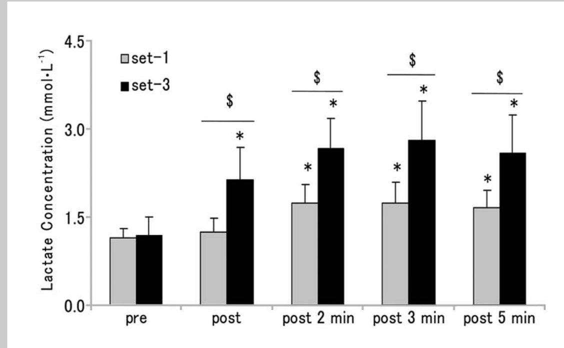

Figure 2. Comparison of blood lactate concentration at the pre-exercise session and at 2, 3, and 5 minutes after the last set for the 1-set and 3-set arm groups (mean ± SD); $n = 8$. *Significant difference as compared with pretraining values ($p < 0.05$). $Significant difference between groups ($p < 0.05$).

Both training protocols resulted in significantly increased CSA of the elbow flexor muscles (sum of biceps brachii and brachialis) ($p < 0.05$). The CSA increased from 1,596.6 ± 251.4 mm^2 to 1,677.4 ± 2,41.3 mm^2 in the 1-set arm group and from 1,640.6 ± 303.1 mm^2 to 1,902.3 ± 403.6 mm^2 in the 3-set arm group. The percent gain for the low-volume arm was 8.0 ± 3.7%, whereas it was 13.3 ± 3.6% for the high-volume arm. A significant difference in CSA was observed between the 2 protocols in favor of the 3-set group ($p < 0.05$, Figure 1). The sample size for muscle CSA was 7 subjects because of difficulties with reliably reproducing the correct positioning of 1 subject's right arm.

Compared with pretraining values, blood lactate concentrations at 3 minutes after completing the last set rose significantly in both groups (1 set, 1.1 ± 0.2 $mmol \cdot L^{-1}$ and 1.7 ± 0.4 $mmol \cdot L^{-1}$, respectively; 3 sets, 1.2 ± 0.3 $mmol \cdot L^{-1}$ and 2.8 ± 0.7 $mmol \cdot L^{-1}$, respectively, $p < 0.05$). Blood lactate concentrations measured 3 minutes after the last set were significantly higher for the 3-set arm group compared with the 1-set arm group ($p < 0.05$; Figure 2).

Discussion

The purpose of the present study was to investigate the effects of training volume on muscular strength and hypertrophy in sedentary, untrained young men's elbow flexors. Regarding muscle strength, our experiment demonstrated a nonsignificant trend ($p = 0.076$) for the superiority of 3 sets of RT over 1 set, with this trend becoming more apparent from week 8. In relation to muscle growth, 3 sets of RT resulted in significantly greater gains ($p < 0.05$) than 1 set. Although several studies (13,16–18,20,25,28,34,37,39) have been undertaken to examine the effects of training volume in sedentary untrained individuals, to our knowledge, this is the first study to train upper limbs of the same subject in a crossover-like design with different training volumes (1 or 3 sets). Our findings are in line with recommendations of recent American College of Sports Medicine's position stands (2,10) and other scientific works (23,24,41).

Neural adaptations are known to be responsible for strength growth in sedentary untrained individuals during early stages of RT (36). Comparing the gains in strength revealed a tendency to favor the three-set protocol (1 set, 20.4 ± 21.6%; 3 sets, 31.7 ± 22.0%, $p = 0.076$). Untrained subjects, like in our experiment, are known to experience bigger gains of 25–30% compared with 2–7% strength gains in trained populations (1,8,11,28). This significant increase can occur without any overt changes in muscle mass. Rapid strength gain in untrained subjects can be partly explained with the fact that untrained individuals are not able to fully activate their muscles and there seems to be a functional reserve that is not immediately available for use (35).

After 12 weeks of twice per week elbow flexor training (preacher curl), muscle CSA had increased 8.0 ± 3.7% for 1-set arm group and 13.3 ± 3.6% for 3-set arm group ($p < 0.05$). Significantly bigger gains in muscle CSA were obtained with 3 sets. Hubal et al. (15) also reported bigger gains in muscle CSA with multiple sets. In their experiment, 20% gain in CSA was reported after training untrained subjects' elbow flexors for 12 weeks with 3 different exercises of 3 sets. These findings demonstrate that muscle hypertrophy is more training volume dependent.

Acute response of the neuroendocrine system to RT has been suggested to be of primary importance for muscle hypertrophy (22). Although hormonal responses were not measured during our experiment, multiple sets are known to elicit larger amounts of anabolic hormones than 1 set (40). However, recent scientific evidence has found that hormones, while important, do not have direct effect on muscle hypertrophy. Resistance training elevates muscle protein synthesis and repeated bouts of mechanical stress will summate over time to muscle hypertrophy (31). West et al. (40) trained 8 young men with 2 different exercise protocols to determine whether exercise-induced elevations in concentration of systemic anabolic hormones enhances myofibrillar protein synthesis after exercise. In high hormone exercise protocol, unilateral elbow flexor training was followed by high-volume leg training. This resulted in significant increase in concentration of anabolic hormones; however, no increases in the rate of myofibrillar protein synthesis was observed. Therefore, contribution of anabolic hormones to greater muscle hypertrophy can be considered low in our experiment.

Blood lactate measured immediately after training showed significant differences between the 2 protocols in favor of 3 sets. Blood lactate accumulates with heavy weight training, which activates fast twitch (FT) muscle fibers. This explains why both of the trained arms hypertrophied significantly compared with pretraining. The 3-set arm had a larger rate of hypertrophy because more work was done by the FT muscle fibers in that arm. Intense muscle work causes central and peripheral muscle fatigue, which seems to contribute to maximizing muscle strength (38) and hypertrophy.

Finally, the cross-educational effect must also be considered. Some strength from the 3-set arm could transfer to the arm trained with 1 set because of a cross-educational effect, which may be another reason why significant differences in muscle strength were not observed between the 2 protocols. A recent meta-analysis (25) determined that the magnitude of cross education is approximately equal to 7.8% of the initial strength of the untrained limb. Many studies have reported on cross-educational effect from trained limbs to nontrained limbs. But the magnitude of the cross-educational effect from a high-volume trained limb to a low-volume trained limb, as in this study, remains unclear. This made it difficult to determine how much cross-educational effect contributed to the strength gains in the low-volume arm in the present study.

The chosen study design made it possible to effectively exclude individual differences in subjects. Our results support that RT program of 3 sets are more beneficial for sedentary, untrained young male subjects wanting to increase their lean body mass. However, significant differences were not detected between 1-set and 3-set protocols for muscle strength in this population. Gains in muscle strength progressed in similar fashion until week 8 from where the effect of multiple sets on strength became more apparent. Therefore, further studies should focus on finding ways to maximize training effect from a single-set RT program. That would be a big contribution not only for sedentary untrained populations having difficulties with adherence but other beginners as well.

Practical Applications

Previous studies have explored training volume (1 set vs. 3 sets) using different groups of subjects or a washout period between 2 training periods with different volumes. We used a crossover-like study design, however, which made it possible to eliminate individual differences such as genetic variation, daily condition of the body, nutritional intake, sleep, and training method. The data indicate that both protocols (1 and 3 set) were effective to increase muscle strength and CSA in sedentary untrained subjects. Although multiple sets produced significantly greater increases in CSA, only a tendency to increase muscular strength was observed. Based on our results, we recommend that personal trainers and fitness professionals use 3 sets as a starting point for sedentary untrained individuals. However, light training days of 1 set should be incorporated into the training program for this population to prevent overtraining and ensure adherence. Such an approach guarantees that training volume will not be too high or low for this population.

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