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The Influence of Volume of Exercise on Early Adaptations to Strength Training

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ABSTRACT

The purpose of this investigation was to compare the effects of single-set strength training and 3-set strength training during the early phase of adaptation in 18 untrained male subjects (age, 20–30 years). After initial testing, subjects were randomly assigned to either the 3L–1U group ($n = 8$), which trained 3 sets in leg exercises and 1 set in upper-body exercises, or the 1L–3U group ($n = 10$), which trained 1 set in leg exercises and 3 sets in upper-body exercises. Testing was conducted at the beginning and at the end of the study and consisted of 2 maximal isometric tests (knee extension and bench press) and 6 maximal dynamic tests (1 repetition maximum [1RM] tests). Subjects trained 3 days per week for 6 weeks. After warm-up, subjects performed 3 leg exercises and 4 upper-body exercises. In both groups, each set consisted of 7 repetitions (reps) with the load supposed to induce muscular failure after the seventh rep (7RM load). After 6 weeks of training, 1RM performance in all training exercises was significantly increased (10–26%, $p < 0.01$) in both groups. The relative increase in 1RM load in the 3 leg exercises was significantly greater in the 3L–1U group than in the 1L–3U group (21% vs. 14%, $p = 0.01$). However, the relative increase in 1RM load in the 3 upper-body exercises was similar in the 3L–1U group (16%) and the 1L–3U group (14%). These results show a superior adaptation to 3-set strength training, compared with 1-set strength training, in leg exercises but not in upper-body exercises during the early phase of adaptation.

Key Words: single set, multiple sets, leg muscles, upper-body muscles

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Introduction

When composing a strength-training protocol, the number of sets per exercise is an important issue to consider. A common belief among scientists, bodybuilders, powerlifters, weightlifters, and strength-training amateurs is that when the purpose is to increase maximal strength or build muscle mass, multiple sets are superior to single sets (4, 15). However, in a review article, Carpinelli and Otto (3) concluded that 1 set per exercise is as effective as multiple sets and results in the same increase in maximal strength and hypertrophy as do multiple sets.

Carpinelli and Otto (3) reviewed 35 studies and found multiple sets to be favorable only in 2 studies (1, 7). On this basis, the authors concluded that there was no evidence to support the belief that multiple sets are superior to single sets, when the purpose is to achieve maximal strength progress or hypertrophy—irrespective of gender, age, muscle group, exercise equipment, and training status. Recommending the same number of sets for trained and untrained subjects is questioned because untrained subjects are used in most of the reviewed studies. For instance, Kraemer et al. (10) claimed that trained subjects were indeed dependent on multiple sets to ensure strength progress and hypertrophy. The latter suggestion is supported in recent studies by Kraemer (9) and Schlumberger et al. (14) but not by Hass et al. (6). Sanborn et al. (13) and Borst et al. (2) found, in 2 recent studies, multiple sets to be superior even in untrained men and women. This was also the case in the study of Marx et al. (11), but in this study, the groups differed regarding periodized training and number of strength-training bouts per week.

Therefore, it seems clear that Carpinelli and Otto (3) were too hasty in their conclusion because in most studies designed to actually compare single and multiple sets, multiple sets are reported to be superior to single sets. The picture is however not clear, and there seems to be a need for studies in which this topic is explored in different ways (e.g., untrained vs. trained subjects, short-term vs. long-term adaptations, and small muscle groups vs. large muscle groups). In this study, we wanted to look at possible differences between the effects of single and multiple sets in the early phase of adaptation to strength training and to examine possible differences in response to the 2

strength-training regimens between muscle groups in the upper body and in the legs.

The reason for choosing the early phase of adaptation (first 6 weeks of training) is that we hypothesize that if there is any period when single set theoretically could be as effective as multiple sets, it should be this phase during which both exercise stimuli represent great changes for the untrained muscles. The reason for looking at differences in responses between muscle groups is that antigravity muscles (e.g., most leg muscles) are more active during daily tasks (e.g., walking and standing) and might therefore need a greater stimulus than other muscles to achieve an increase in strength.

If 1 set should prove to be as effective as multiple sets during the early phase of adaptation, it is first of all a time-saving concept, which would probably be considered as an important advantage for many individuals starting strength training and in rehabilitation of patients suffering from atrophy after immobilization. The saved time could be used to practice other training forms or just as spare time.

The purpose of this study was to compare the effects of a single set against 3 sets during a 6-week training intervention. In addition, the study was designed to regard possible differences between upper-body and lower-body muscle groups.

Methods

Experimental Approach to the Problem

To address the question whether differences in training volume in the early phase of strength training affect strength gains, we compared the effects of 6 weeks of 1-set and 3-set strength training on maximum strength in untrained men. In an effort to reduce any possible effects of differences in whole-body training volume, one group performed 3 sets in leg exercises and 1 set in upper-body exercises, whereas the other group performed 1 set in leg exercises and 3 sets in upper-body exercises. Effects on strength gains were tested in 1 repetition maximum (1RM) tests in 3 leg exercises and 3 upper-body exercises and in 2 isometric tests before and after the 6-week training period.

Subjects

Twenty men (age, 20–30 years; height, 1.82 ± 0.05 m) served as the subjects. Two subjects withdrew before completion of the study because of causes unrelated to the study. The study was approved by the Regional Ethics Committee of the Norwegian Research Council for Science and the Humanities.

Subjects were randomly divided into 2 different groups. Group 1L–3U (n = 10) trained 1 set in leg exercises and 3 sets in upper-body exercises. Group 3L–1U (n = 8) trained 3 sets in leg exercises and 1 set in upper-body exercises. The objectives of this training protocol were to address differences between 1 and 3 sets and to address possible differences between upper-body muscle and muscle of the lower extremities. The reason for letting both groups perform both single and multiple sets in different exercises was to minimize any possible effect of whole-body training volume when the effects on the different muscle groups were evaluated.

Testing was conducted at the beginning and at the end of the study. Before the first test, all subjects were introduced to the training exercises and participated in 2 test workouts supervised by the investigators. Exercise machines were adjusted for each subject, and feedback on technical performances was given to each subject. Three days after the last pretesting workout, isometric peak torque in knee extension, isometric peak force in bench press, and 1RM in squat, knee extension, leg curl, bench press, shoulder press, and pull-down were tested. The order of tests was similar before and after training. The tests after training were conducted 3 days after the last workout. The subjects had to complete 15 of 18 (83%) workouts for inclusion in the study without training consecutive days or participating in other exercise activities. A training diary was written and controlled.

Training

The 6-week training period consisted of 3 workouts per week. The workouts consisted of squat, knee extension, leg curl, bench press, shoulder press, rowing, and latissimus pull-down. In all workouts, subjects performed all exercises. Subjects warmed up with 10 minutes of cycling at a workload of 60–70 W. A light warm-up set (40–50% of 1RM) preceded the target set(s) in each exercise in both groups. All subjects were supervised by one of the investigators in at least 1 of the 3 workouts per week during the entire training period.

In both groups, 7 repetitions (reps) were performed in each set. In each set, subjects tried to find the load that could be lifted for 7 reps before failure (7RM load). Subjects were encouraged to continuously increase their 7RM loads during the intervention. In exercises with 3 sets, the load could be changed between each set. Subjects were allowed assistance on the last rep. In all sets, subjects had to perform each rep with maximal speed in the concentric phase of the exercise. The eccentric phase had to be performed with proper control at a lower speed than the concentric phase.

Testing

Isometric knee extensions were performed in a Cybex 6000 (Lumex, Ronkonkoma, NY), and isometric force in bench press was obtained on an AMTI force-platform (SG-9, Advanced Mechanical Technologies, Newton, MA). The equipment used in isometric tests was calibrated daily during testing.

Isometric knee extension tests were performed af-

Table 1. Isometric peak torque in knee extension and peak force in bench press before and after the 6-week training period. Values are means ± *SE* (% progress ± *SE*).

Variables	Group 1L–3U†		Group 3L–1U‡	
	Before	After	Before	After
Knee extension (N·m)	329 ± 15	339 ± 14 (3.6 ± 3.5)	330 ± 12	357 ± 12 (8.7 ± 3.0)*
Bench press (N)	843 ± 31	956 ± 28 (13.7 ± 2.1)*	867 ± 50	967 ± 62 (11.4 ± 1.8)*

† Trained 1 set in leg exercises and 3 sets in upper-body exercises.
‡ Trained 3 sets in leg exercises and 1 set in upper-body exercises.
* Marks significant increase within the groups ($p < 0.05$).

ter 5 minutes of cycling at a workload of 60–70 W. Only the right leg was tested. Isometric peak torque was measured at a knee angle of 60° from full extension, and the contraction lasted for 5 seconds. Each subject performed 3 maximal contractions with 30 seconds of rest between each attempt.

The isometric bench press tests were performed after warming up with 2 sets of 12 reps with 50% of body weight. The test was performed with the bench on the forceplate, and the barbell was fixed 10 cm above the subjects' chest in line with the subjects' nipples. The subjects could choose a grip as wide as 120 cm in the first test. The chosen grip width was measured and used in both tests. Force was measured as the reactant force toward the forceplate, and the weight of the subjects and the bench was subtracted. Each subject performed 3 attempts of 5 seconds each, with 3 minutes of rest between each attempt.

Before 1RM tests, subjects cycled for 10 minutes at a workload of 60–70 W. In all exercises, the subjects performed a standardized warm-up consisting of 3 sets with gradually increasing load (40–75–85% of expected 1RM) and decreasing number of reps (12–7–3). The first attempt in all tests was performed with a load approximately 5% below the expected 1RM load. After each successful attempt, the load was increased by 2–5% until failure in lifting the same load in 2–3 following attempts. The rest period between each attempt was 3 minutes. All tests began with an eccentric phase. The coefficient of variation was <2% in all 1RM tests.

Statistical Analyses

All values given in the text, figures, and tables are means ± *SE* if nothing else is stated. Paired *t*-tests were used for within-groups comparison, and unpaired *t*-tests were used to compare the relative changes in strength between groups. The coefficient of variation for test-retest reliability was <2% in all 1RM tests. The level of significance for all statistical procedures was $p \leq 0.05$.

Results

Body Weight

In both groups, body weight increased during training: from 81.0 ± 5.4 kg to 82.2 ± 5.5 kg (mean ± *SD*, $p < 0.05$) in the 1L–3U group and from 82.3 ± 13.2 kg to 83.8 ± 12.8 kg in the 3L–1U group ($p = 0.06$).

Isometric Strength

Isometric bench press strength increased in both groups ($p < 0.05$, Table 1). Isometric knee extension strength increased in the 3L–1U group ($p < 0.05$) but not in the 1L–3U group. There were no statistically significant differences between groups in relative isometric strength increases in either isometric test.

1RM Tests

In both groups, 1RM increased in all 6 exercises during the training intervention ($p < 0.01$, Table 2). The relative strength increase in the 3 leg exercises considered together was greater in the 3L–1U group than in the 1L–3U group ($p = 0.01$), but there was no difference between groups in relative strength increase in the 3 upper-body exercises considered together (Figure 1).

Training Volume and Intensity

Total training volume (sum of all exercises) was not different between the 2 groups (Figure 2). In both the 1L–3U and the 3L–1U groups, total training volume in each workout increased from 6,602 ± 225 kg and 5,978 ± 269 kg, respectively, in the first week of training to 7,700 ± 189 kg and 7,591 ± 459 kg, respectively, in the last week of training ($p < 0.01$). In both groups, relative training intensity, given as percent of 1RM, increased during the training period (Table 3). The 3L–1U group used a significant lower relative training intensity than the 1L–3U group in the leg exercises at the beginning of the period. This difference continued through the training period; however, the difference was not significant at the end.

Discussion

We found that during the early phase of adaptation to strength training, 3 sets were superior to 1 set, regarding the increase in maximal strength in leg exercises. However, 1 set was equally effective as 3 sets regarding the increase in maximal strength in upper-body exercises in the specific training protocols used in this study.

Table 2. One repetition maximum loads in dynamic strength before and after the 6-week training period. Values are means ± *SE* (% progress ± *SE*).

Variables	Group 1L–3U†		Group 3L–1U‡	
	Pretraining	Posttraining	Pretraining	Posttraining
Squat (kg)	129.5 ± 20.6	147.0 ± 21.2 (14.1 ± 9.1)*	122.5 ± 29.0	149.4 ± 29.0 (23.1 ± 7.0)*,**
Knee extension (kg)	125.8 ± 16.7	144.0 ± 11.9 (15.5 ± 8.1)*	117.8 ± 13.5	142.5 ± 8.9 (21.8 ± 9.4)*,**
Leg curl (kg)	57.3 ± 9.6	64.8 ± 7.6 (14.4 ± 10.1)*	55.9 ± 10.3	65.3 ± 13.1 (16.6 ± 5.8)*
Bench press (kg)	74.8 ± 7.0	82.3 ± 8.3 (10.1 ± 5.2)*	77.8 ± 11.3	85.0 ± 12.9 (9.2 ± 3.9)*
Shoulder press (kg)	64.0 ± 6.9	76.5 ± 5.2 (20.3 ± 10.7)*	63.8 ± 11.9	79.4 ± 11.6 (25.7 ± 12.3)*
Pull-down (kg)	81.5 ± 8.1	91.5 ± 7.7 (12.6 ± 6.9)*	80.3 ± 7.4	91.9 ± 10.1 (14.3 ± 3.2)*

† Trained 1 set in leg exercises and 3 sets in upper-body exercises.
‡ Trained 3 sets in leg exercises and 1 set in upper-body exercises.
* Marks significant increase within the groups ($p < 0.01$).
** Marks significant differences between groups ($p < 0.05$).

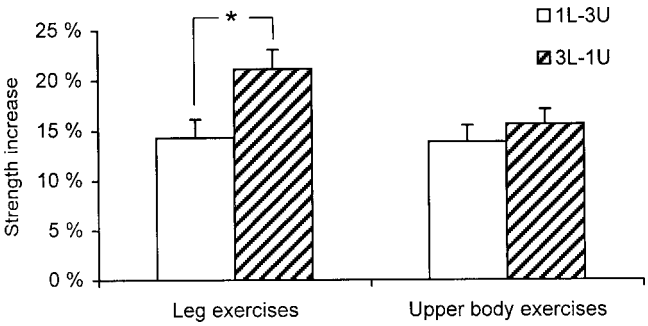

Figure 1. Relative changes in 1 repetition maximum load during the 6-week training period in the leg exercises and upper-body exercises. 1L–3U = 1 set in leg exercises and 3 sets in upper-body exercises; 3L–1U = 3 sets in leg exercises and 1 set in upper-body exercises. * marks significant differences between groups ($p < 0.05$).

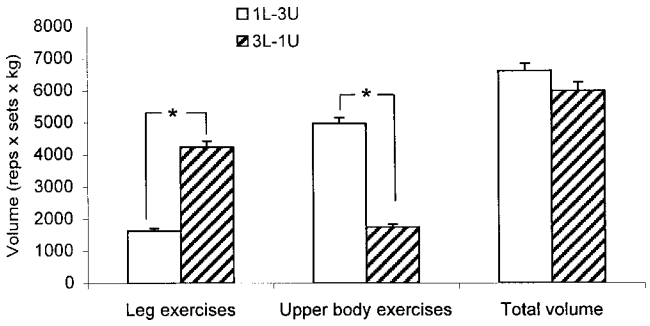

Figure 2. Mean training volume (kg × reps × sets) in leg exercises and upper-body exercises, and total volume in 1 workout during the first week of training. 1L–3U = 1 set in leg exercises and 3 sets in upper-body exercises; 3L–1U = 3 sets in leg exercises and 1 set in upper-body exercises. * marks significant differences between groups ($p < 0.01$).

These findings add a new aspect to the issue concerning the optimal number of sets. The results from the leg exercises agree with the ''traditional'' view (4, 15). On the other hand, the results from the upper-body exercises indicate that single-set exercise might be as effective as multiple-set exercise during the early phase of adaptation to strength training. The results from the present study and from the recent studies by Sanborn et al. (13), Schlumberger et al. (14), and Borst et al. (2) indicate that Carpinelli and Otto (3) have made premature conclusions. One of the most disturbing claims made by Carpinelli and Otto (3) is the generalization of recommendations—primarily regarding untrained and trained individuals. Few studies have used trained subjects, and results from studies on trained subjects (9, 14) indicate that multiple sets are

Table 3. Training intensity (% of 1 repetition maximum) at the beginning and at the end of the 6-week training period. Values are means ± *SE*.

	Group 1L–3U†		Group 3L–1U‡	
	Leg exercises	Upper-body exercises	Leg exercises	Upper-body exercises
Beginning of the training period	74.8 ± 7.5%	75.4 ± 3.6%	68.8 ± 7.1%*	78.5 ± 5.8%
End of the training period	78.5 ± 4.6%	78.2 ± 4.8%	73.5 ± 6.6%	80.0 ± 4.3%

† Trained 1 set in leg exercises and 3 sets in upper-body exercises.
‡ Trained 3 sets in leg exercises and 1 set in upper-body exercises.
* Marks significant differences between groups ($p < 0.05$).

superior to single-set training protocols, although there are still some contradictions (6).

When considering the present results, it is logical to draw the assumption that upper-body muscle groups could have a lower stimulus threshold for training volume (reps × sets) than lower-body muscle groups during the early phase of adaptation to strength training. We cannot exclude the possibility that upper and lower muscle groups need different training protocols to achieve the same cumulative strength increases. Possibly, training the upper-body muscles may require a lower training volume per workout (few or a single set), but a higher training frequency, compared with lower-body muscles (15).

The assumed adaptation differences between lower- and upper-body muscle groups could be associated with the differences in the muscle groups' involvement in daily tasks. The leg extension muscles are antigravity muscles: these muscles are exposed to a substantially greater total load per day—as a result of carrying the body mass—compared with the upper-body muscles. Intuitively, these muscle groups might require a higher training volume per session. Interestingly, the strength increases in the leg curl exercise were equal in both groups, and the hamstring muscles are by far as pronounced antigravity muscles as are the quadriceps and gluteus muscles.

Strength-exercise protocols, which are effective in eliciting increased blood concentrations of growth hormone (GH) and testosterone (T), are characterized by the use of large muscle groups and a high training volume (for review, see [8]). Later studies have addressed the importance of multiple sets instead of single sets regarding the magnitude of GH and T secretion during strength exercise (5, 12). Kraemer (9) suggests that the difference in cumulative strength increase between groups using single- and multiple-set protocols could be the result of more pronounced secretion of anabolic hormones during multiple-set protocols. Therefore, the hormone theory can enlighten our results. Subjects in the 3L–1U group, who practiced 3 sets on the lower-body muscles, probably attained the greatest training-induced serum anabolic hormone response. This assumption could explain the difference between groups' strength increase in lower-body exercises. Concerning the upper-body exercises, we speculate the supposed change in serum anabolic hormone concentrations, elicited by 3 sets of lower-body exercises, to contribute to strength increase in the upper-body muscles. However, because whole-body training volume was similar in both groups, possible differences in anabolic hormone secretion were probably less pronounced in our protocols than in pure 3-set vs. pure single-set protocols.

A challenge in research striving to find the optimal strength-training protocol lies in the seemingly endless variability regarding the different elements of the protocol. The actual effect of different sets will plausibly be altered because of the choice of the other elements: reps, number and types of exercises, and training frequency. Accordingly, our results may be valid only when leg and upper-body exercises are performed in the same session, 3 times a week, using 7RM intensity and when the exercises are performed in the specific order.

In conclusion, 3 sets were superior to 1 set, regarding increase in maximal strength in leg exercises—but not in upper-body exercises—during 6 weeks of strength training in untrained subjects. Possible explanations for these differences may be related to a lower stimulus threshold for upper-body muscles or a more favorable hormone milieu, regarding muscle growth, during the 3L–1U strength-exercise protocol.

Practical Applications

It is possible that upper-body muscles have a lower stimulus threshold than lower-body muscles in the early phase of adaptation to strength training. Consequently, upper-body muscles might receive optimal strength increases through a lower training volume per session, compared with lower-body muscles in this phase. When upper- and lower-body muscles are exercised in the same session, the upper body can possibly use an acute, anabolic favorable alteration in blood hormone concentrations created by heavy lower-body exercises executed in multiple sets.

Single-set training protocols for upper-body exercises might be sufficient for untrained individuals in the early phases of a strength-training program. However, no study, including the present one, has found single sets to be superior to multiple-set training protocols, regarding increase in strength and hypertrophy. Multiple-set protocols come out either as effective as or superior to single-set protocols. Therefore, untrained and trained individuals, who desire optimal strength and hypertrophy increases, should choose multiple sets in favor of single-set training protocols. Multiple sets are more likely to ensure progress compared with single-set training protocols.

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