Resistance Training for Strength: Effect of Number of Sets and Contraction Speed

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ABSTRACT

MUNN, J., R. D. HERBERT, M. J. HANCOCK, and S. C. GANDEVIA. Resistance Training for Strength: Effect of Number of Sets and Contraction Speed. Med. Sci. Sports Exerc., Vol. 37, No. 9, pp. 1622–1626, 2005. Purpose: To compare effects on strength in the early phase of resistance training with one or three sets and fast or slow speeds. Methods: A total of 115 healthy, untrained subjects were randomized to a control group or one of four training groups: one set fast (~140°·s⁻¹), three sets fast, one set slow (~50°·s⁻¹), or three sets slow. All subjects attended training 3× wk⁻¹ for 6 wk. Subjects in the training groups performed unilateral elbow flexion contractions with a target six- to eight-repetition maximum load. Control subjects sat at the training bench but did not train. One repetition maximum strength, arm circumference, and biceps skinfold thickness were measured before and after training. Results: One slow set increased strength by 25% (95% CI 13–36%, P < 0.001). Three sets of training produced greater increases in strength than one set (difference = 23% of initial strength, 95% CI 12–34%, P < 0.001) and fast training resulted in a greater increase in strength than slow training (difference = 11%, 95% CI 0.2–23%, P = 0.046). The interaction between sets and speed was negative (~15%) and of borderline significance (P = 0.052), suggesting there is a benefit of training with three sets or fast speeds, but there is not an additive benefit of training with both. Conclusions: Three sets of exercise produce twice the strength increase of one set in the early phase of resistance training. Training fast produces greater strength increases than training slow; however, there does not appear to be any additional benefit of training with both three sets and fast contractions. Key Words: MUSCLE STRENGTH, STRENGTH TRAINING, EXERCISE, TRAINING VOLUME

Many people from both healthy and patient populations undertake resistance exercise to develop muscle strength and produce muscle hypertrophy. However, training parameters for resistance exercise have been the subject of surprisingly little research.

Conventionally, strength training involves multiple sets of resistance exercise rather than single sets. (A training “set” is a group of contiguous repetitions of a specified exercise.) The practice of performing multiple sets of resistance exercise is supported by the early and influential work of Berger (3), who suggested that multiple sets produce greater gains in strength than a single set. Evidence to support this premise is ambivalent. Several literature reviews comparing training responses to single and multiple sets of resistance exercise (4,5,10) have concluded that similar increases in strength are produced with both and that there is little scientific evidence to support the use of multiple sets of exercise. However, a recent meta-analysis concluded that three sets are superior to a single set (standardized effect = 0.70) (27). Another meta-analysis (28) concluded that four sets of resistance training produced twice the strength increases of one set. The conclusions from both narrative reviews and meta-analyses include non-randomized studies, so the reviews’ findings are potentially seriously biased (1). Moreover, the meta-analyses by Rhea and colleagues (27,28) involved comparisons between studies, not within studies, which exposes the conclusions to serious risk of confounding (31).

The speed at which a resistance exercise is performed is another training variable that may influence effectiveness of strength training. There is no consensus on the effect of movement velocities on strength increases associated with resistance training (for review, see Pereira and Gomes (24)). Even though it is common practice to train by lifting weights (dynamic resistance training), most experimental studies have used isokinetic training to investigate effects of training speed. Few studies have examined the effects of lifting speed on strength with dynamic resistance training. Morrissey and colleagues (20) examined the influence of movement speed with weight training and found greater improvements in strength with fast training (1-s lift phase, 1-s lower...
phase) for isokinetic work, but similar improvements for increases in strength for a specific training exercise.

Given the absence of clear evidence of the number of sets and training speed, this study aimed to determine in the early phases (first 6 wk) of training the effects on dynamic strength, if any, of i) the number of training sets (one or three) and ii) the speed of contractions used in training (slow (~50°·s⁻¹) or fast (~140°·s⁻¹)). In addition, we assessed whether the number of sets and speed of contraction affected limb circumference or skinfold measurements of the trained arm.

**METHODS**

The study design is illustrated in Figure 1.

**Subjects.** A total of 115 untrained, apparently healthy subjects (21 males and 94 females) with mean (±SD) age 20.6 ± 6.1 yr (height 168.1 ± 9.1 cm and weight 64.2 ± 11.6 kg) participated in the study. Subjects were included if they were deemed able to safely participate in physical activity according to the Physical Activity Readiness Questionnaire (2), free from upper limb injury, and not involved in regular upper limb strength training in the 6 months before commencement of the study. Subjects were instructed of all study requirements and gave written informed consent. Approval for this study was granted by the university’s human ethics committee.

**Measures.** Elbow flexor strength for the right and left arms of each subject was measured. The largest weight a subject could lift only once (one repetition maximum (1 RM)) using a loaded handheld bar from a position of full elbow extension and forearm supination was recorded. Subjects were seated with the testing arm supported on a bench. Before testing, subjects were familiarized with the testing protocol and performed a warm-up consisting of six to eight contractions through full range of elbow motion with a weight estimated to be 50–60% of the individual’s 1 RM.

There was a 1-min rest period after the warm-up and before the test period. Instructions were given to ensure the lift was performed correctly to minimize compensatory actions. To ensure maximal effort by the subjects, the procedures suggested by Gandevia (11) were adopted. Subjects were reminded before each lift to perform maximal exertion, they were loudly exhorted by the researcher, and they were able to discount an attempt if they believed a contraction was submaximal. They were informed that a prize would be awarded to the person whose strength, adjusted for gender, weight, and height, was greatest. Testing of the elbow flexors was performed with the subject lifting the weight through full elbow range of motion then lowering the weight back to the starting position. This procedure was repeated to determine the 1 RM to the closest 0.25 kg. A 2- to 3-min rest interval was given between each attempt. The nontest arm remained in a relaxed posture behind the subject’s back throughout the testing procedure. Repetition maximum testing for the elbow flexors has been reported previously as highly reliable (7).

Measures of skinfold thickness at the biceps and upper arm circumference were taken. Skinfolds were recorded with Harpenden calipers using standardized methods (21). Arm circumference was measured with a tape measure at the widest circumference of the upper arm with the subject attempting a strong contraction of the elbow flexors in a shortened position (shoulder at 90° flexion with the lower arm at 45° to the horizontal arm) (21).

After baseline measurements subjects were randomly allocated to one of five groups: control (N = 23), three sets fast training (N = 23), three sets slow training (N = 23), one set fast training (N = 23), or one set slow training (N = 23). The training arm was also randomly assigned.

**Training protocol.** All subjects attended 18 training sessions over a 6- to 7-wk training period. Ideally, subjects completed three sessions on three nonconsecutive days per week within a 6-wk period. When a session was missed, subjects were allowed to make up this session to ensure they completed the target number of training sessions. Subjects in the training groups warmed up before training by performing one set of six to eight repetitions with a weight approximately 50% of the training weight for that session. Subjects trained with a 6- to 8-RM load (approximately equivalent to 80% MVC) to failure (i.e., until the weight could no longer be lifted without compensatory movement) for either one or three sets, according to assignment. When more than eight repetitions could be performed in a set, the training weight was increased by the experimenters for the subsequent training session to maintain a training intensity of 6–8 RM. A maximum of a 2-min rest between each set was given for training with three sets. At each training session, subjects listened to a tape recording that instructed them to keep the nontraining arm relaxed. The tape also set the training pace. In the slow training group, a 3-s lift and 3-s lower time (average speed ≈ 50°·s⁻¹) was required, and
in the fast training groups a 1-s lift and 1-s lower time (average speed = 40°/s) was required. The tape instructed control subjects to rest the training arm on the training bench and keep both arms relaxed for 4 min (the average time for all training groups). A physical therapist experienced in resistance training was present at all training sessions.

After the training period, all subjects were retested for elbow flexor strength and anthropometric measures of both limbs (as described above). The rest period between the completion of training and retesting was usually between 2 and 5 d but no less than 48 h to minimize the impact of fatigue, and not longer than 7 d to minimize the effect of detraining.

**Data analysis.** The sample size of 115 subjects determined a priori was estimated to provide an 80% probability of detecting a 10% difference in strength between groups. Data for pre- and posttraining measures for the trained arm were analyzed with a nested factorial ANCOVA using a linear regression approach to determine the effect of number of sets and speed of contraction. The regression model was outcome = a + b (initial value) + c (trained) + d (sets) + e (speed) + f (sets × speed), where outcome is the final measure of strength (arm girth or biceps skinfold thickness); initial value is the initial measure of strength, arm girth, or biceps skinfold thickness; trained indicates whether the subject trained (dummy-coded as 0 or 1 for control and trained subjects, respectively); sets indicates whether the subject trained with one or three sets (dummy-coded as 1 for subjects who trained with three sets and 0 for all other subjects); and speed indicates whether the subject trained at fast or slow speeds (dummy-coded as 1 for subjects who trained fast and 0 for all other subjects). a, b, c, d, e, and f are coefficients that describe the magnitude of each of these effects. Significance for all statistical analysis was set at P < 0.05. Only data for the trained arm are reported in this paper.

**RESULTS**

Of the 115 randomized subjects, two dropped out before commencement of training (one in the control group and one in the three sets slow training group) as they decided not to adhere to the training protocols. One subject (one set slow training group) only completed 4 wk of training (12 sessions) because she developed neck pain attributed to training. Outcome data were obtained from these subjects and analyzed by intention to treat (15). No other adverse events were reported. All other subjects completed 18 training sessions within a 6- to 7-wk training period.

**Strength.** Strength measures before and after training are given in Table 1. Changes in strength following the training period for control and trained subjects are illustrated in Figure 2. Training with one set at the slower speed resulted in an increase in strength of 25% of initial strength (1.38 kg, 95% CI 0.75–2.02 kg, P < 0.001, Table 2), compared with the control condition. Three sets of training were superior to a single set, increasing initial strength by 48% (2.66 kg, 95% CI 1.40–3.94 kg) or an additional 23% compared with training with one set (1.28 kg, 95% CI 0.65–1.92 kg, P < 0.001, Table 2). Fast training resulted in an 11% (0.64 kg, 95% CI 0.01–1.27 kg, P = 0.046, Table 2) greater strength increase than slow training. Although of borderline significance (P = 0.052), there is a suggestion that the effect for the interaction between sets and speed is negative (effect = −15%), suggesting that there is a benefit of training fast or with three sets but no additional benefit of doing both.

**Girth and skinfolds.** Data for arm circumference and skinfold thickness are reported in Table 1. Strength training resulted in a small but significant increase in the circumference of the trained arm (mean = 0.5 cm, 95% CI 0.10–0.91, P = 0.015). There was not a statistically significant added effect for training three sets compared with one set (0.24 cm, 95% CI −0.17 to 0.64, P = 0.252) or for training at a fast
compared with a slow speed (−0.28 cm, 95% CI −0.67 to
0.12, P = 0.175). Training had no effect on skinfold thick-
ness.

DISCUSSION

Six weeks of training with three sets of resistance exercise
produces about twice the increase in strength (48%) ob-
tained when training with one set (25%) at the same training
intensity. This difference is similar to that found with 12 wk
of strength training for the lower limb (56% increase in
initial strength for three sets compared with 26% for one set
(26)). These findings support superior strength increases
with larger training volumes in the early phases of training.
Increased exposure to the training stimulus (three training
sets compared with one) induces further strength adapta-
tions even in the acute phase of training.

One set of contractions produced significantly smaller
strength increases than training with three sets. However,
strength increases produced by a single set of training may
still be large enough to be useful (25% of initial strength,
95% CI 13–36%). Previous research has shown that com-
pliance with training programs is higher in one-set programs
than three-set programs (13), and in short programs (25)
with fewer exercises (14). Moreover, training with one set is
less time-consuming than training with three sets where the
same exercises are being performed. Thus, although three
sets of resistance exercise clearly produce greater strength
gains in the early phases of training, a one-set protocol
might sometimes be preferable to a three-set protocol if
subject compliance or time prioritization is a concern.

Training at fast speeds resulted in greater strength gains
than training at slow speeds. However, the effect of speed on
strength was smaller than the effect of number of sets (11%
greater strength increase if training fast rather than slow
compared with a 23% greater strength increase if training
with three sets instead of one). The effect of training speed
is consistent with observations made by Paddon-Jones et al.
(23) and Farthing and Chilibeck et al. (9), who showed that
eccentric training at faster contraction velocities (180°s⁻¹)
produced greater increases in strength than training at slow
velocities (30°s⁻¹). The mechanisms by which speed of
training influences strength adaptations was not investigated
in this study, but some authors have speculated that mech-
nisms could include change in muscle fiber type (16,23) or
increased ability to selectively recruit fast-twitch motor
units (6). The latter mechanism is unlikely because recruit-
ment order of motor units appears to remain unchanged with
fast compared with slow contractions (8). Training with fast
speeds leads to higher discharge rates of single motor units
and more frequent occurrence of brief interspike intervals
(doublet discharges) (33); these phenomena might underlie
the greater training response.

Training resulted in a small but significant increase in
upper arm circumference. This increase is most likely due to
a change in gross muscle size of biceps brachii and brachia-
lis. It is unlikely that other structures (such as bone or
subcutaneous tissue) underlying the site of measurement
would have undergone adaptive changes that would be
reflected by an increase in arm circumference. Previous
research on recreational weight lifters has also found in-
creased biceps circumferences following 13 wk of training
but only in subjects training with three sets (13). In the
current study, there was no evidence that one type of train-
ing (i.e., one set or three sets, fast or slow) was superior for
increasing arm circumference in the early phase of training.

Resistance training for 6 wk with either one or three sets
had no effect on skinfold thickness. Several studies have
shown reduced skinfold thickness after resistance training,
but these studies used exercises incorporating several mus-
cle groups (13). The effect of training on skinfold thickness
is likely to be related to the total caloric expenditure of the
exercise program and not the individual resistance exercise
at the target site. In the present study, only one exercise was
performed that may be why no change in skinfold thickness
was detected.

In conclusion, a one-set strength training program for
ebicep flexor strength at a slow training speed (average
speed ≈ 50°s⁻¹) performed 3 x wk⁻¹ for 6 wk will increase
strength of untrained subjects by about 25%, and this effect
is doubled if three sets are performed. Training with fast
repetitions (average speed ≈ 140°s⁻¹) results in an 11%
greater strength increase than training with slow repeti-
tions. There is no additional benefit of performing fast
contractions if training with three sets. It is recommended
that three-set programs be used in preference to single-set
programs if the aim is to maximize strength gains. If one-set
programs are adopted, fast rather than slow repetitions will
produce larger gains in strength. These findings may have
implications for clinical populations where strength training
forms part of rehabilitation or health promotion intervention.

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**TABLE 2. Coefficients, 95% CI, and P values for the linear regression analysis for strength of the trained arm.**

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Mean effect (kg) (95% CI)</th>
<th>Effect as % of pooled initial value (5.58 kg)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>−0.93 (−1.59 to −0.28)</td>
<td>−17%</td>
<td>0.006</td>
</tr>
<tr>
<td>Initial strength</td>
<td>1.20 (1.11 to 1.28)</td>
<td>1.20% per % initial</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Training (one set slow vs control)</td>
<td>1.38 (0.75 to 2.02)</td>
<td>25%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Three sets vs one set</td>
<td>1.28 (0.65 to 1.92)</td>
<td>23%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fast vs slow speed</td>
<td>0.64 (0.01 to 1.27)</td>
<td>11%</td>
<td>0.046</td>
</tr>
<tr>
<td>Interaction (sets × speed)</td>
<td>−0.88 (−1.77 to 0.01)</td>
<td>−15%</td>
<td>0.052</td>
</tr>
</tbody>
</table>

The regression model is strength (kg) = a + b (initial strength) + c (trained or control) + d (sets 3 or 1) + e (speed fast or normal) + f (interaction sets × speed).
REFERENCES