Resistance training for strength and muscle thickness: Effect of number of sets and muscle group trained

Entraînement en résistance pour le développement de la force et de l’épaisseur du muscle : effets du nombre de séries et des groupements musculaires entraînés

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Summary
Objectives. — To investigate the effects of resistance training volume on the adaptations of different muscle groups in untrained young men.

Equipments and methods. — The volunteers were randomly assigned into two groups: (1) three sets of knee extension and a single set of elbow flexion (3K-1E; \(n = 11\)), or (2) single set of knee extension and three sets of elbow flexion (1K-3E; \(n = 13\)). Subjects trained two days per week for 12 weeks. Peak torque (PT) was measured at 60° s\(^{-1}\). Muscle thickness (MT) was measured by ultrasound.

Results. — Elbow flexors’ MT increased significantly for both groups (7.2% for 3K-1E and 5.9% for 1K-3E), while changes in quadriceps’ MT were not significant for either group (2.5% for 3K-1E and 2.9% for 1K-3E). Increases in elbow flexors’ PT were 11.2% for 3K-1E and 12.5% for 1K-3E (\(P < 0.05\) for both). Changes in knee extensors’ PT were significant for 3K-1E (10.9%, \(P < 0.05\)) but not for 1K-3E (5.1%, \(P > 0.05\)).

Conclusion. — Single-set training protocols might be sufficient for increasing strength and MT of the elbow flexors and muscle strength of the knee extensors in untrained individuals. On the other hand, neither training stimulus (one set nor three sets) was sufficient to improve the MT of the knee extensors.

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1. Introduction

Resistance training has been shown to be an effective stimulus for promoting muscle strength and hypertrophy [1,2]. For optimal benefit, resistance training programs should be based on scientific principles that consider training variables such as exercise selection, resistance modality, load, sets, repetitions and rest. Volume (sets x repetitions x load) is probably the training variable that has received the most attention in the last 10 years, with an extensive debate concerning the use of single set versus multiple sets programs [3–5]. According to a meta-analysis by Rhea et al. [6], most studies have reported that resistance training with multiple sets is more effective for increasing strength than training with a single set. Later, Munn et al. [7] reported that three sets of exercise produced twice the strength increase of one set in the early phase of resistance training in untrained subjects. Thus, research has suggested that a training volume greater than one set is recommended to improve strength gains [6]. However, these results might not be valid for different muscle groups [8,9].

Studies involving upper-body muscles reported no differences for strength gains between one and three sets [10–12], while studies involving lower-body muscles reported three sets to be superior to one set [10–14]. McBride et al. [15] compared the effects of single versus multiple sets on strength gains in upper-body versus lower-body muscles and reported that multiple sets produce a greater increase in strength gains in upper-body exercise (biceps curl) when compared to a lower-body exercise (leg press). On the other hand, Paulsen et al. [10] and Ronnestad et al. [12] reported superior strength gains for three sets in lower-body exercises but not in upper-body exercise in untrained subjects.

With regard to muscle hypertrophy, Ronnestad et al. [12] reported that three sets of strength training was superior to one set in leg muscles, while no difference existed between one and three sets in the upper-body muscle mass gains of untrained men. Starkey et al. [16] also reported that one set of high-intensity resistance training was as effective as three sets for increasing the muscle thickness (MT) of the knee extensors in previously untrained adults. On the other hand, Starkey et al. [16] did not investigate the difference in MT changes between upper- and lower-body muscle groups. Thus, due to the controversy between studies on muscle strength gains, and due to the small number of studies that have investigated the effect of training volume on muscle mass changes, the purpose of this study was to determine the effect of one set versus three sets of resistance exercise on the strength and MT gains of different muscle groups in untrained male subjects.

2. Methods

2.1. Experiment overview

Subjects were randomly assigned to one of two groups. One group performed three sets of knee extension exercise and one set of elbow flexion exercise (3K-1E), while the other performed one set of knee extension exercise and three sets of elbow flexion exercise (1K-3E). Training was conducted across 12 weeks, two days a week, with a minimum of 48h between sessions. Both groups were instructed to perform 8–12 repetitions until volitional fatigue at a speed of 4s per repetition (2s for the concentric phase and 2s for the eccentric phase). The effects on strength gains were tested before and after the 12-week training protocol via isokinetic tests (knee extension and elbow flexion), and the effects on MT were tested through ultrasound images of the elbow flexors and knee extensors.
2.2. Subjects

Thirty young men with no resistance training experience agreed to participate in this study. Eleven college-aged male subjects in the 3K-1E group (22.2 ± 3.2 years; 72.7 ± 13.2 kg; 174.3 ± 6.8 cm) and 13 in the 1K-3E group (23.4 ± 2.6 years; 73.1 ± 13.6 kg; 171.9 ± 8.2 cm) completed the study protocol. Drop-outs were due to lack of time and the performance of other resistance training programs than the study protocol. The inclusion criteria for participation in the study included being older than 18 years and being free of clinical problems that could be aggravated by the protocol. To be included in the statistical analysis, participants were permitted to miss only two training sessions during the 12-week program. Participants were notified of the research procedures, requirements, benefits and risks before providing informed consent. The Institutional Research Ethics Committee granted approval for the study.

2.3. Muscle thickness

Participants were tested before and after the 12-week training period for MT of the elbow flexors and knee extenders of the right limb. All tests were conducted at the same time of the day, and participants were instructed to hydrate normally 24 h before the tests. Measures were taken 3–5 days after the last training session to prevent any swelling from contributing to the MT measurement [17]. During this time, participants were instructed not to participate in any other exercise sessions or intense activity. MT was measured using B-Mode ultrasound (Philips-VMI, Ultra Vision Flip, model BF). A water-soluble transmission gel was applied to the measurement site and a 7.5-MHz ultrasound probe was placed perpendicular to the tissue interface while not depressing the skin. MTs of the rectus femoris muscle (RF) and of the biceps brachii (BIC) were measured according to Abe et al. [18]. Once the technician was satisfied with the quality of the image produced, the image on the monitor was frozen. With the image frozen, a cursor was enabled in order to measure MT, which was taken as the distance from the subcutaneous adipose tissue-muscle interface to muscle-bone interface [18]. A trained technician performed all analyses [19]. The coefficients of variation for BIC and RF MTs were less than 3.0%. Baseline test and retest intraclass correlation coefficient (ICC) for BIC MT was 0.96 (0.93–0.98) and for RF MT was 0.99 (0.98–0.99).

2.4. Peak torque

Unilateral knee extension and elbow flexion peak torque (PT) were tested for both groups, using two sets of four repetitions at 60 s⁻¹, on a Biodex System 3 isokinetic dynamometer (Biodex Medical, Inc., Shirley, NY) with 60 s rest between sets. Calibration of the dynamometer was performed according to the manufacturer’s specifications before every testing session. Knee extension strength assessment procedures were as follows: the participants sat upright with the axis of rotation of the dynamometer arm oriented with the lateral femoral condyle of the right knee. Belts were used to secure the thigh, pelvis and trunk to the dynamometer chair to prevent additional body movement. The chair and dynamometer settings were recorded to ensure the same positioning for all tests. The flexor torque produced by the relaxed segment was used for gravity correction. Participants were instructed to fully extend and flex the knee and to work maximally during the test. Elbow flexion strength assessment was as follows: the participants were seated on an arm curl bench with the exercised upper arm supported at 45° of shoulder abduction and their elbow aligned with the axis of rotation of the dynamometer’s lever arm. The forearm remained in a supinated position throughout the test session. Verbal encouragement was given throughout the test. The procedures were administered by the same investigator [20]. Baseline test and retest intraclass correlation coefficient and standard error of the mean (S.E.M.) for peak torque were 0.98 and 2.3% for quadriceps, and 0.96 and 2.4% for biceps.

2.5. Training

All training sessions were closely supervised to ensure safety and compliance with the procedures, and because previous research has demonstrated greater gains in supervised versus unsupervised training [21]. Each group was assigned a different volume of the same exercise over the same period of time. Both groups trained with 8–12 RM. If a subject could not perform eight repetitions or could lift the load more than 12 times, he was instructed to adjust the load in order to ensure the completion of the required number of repetitions. Each subject maintained a training log where the number of repetitions performed and the weight used in each set were recorded.

Training was conducted two days a week, with a minimum of 48 h between sessions, for 12 weeks. Twice/week training sessions was chosen because the current physical activity guidelines state that adults should do at least 150 min/week of moderate-intensity physical activity and also two or more days/week of muscle-strengthening activities [22]. One group used a single set of knee extension and three sets of elbow flexion (1K-3E) while the other used three sets knee extension and a single set of elbow flexion (3K-1E). Sets began every 3 min, and the work rest ratio was ~1:3. During training sessions, music tracks with 120bpm were played in order to facilitate control of movement speed. Before each training session, subjects were instructed to maintain their normal diet over the duration of the study.

2.6. Statistical analyses

Normality of the distribution for outcome measures was tested using the Kolmogorov-Smirnov test. All values are reported as mean ± standard deviation. Paired t-tests were used to compare pre- and post-values within groups. To compare differences in PT and MT between groups, final values were compared with ANCOVA, using the initial values as covariates. When groups are assigned at random, ANCOVA is considered an adequate method for comparing changes between groups [23]. Relative percentage change was calculated using the following equation: \([\frac{(Post-values - Pre-values)}{Pre-values} \times 100]\). Statistical significance was set at \(P \leq 0.05\). Data were analyzed using the Statistical Package...
Table 1A Values of muscle thickness (MT) and peak torque (PT) pre and post 12 weeks of resistance training (means ± standard deviations).

<table>
<thead>
<tr>
<th>Variable</th>
<th>3K-1E</th>
<th>1K-3E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Elbow flexors MT (mm)</td>
<td>27.9(±4.2)</td>
<td>29.9(±3.3)</td>
</tr>
<tr>
<td>Knee extensors MT (mm)</td>
<td>20.3(±3.7)</td>
<td>20.8(±4.1)</td>
</tr>
<tr>
<td>Elbow flexors PT (N m)</td>
<td>46.57(±10.56)</td>
<td>51.79(±7.28)</td>
</tr>
<tr>
<td>Knee extensors PT (N m)</td>
<td>203.31(±33.64)</td>
<td>225.39(±32.22)</td>
</tr>
</tbody>
</table>

MT: muscle thickness; PT: peak torque.
<sup>a</sup> P < 0.05.

Table 1B Values of muscle thickness (MT) and peak torque (PT) pre and post 12 weeks of resistance training (means ± standard deviations).

<table>
<thead>
<tr>
<th>Variable</th>
<th>1K-3E</th>
<th>1K-3E</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Elbow flexors MT (mm)</td>
<td>28.8(±2.8)</td>
<td>30.5(±4.7)</td>
</tr>
<tr>
<td>Knee extensors MT (mm)</td>
<td>23.9(±3.6)</td>
<td>23.2(±3.5)</td>
</tr>
<tr>
<td>Elbow flexors PT (N m)</td>
<td>49.67(±10.47)</td>
<td>55.59(±10.61)</td>
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<tr>
<td>Knee extensors PT (N m)</td>
<td>231.16(±31.77)</td>
<td>243.00(±30.56)</td>
</tr>
</tbody>
</table>

MT: muscle thickness; PT: peak torque.
<sup>a</sup> P < 0.05.

for Social Sciences (SPSS) version 14 software (SPSS Inc.,
Chicago, IL). Also, the calculation of increases by the effect
size in PT (the difference between pretest and posttest
scores divided by the pretest standard deviation) and the
scale proposed by Rhea [24] were used.

3. Results

Results are shown in Table 1. BIC MT increased significantly
for both groups (7.2% for 3K-1E and 5.9% for 1K-3E), while
changes in RF MT were not significant for any group (2.5% for
3K-1E and -2.9% for 1K-3E). Increases in elbow flexors PT
were 11.2% for 3K-1E and 12.6% for 1K-3E (P < 0.05 for both).
Besides no significant differences between groups, changes
between pre-and post-test in knee extensors PT were sig-
nificant for 3K-1E (10.9%, P < 0.05) but not for 1K-3E (5.1%,
P > 0.05). Comparisons between groups revealed no differ-
ence in the changes of any variable. According to the scale
proposed by Rhea [24], the effect size for the change in PT of
the knee extensors was small (0.65) for 3K-1E and trivial
(0.37) for 1K-3E. The effect size for the change in PT of the
elevator flexors was trivial to small for both 3K-1E (0.50) and
1K-3E (0.56) (Table 1).

4. Discussion

The purpose of this study was to verify the effect of one
set versus three sets of resistance exercise on the strength
and MT gains of different muscle groups. The results suggest
that independent of the number of sets (1 or 3) the strength
 gains are similar for the elbow flexors. Also, no difference
was found between one and three sets for knee extensors
strength gains. However, the effect size for the knee exten-
sors’ PT was higher (0.65) for the three sets compared to
the one set group (0.37). Furthermore, the MT of the elbow
flexors also improved similar for both groups. However, the
training volume used was not sufficient to improve MT of the
knee extensors for either training group.

The effects of resistance training volume differences in
strength gains between upper- and lower-body muscles have
been the subjects of a few studies. Paulsen et al. [10]
compared the effects of single set and three sets resis-
tance training protocols in 18 untrained males. Subjects
trained three times a week for six weeks. According to
the results, the increase in 1 RM load for the leg exercises
was significantly greater for the three sets group. However,
the relative increase in 1 RM load for the upper-body exer-
cises was similar between groups. More recently, Ronnestad
et al. [12] compared the effects of single and multiple-
sets resistance training on hypertrophy and strength gains
in untrained men after 11 weeks of training, conducted
three times a week. According to the results, the increase
in 1 RM in the lower-body exercises and knee extension
PT was significantly greater for the three sets program,
while no difference existed in 1 RM between groups in
upper-body exercises. The results of Paulsen et al. [10] and
Ronnestad et al. [12] are in agreement with the present
study.

Thus, based on our results and previous studies, it can
be suggested that upper-body muscles have a lower stimu-
lus threshold for training volume than lower-body muscle
groups. Some authors suggest that the difference in the
responsiveness of lower-body muscles to increases in train-
ing volume are due to the fact that leg muscles are used
in daily-life activities to a greater extent than upper-body
muscles [10,12]. Therefore, some of their growth potential
may have already been reached, making it necessary to use
a greater training volume to see favorable muscular strength adaptations.

However, contrary to our results, McBride et al. [15] indicated that, compared to a single set, multiple sets resulted in a significantly greater increase in percentage strength only in the biceps curl exercise (8.5% for single set and 22.8% for multiple sets) and not in the leg press exercise (41.2% for single set and 52.6% for multiple sets). These differences in the results among studies may be due to training volume and training population. McBride et al. [15] divided 25 untrained men (n = 15) and women (n = 13) into two groups, one group performed one set of leg press and biceps curl exercises, and the other group performed six sets of leg press and a biceps curl exercises. Also, McBride had men and women in both groups. According to Pincivero et al. [25], muscle force-generating ability depends upon many factors, such as muscle mass, muscle fiber type and muscle activation characteristics. This ability has been shown to be significantly higher in males than females, and is considered to be a reflection of greater muscle mass, a higher percentage of fast-twitch muscle fibers and a gender-specific pattern of muscle recruitment. Thus, training volume may lead to different strength gains in men and women.

Regarding muscle mass gains, Ronnestad et al. [12] also assessed the differences in upper- and lower-body training volume on muscle hypertrophy. They reported that thigh cross-sectional area (CSA) increased more in the three sets group than in the one set group. The authors suggested that the strength gains in the three sets group may be due to muscle hypertrophy. Contrary to the suggestion of Ronnestad et al. [12], the increase in muscle mass in the present study may not be the major explanation for the strength gains in the 3K-1E group, since there were no changes in lower-body MT in either group. The cause for the lack of MT gains in the present study may be related to the reduced training volume. In the present study, the 3K-1E group performed only six sets per week for the knee extensors, while the 1K-3E group performed a total of only two sets weekly. Also, Ronnestad et al. [12] used two knee extensors’ exercises (i.e., leg press and knee extension), and our study used only one exercise for the knee extensors.

It is interesting to note, however, that the changes in peak torque obtained in the present study (10.9% and 5.1% for the 3K-1E and 1K-3E, respectively) are similar to those values obtained by Ronnestad et al. [12], who reported increases of 15% and 7% for the protocols involving three sets and one set of exercise, respectively. Therefore, the reduced volume used in the present study compromised more hypertrophy than strength gains. However, we cannot exclude the possibility that our measurement method (ultrasound) may not be as sensitive as magnetic resonance imaging (MRI) in detecting changes in muscle mass.

Regarding upper-body hypertrophy, Ronnestad et al. [12] found that both training groups improved upper trapezius muscle CSA, but there was no difference between groups. These results are in agreement to the present study. However, our results for upper-body muscle mass gains were lower (8.16% for 3K-1E and 5.43% for 1K-3E) than the CSA gains from the Ronnestad et al. [12] study (13.9% for the three sets and 9.7% for the single set). These differences may be due to training frequency (two versus three times/week), muscle group assessed (biceps versus trapezius) and measurement method (ultrasound versus MRI). Furthermore, the higher gains in muscle hypertrophy in the upper-body when compared to lower-body in the present investigation are in agreement with previous studies that observed a greater hypertrophic response to resistance training in upper extremity muscles compared to the lower extremity when the relative intensity and amount of training of the arms and legs were similar [26]. Starkey et al. [16] also determined the effects of different volumes of resistance training on knee extensors’ MT assessed by ultrasound. Training was conducted three times per week using one set or three sets of dynamic variable resistance exercise. Similar to the present study they reported no difference for MT between three and one set groups. However, different than our results and those of Ronnestad et al. [12], they found that both training groups improved MT after 14 weeks. Their training frequency was greater than ours (two versus three times/week), which may account for the difference in hypertrophy between studies.

5. Conclusion

In summary, it was concluded that single-set training protocols might be sufficient for increasing strength and MT of the elbow flexors in untrained individuals, while additional sets seem to be necessary for increasing lower body strength. On the other hand, neither training stimulus (one set or three sets) was sufficient to improve the MT of the knee extensors. These findings have important practical implications for adult fitness and rehabilitation programs in which many individuals have limited time for resistance-type training. Also, our results support the idea that different workout volumes may be used for different muscle groups in untrained individuals.

Conflict of interest statement

None.

References


